Chapter 10

RESTORATION OF ARID AND SEMI-ARID LANDS

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10.1 INTRODUCTION

Arid and semi-arid lands occur in areas where climatic conditions create water limitations and the water lost through evaporation exceeds the water gained from precipitation (Bailey 1996). Truly arid regions are called deserts, and they may be cold, temperate or hot, but all are relatively very dry. Definitions vary, but areas with annual precipitation of 25 cm or less are often considered as deserts. Semi-arid regions, often called steppes, typically surround or occur adjacent to deserts, but may also occur in isolation. The severe water limitations and climatic extremes that prevail in these regions render arid and semi-arid regions vulnerable to disturbance and very slow to recover (United Nations Environment Programme (UNEP) 1992; Aronson *et al.* 2002; Bainbridge 2007a). In other words, they have less **resilience** and **resistance** than most other **biomes**.

Arid and semi-arid lands make up approximately 40% of the Earth's continental surface and are home to more than 2 billion people (Adeel *et al.* 2005). Many of these are city dwellers, but ecosystem deterioration in the rural drylands – a common shorthand term for arid and semi-arid lands – is widespread and getting worse. Approximately 250 million people at present are affected by the loss of productivity from **degradation** of ecological resources or **desertification**, while as many as 1.2 billion people will be affected in the next few decades (Randriamiarina 2009). This will lead to increased suffering, growing numbers of environmental refugees and regional and international migrations that will no doubt cause civil unrest and turmoil (Sachs 2007). Half of the dryland dwellers earn very little money and as they live with very limited resources they are very vulnerable to unforeseeable events and slow-moving processes (Dobie 2001).

The semi-arid regions of the planet are more commonly occupied and more intensively managed than the arid areas, but all are vulnerable to ecosystem deterioration or desertification. A review of desertification risk in 2001 suggested the vulnerability classes and estimates of area involved and population at risk as given in Table 10.1.

Many of the more extreme desert areas are rarely used, although indigenous people in the past survived in some of them (Figure 10.1). It is important to remember these past uses by people because they often shaped the ecosystems we see today (Nabhan *et al.* 1982). Often, areas in the transition zones between arid and semi-arid regions are used by people only during wet periods (Felger & Moser 1985). Some of the most severely damaged areas are **abandoned** after their usefulness declines through over-exploitation (see Chapter 2). The lands at risk of desertification should be further categorized by current and historic use, current condition and tenure (ownership or use rights), but this has not been done in a systematic manner. Despite many similarities, the challenge of desertification can be very different from one region to the next, and perhaps even from one valley to the next.

In this chapter, I attempt a comprehensive approach to restoration that explicitly examines the socio-economic drivers that create unsustainable pressures on arid lands in addition to nonhuman drivers. In addition, I develop a *holistic approach* to restoration considering the people that are most affected by desertification. The goal is to integrate the best practices from past societies and cultures around the world that have addressed similar problems, with the latest findings from research and development on more sustainable ecological, technical and political or economic solutions (Bainbridge 2007a). A key aspect of this effort is to understand these problems well enough to

Table 10.1 Estimates of land area considered vulnerable and corresponding numbers of impacted human populations. Note: The global population density map is limited to latitudes 72°N to 57°S. Not all vulnerable lands are arid and semi-arid lands. After Eswaran *et al.* (2001).

Vulnerability class	Area subject to desertification		Population affected	
	Million km^2	% global land area	Millions	% global population
Low	14.60	11.2	1085	18.9
Moderate	13.61	10.5	915	15.9
High	7.12	5.5	393	6.8
Very high	7.91	6.1	255	4.4
Total	44.24	34.0	2648	44.0

Figure 10.1 Agave roasting pit. This seasonal Kumeyaay village site was occupied for thousands of years. It is located in the extreme desert with annual rainfall <7.5 cm. Much can be learned from careful analysis of resource utilization by these successful cultures. Restoration efforts can include species like agave (*Agave deserti*) that provide food for wildlife and insects as well as people. (Photograph by David Bainbridge.)

address the root causes, and not just the symptoms (Mitroff & Silvers 2009).

10.2 CAUSES OF DESERTIFICATION

The causes of desertification are complex and often interlinked in ways that are not readily apparent (Hallsworth 1987; Bainbridge 2007a). Mismanagement often leads to ecological decline and desertification. The causes commonly include socio-economic, administrative and ecological factors.

10.2.1 Socio-economic factors

The most critical socio-economic pressure on people who live in drylands is often simply basic survival (i.e. obtaining enough food to eat, or the small amount of cash needed for critical purchases). Population growth can compound the challenge. This often leads to overstocking of domestic livestock or, more generally, overuse of resources. The quest for respect, power or a sufficient dowry or resources for marriage (based on animal ownership) can also be a factor. Ignorance or greed may lead to management practices that are ill-advised, in the long term, and unsustainable.

The socio-economic factors that lead to desertification must be explored at the scale of the local area or region (see e.g. van Dresser 1976; Termorshuizen & Opdam 2009). The goal should be a long-term perspective, not just 1 year, 5 years or 10 years, but rather 50 or 100 years, or 1000. Even in regions where the transition from the agrarian to the industrial regime is still underway, or has hardly begun, a centuries-long perspective is often possible thanks to colonial archives (Wardell *et al.* 2003) and oral histories of indigenous people. Improving understanding of the drivers of desertification as well as the local ecosystem response can encourage more sustainable practices and restoration in use by land managers.

10.2.2 Administrative factors

Tenure (ownership or use rights) plays an important role in management decision making in drylands (Bainbridge 2007a). While in some areas tenure rights may be very clear, with known boundaries and legal documents supported by courts and law or cultural precedent, many of the arid and semi-arid lands are without clearly defined owners or explicitly owned by the government, but lacking clear management and supervision. Both situations lead to over-exploitation and discourage investment of time, energy and financial capital in long-term projects of conservation and restoration. The result is overuse, soil loss and eventually decline to bare rock and abandonment. Restoration efforts can be facilitated if tenure can be clarified by agreement or legislation. Satellite photos and mapping can make tenure allocation easier (Williamson 2000).

10.2.3 Ecological factors

In arid and semi-arid lands, water is the major limiting factor for plant establishment and growth. In degraded or desertified areas, this deficit becomes even more critical. Even if viable seeds are still present in the soil **seed bank**, they cannot germinate or grow without water; and changes in surface soils, microclimate and removal of vegetation and litter increase **runoff**, limit water retention and slow water movement into the soil (infiltration). As soil water is restricted by these changes, the decline in biomass intensifies grazing pressure on the few remaining plants in a downward spiral that may end with barren rock.

10.3 THE RESTORATION RESEARCH CHALLENGE

Restoring degraded ecosystems in arid and semi-arid lands requires a clear understanding of the complex interplay of environmental and social factors and the increasing impact of **climate change** (Reynolds *et al.* 2007). Basic research is also needed to better understand less disturbed **reference ecosystems** and to identify effects from climate change. The unpredictability of climate in most desert and semi-arid regions, and the extreme conditions at the soil surface make restoration challenging even when adequate financial resources are available. Restoration research is needed to help clarify the best strategies for each site and situation.

Renewed funding for fieldwork and applied research is urgently needed. Training for both participating in and managing **transdisciplinary** field studies is extremely important, yet rarely offered. Problem-oriented group studies like those proposed here are among the best method for developing these skills. These types of applied transdisciplinary studies do not fit in comfortably with the current academic environment (Bainbridge 1985, 2007b; Janssen & Goldsworthy 1996).

10.3.1 Improving understanding of the socio-economic and ecological setting

The primary challenge of restoration is to reverse the process of desertification, to capture and retain more water and to begin re-establishing plant communities and **ecosystem health** and complexity. Many techniques can be used to improve water capture, storage and infiltration, depending on soil conditions, budget and equipment availability. These include decompacting or scarifying the surface to break up crusts and increase water capture, laying out rock lines (Figure 10.2) or grids to slow surface flow and increase absorption, spreading brush or vegetation and creating swales, microcatchments or berms to capture rain (Tongway & Ludwig 1996; Lancaster 2008; Chapter 4). Soil amendments, planting and restoration of soil microorganisms can also increase water capture and infiltration. Establishment and succession can be very slow on undisturbed arid and semi-arid lands, and any additional damage due to mismanagement makes plant establishment even more difficult (Bainbridge 2007a). Techniques to capture and store water are essential, but just a start.

In the drylands, more than anywhere else, restoration planning must be based on understanding, intervention must be timely and restoration workers must be persistent. The planning effort should include consideration of ecosystem structure, function and use. Traditionally planning has focused on **ecosystem structure**, 'How many plants should be planted per acre or hectare? What canopy cover should be sought?' but repairing **ecosystem function**, 'How does water flow through the site? What is the soil health?' is often more important (Aronson *et al.* 2002; Bainbridge 2007a). Restoring function can speed *recovery* and make long-term success more likely (Allen 1988; Whisenant 1999). Attempting to return a plot of land to the historic plant community by seeding or container planting without restoring the soil and water functions that supported that community has led to many costly failures. Restoration of protected areas

Figure 10.2 Rock lines (Burkina Faso), brush piles, soil berms or terraces can be used to stabilize soil and retain water to allow for infiltration during rainstorms. These low-cost interventions work well in some arid and semi-arid lands to initiate recovery and aid restoration. (Photograph by William Critchley, VU University, Amsterdam.)

can be straightforward because use pressure can often be eliminated. Developing restoration efforts for land used for production is much more difficult and requires careful ecological and socio-economic analysis of management activities (Scherr & McNeely 2007).

Desertification gained worldwide attention with the Sahel drought in the 1970s, although in retrospect it was perhaps more cyclic drought than human-induced deterioration. In any case, the publicity led to the creation of a number of initiatives to reduce or control desertification, including the United Nations Convention to Combat Desertification (UNCCD), adopted in 1994, and a number of new research institutes, programmes and proposals around the world, resulting in much talk, but little action. However, the recognition of the need for more comprehensive projects led the United Nations to launch the *Integrated Drylands Development Programme*, in 2002. This recognition that deterioration would not halt and restoration would be unlikely to occur without integrated action was a critical step in understanding. The growing realization in recent years that climate change is likely to make the challenges of desertification worse has led to renewed efforts to undertake research that will provide better approaches for understanding, managing and restoring arid and semi-arid lands.

10.3.2 Identifying the causes of desertification

Improving our understanding of the social and ecological settings is critical because arid and semi-arid ecosystem restoration is challenging, costly and slow (Figures 10.3 and 10.4). Minimal research funding has limited the understanding of **desertification** and restoration **trajectories** needed to disentangle symptoms and causes (Bainbridge 2007b). Research on the ecological symptoms of desertification has been much more common than analysis of the causes of desertification. The technical solutions developed to treat these symptoms often fail because the causes have not been addressed. The causal chain (Figure 10.5) must be followed from the field to the government policies and international trade agreements that shape local economies.

When the causes of desertification are not well understood suggested solutions can lead to new,

Figure 10.3 Restoration work in progress, mesquite (*Prosopis glandulosa*) mounds (1995). Re-establishing trees or shrubs can provide critical habitat and initiate recovery of many species. Multipurpose tree crops like the nitrogen-fixing mesquite tree can also provide food and resources for people and livestock. (Photograph by David Bainbridge.)

Figure 10.4 Mesquite mound after 13 years (2008). The fine-leaved mesquite captures blowing sand to create nebkas or mounds. Capturing blowing sand and soil symbionts under the canopy creates a mound with a moist, resource-rich environment for plant, insect and animal species. (Photograph by David Bainbridge.)

Figure 10.5 The causal chain of desertification or restoration. To understand what we see in the field, we need to understand the policies that guide behaviour. Improved management and restoration may require changes in financial and political policies that create incentives for conservation instead of exploitation.

more serious problems. The specialized narrowly focused research rewarded in academia and by funders can lead to misunderstandings of complex **socio-ecological systems**. Desertification often involves cumulative (over decades) and synergistic effects that can make isolating causes and symptoms difficult. Research on desertification has focused on a small range of factors, most commonly a subset of ecological symptoms while the more sensitive issues of political and economic causes are ignored or neglected. To be successful, restoration must include ecological and cultural factors.

Understanding is also limited by the lack of historical baseline information for both ecological and cultural factors. To develop an effective restoration plan, we need to know how the **degradation** came about. What went wrong? This type of information can be provided by historical ecology and, going forward, with consistent monitoring. Drylands monitoring programmes currently in operation must provide a broader spectrum of information to improve our understanding of ecological and cultural sustainability and restoration opportunities (Scherr & McNeely 2007). In developed countries, information from census bureaus, health and education departments and economic analysis may make it possible to apply integrated measures like the *Genuine Progress Indicator* (Costanza *et al.* 2004), but in many areas there will be little or no information available and field work will be needed. Failure to address the social causes of desertification can lead to ecosystem collapse and political and cultural unrest as environmental refugees migrate from the arid and semi-arid lands.

10.3.3 Rediscovering traditional solutions

Restoration begins with understanding, and it is essential to understand how arid and semi-arid ecosystems have been managed by people for hundreds, or even thousands, of years if we want to restore them. Ecological assessments should always include a review of traditional management practices and their impact on the environment. Valuable lessons may be learned by studying traditional solutions for managing these fragile lands (Nabhan 1979; Evenari *et al.* 1982; Wilken 1987; Agarwal & Narain 1997; Rivera 1998). Rediscovering and applying the traditional wisdom developed over centuries of experimentation and innovation can improve yields and sustainability in arid and semi-arid lands, offering the potential for restoration in use by pastoralists, ranchers, farmers or agroforesters and speed restoration of lands freed from management by abandonment or inclusion in protected areas.

Students and faculty can also help improve the application of traditional knowledge to restoration. We can learn much from studying the water-efficient waffle gardens of the Zuni (Figure 10.6), the terraces of Yemen, clay pot irrigation in ancient China and the graceful water wheels of Hama, Syria. It is essential to rediscover the best practices of the past, not only for each region but from around the world. The Society for Ecological Restoration now includes an *Indigenous Peoples' Restoration Network* in their activities (Martinez 2010). This project deserves personal, foundation and government support. Further study and education on best practices from the past and present are important everywhere, but are even more critical for areas where

Figure 10.6 The annual maintenance of the *acequias* or irrigation ditches is a community-building activity as well as a method of maintaining critical water infrastructure. This water can improve production on farms and ranches and reduce pressure on adjacent drylands to allow restoration to begin. Social activities that promote cohesion should be included in restoration projects. (Photograph by Rick Romancito.)

migrants and refugees may have arrived with practices and beliefs that do not fit their new environment.

Recent work has highlighted the importance of **traditional ecological knowledge** as a key to success in arid land management and restoration (Committee on Science and Technology 2005; Youlin 2005). The UN Convention of Parties to Combat Desertification (UNCCD) first established an ad hoc committee on traditional knowledge in 1999 (UNCCD 1999, 2005). This represented a major turning point as the value of knowledge acquired over generations of experimentation was recognized. Understanding traditional practices should be the first step in any large-scale restoration or management programme for the drylands.

10.3.4 Transdisciplinary integrated restoration research with stakeholder engagement

Although I was trained as an ecologist and spent much of my career working on ecotechnical solutions to resource management and restoration problems and basic research, it became increasingly clear to me that the social factors that drive behaviour are more important than the ecological factors (Bainbridge 2007a, 2009). Including local people in research and demonstration adds strength but complexity. The residents of the arid and semi-arid lands, often portrayed as victims, typically have excellent coping capacities, are innovative and are extremely responsive to economic signals and opportunities (Dobie 2001; Critchley 2010). They often do a remarkable job with what they have, as Thomas Sheridan (1996) showed in his ecological and cultural analysis of a small town in Sonora, Mexico. The farmers, ranchers and pastoralists causing damage are often well aware of the environmental problems they are creating but are typically caught in a system with drivers and incentives that discourage sustainable management. Arid and semi-arid lands restoration may depend more on government economic policy (including reduction or removal of farm subsidies in developed countries), international trade agreements and World Trade Organization policy than on ecological research. More emphasis in restoration must be placed on policy change at this level.

Stakeholder engagement is essential to understand and address the complex problems of desertification and dryland restoration. The boundaries of the problem analysis must be large enough to capture the system, to reach across disciplines from employment to ecosystem resilience. Even when environmental and economic models of management activities are developed, they are rarely integrated. But to develop solutions that will work, they must be integrated and include feedback and interactions that more accurately represent the complexity of real-life systems (Reynolds *et al.* 2007). A **transdisciplinary** systems approach is essential for unravelling these types of complex problems (Meadows 2008; Chapters 2 and 22). NGOs with long-term experience in an area may be able to provide very useful insight and information about restoration and management opportunities and challenges. This will require new types of funding and support within government, academia and nongovernmental organizations (NGOs).

The elements needed for success include involving all affected stakeholders, conducting research to improve understanding of social and biophysical processes and developing long-term programmes to suggest, demonstrate, test and refine solutions. These are described in the following section on management.

10.4 THE MANAGEMENT CHALLENGE

The need for integrated approaches to arid and semi-arid lands research and management has been increasingly recognized by research groups, NGOs and advocates (Haberl *et al.* 2006; Reynolds *et al.* 2007). Since the 1990s, a number of initiatives have been started to encourage more interdisciplinary, multidisciplinary and transdisciplinary research, but the results overall have been disappointing (Glenn *et al.* 1998). In part this is the result of limited funding, but even the money that has been spent has yielded less than expected, often because local communities have not been engaged, encouraged and empowered (Chambers *et al.* 1991). Stakeholder outreach is critical (Partridge *et al.* 2005; Prell *et al.* 2007). When stakeholder engagement is managed well, I have also seen it ease conflicts between competing groups.

10.4.1 Setting sustainability goals

The importance of setting sustainability goals for a community or region cannot be underestimated (van Dresser 1976). Putting people first can help promote cooperation with the local community (Chambers 1995; Gómez-Pompa & Bainbridge 1995). Interrelating social and ecological factors provides the critical insight needed to understand the problems and suggest solutions. The challenges in determining what makes a particular community sustainable need to be understood, including questions of health, education, employment, innovation, community involvement, crime and corruption, culture and opportunities for improvement. Often the goals may be as simple as safe and comfortable housing, adequate food, clean water and economic opportunity. It is important to compare the relations between these over time by ethnicity, caste and income class as well. The Genuine Progress Indicator or the *Index of Sustainable Economic Welfare* can help us understand the sustainability of social systems (Costanza *et al.* 2004). Developing **ecological footprint** and sustainable area budgets for the area or region may also be instructive (Rees 2006; Levine *et al.* 2010). These can help establish budgets for energy, water, food or other resources that would be sustainable over the long term. If the community and culture are not sustainable, successful environmental restoration will not be possible.

Evaluating the **sustainability** of socio-economic systems involves measures of both structure and function much like the ecosystem factors. The flow of money is very important, but many social system interactions do not involve cash flow, and labour contributions or gifts and exchanges have not been recorded, studied or counted by conventional economics. Ecological impacts are even less likely to be costed and incorporated in accounting (Bainbridge 2006). All countries also have shadow economies (illegal activities or economic enterprises with no records and no taxes). These shadow flows may be very important, particularly in marginal arid lands. Understanding these economic factors can be critical in analysing the resource management practices leading to desertification or restoration.

Reducing or eliminating economic incentives that promote poor management can lead to changes in resource utilization that lead to restoration in use. Destructive incentives can be corrected by the activities of association, cooperation and lobbying, but those who benefit from current inequities and subsidies are very reluctant to see policies and programmes change. The problem is rarely at the farm or ranch level, but further up the economic system with the banks, companies and organizations involved in resource management and finance. In the 1980s, for example, we found that dryland farmers in Sonora, Mexico, were being forced to abandon their sustainable locally adapted traditional corn varieties. To obtain credit, they had to agree to use high-response corn and buy chemical fertilizer. This increased risk and debt, with inevitable failures driving people off the land, leading to land consolidation, further involvement in illegal activities and emigration. Challenging and changing long-standing subsidies and incentives are never easy. In developed countries, protesting land managers may be snubbed, ridiculed or shunned; but in developing countries, the risks are much higher (Sinha 1991). Engaging stakeholders in efforts to reshape socio-economic drivers to be more sustainable is critical to improve management, to facilitate restoration in use and to encourage the conservation and restoration of important ecosystems in reserves or protected areas.

10.4.2 Developing and demonstrating solutions

More than half of the people living in drylands still depend on farming, grazing, fuelwood harvesting, hunting, poaching or wild gathering for a significant part of their living. All will have to add restoration to their existing management activities if they intend to move toward more sustainable **socio-ecological systems**. Restoration activities can improve the quality of life and the economic viability of small farm, forestry or ranch enterprises (Tiedeman 2005). Restoration may be undertaken on individually owned or controlled land, or else on lands and resources held in common, leased from or held by the government.

Land managers are most likely to adopt new practices if they have seen, visited and participated in a working demonstration, yet demonstrations are rarely included in restoration programmes. Degraded and damaged lands are almost worthless and are not costly to purchase or lease for restoration research and demonstration. Cooperative on farm or ranch demonstrations are very useful and can be encouraged by protecting land owners with a funding guarantee of no loss of income or yield while they experiment with new crops or management practices. This strategy proved useful for the Carter Foundation (set up by former US President Jimmy Carter) in efforts to improve agriculture in Africa. Small landholders are conservative and often work to minimize risk rather than

Figure 10.7 The waffle gardens of the Zuni were remarkably effective in capturing rainwater, and protecting plants from winds and animals. Lessons from traditional societies can be applied to restoration efforts. These waffle gardens would be well suited for nurseries growing native plants for restoration work. (Photograph by Jesse Nussbaum, 1911. Courtesy Denver Public Library, Western History Collection.)

maximize output. A no-loss guarantee, provided by a participating NGO or government programme, can encourage participation and experimentation with restoration activities.

I would suggest a new approach to the development and implementation of solutions that includes local, long-term research and validation. This approach would engage local communities in transdisciplinary systems analysis, research, demonstration and extension needed for successful restoration. The most important groups involved in solving the problems of dryland desertification are the local communities. Yet they are often a weak link, hampered by poverty, lack of respect by outsiders for their wisdom and internal power relationships that limit their ability to voice their concerns. Encouraging local farmers and ranchers to participate can help offset the narrow goals of special interest groups and their economic and political dominance.

While much has been learned about the functioning of some dryland ecosystems in the last 80 years, much remains unknown. Long-term transdisciplinary research is needed to better understand the challenges we face and the opportunities for improving management practices and restoring arid lands. Diverse stakeholders need to be collectively engaged in designing and delivering strategies that simultaneously address the challenges of meeting goals for rural **livelihoods**, food security and environmental **sustainability** (Scherr & Rhodes 2006). Restoration research and implementation teams can provide insight about the ecosystem and the current and historic national and international economic incentives and cultural pressures that determine land management practices (Figure 10.7). A system-oriented approach to restoration that incorporates socio-economic goals as well as environmental goals is much more likely to succeed than a more traditional eco-technical solution. It is also more likely to get local community buy-in and support. This type of project cannot be fast or short-lived because it takes time to build trust and to research, test and demonstrate solutions. Costs may be much lower than those of many traditional aid programmes, but long-term commitment for the communities and the researchers is essential.

Developing effective restoration programmes will require demonstrating solutions at the field, farm and watershed levels before promoting their widespread use (Leigh 2005). Demonstration is the ultimate test of practice and understanding and is the best way to encourage land managers, volunteers, companies and organizations to become actively involved. Land managers can be very skeptical, and only after they see, touch and apply these methods personally will they believe that they work. Studies in California showed that it took nine interactions with extension and demonstration to initiate change in adding one best management practice (Lubell & Fulton 2007). Demonstration can be done at the farm, ranch, park, watershed or regional level (Naveh 1989; Campbell & Siepen 1994). Dryland managers are justifiably risk averse and cautious, but will readily adapt new approaches that work. These new methods will spread far beyond the demonstration project site with little or no additional spending.

Demonstration projects are well suited for undergraduate and graduate students in both applied and theoretical research programmes. Working with local families can provide critical feedback and reality checks for proposed solutions while improving the sophistication and technical capabilities of small landholders. Field restoration projects also provide students and faculty with transdisciplinary project experience, stakeholder engagement skills and the opportunity to test and refine equipment and plant materials, as well as their understanding of how ecological and social systems behave (Aronson *et al.* 2007a; Bainbridge 2007a). The Natural Environmental Research Council and the Economic and Social Research Council in the United Kingdom currently offer 20 interdisciplinary study awards each year in recognition of the importance of this work (http://www.nerc.ac.uk), but these are for individuals, not teams.

Study teams in these **transdisciplinary** fields of study, **intervention** and ameliorative development must include a wide range of **stakeholders** from the local communities and/or encourage their participation in regular reviews because they are most familiar with the problems and will often be able to rapidly eliminate many of the proposed options. A systems approach working with local communities has rarely been used in analysing arid and semi-arid lands management and restoration. The work done by P. S. Ramakrishnan and his colleagues and students in north-eastern India was a good prototype for the work that is needed (Ramakrishnan 1992). Students lived in and studied traditional land management systems, analysing a wide range of cultural, ecological and economic factors. Box 10.1 presents the outline for a

Box 10.1 A restoration and demonstration project chronology

Year 1. An experienced restorationist/geographer/agroecologist/anthropologist, preferably with considerable experience in the region, revisits the area, reviews the literature, history and current political economy, talks with the local people, and meets with key stakeholders. This research begins to establish the framework for restoration work and potential demonstration projects. A catalogue of native plant communities and rare and endangered species, local cultivars of vegetables, grains, fruits and livestock, their pests and diseases, and economics is begun. Communities suitable for a long-term study/demonstration are evaluated and discussions with community groups, NGOs and governmental organizations will help select a study site.

Year 2. The project team leases (or buys) a representative land holding, farm or ranch for ten years with an option to renew. An experienced restorationist or field research project manager, preferably married with children, is hired to live on site. The presence of a spouse and children facilitates integration with the local community, improves understanding, and reduces the risk of romantic complications. One of their first tasks in the field will be to select and hire a local field staff person from the community. The research programme also recruits and begins training the first team of undergraduate and graduate students. This might include an environmental historian/geographer/anthropologist (a good PhD project), restoration ecologist, agricultural engineer, organic gardener (or animal scientist for range), soil scientist, agroecologist, hydrologist or microclimatologist, and public health/nutritionist/emergency medical technician. Prospective students should ideally be conversant if not fluent in the local language and include some from farm or ranch backgrounds and experience living in primitive conditions. Both men and women would where possible, live with local families. When this would be culturally difficult or inappropriate, they could live on the site property. Applications from married couples and families should be encouraged. The restoration team would be equipped with a container full of restoration tools and supplies, construction and vehicle repair tools, and equipment for restoration work and farm operation.

Continued

Box 10.1 *Continued*

They would also have a used but serviceable ¾ ton 4 × 4 flatbed truck and four-wheel-drive tractor, 30–50 hp, with plow, spader, box scraper, backhoe, and bucket loader.

The goal for this year would be adding to the understanding of the local culture, ecosystems, microclimates, soils and economy – adding to the regional research from year 1. The goal would be to begin developing a history of the political ecology and environmental changes at the project site for the last 50 years or more. This would begin with library research and continue with interviews of the village elders and observation. The restoration ecologist would begin developing a local and regional overview of ecosystem function and structure and identify a plant restoration palette and start a seed banking programme. Seed collection would be a priority. If appropriate, a nursery for native plants and economic cultivars of interest would be started with community involvement.

The facility would be built or retrofitted as an example of sustainable design with assistance from the student team, staff and local workers. Renewable energy and local resource capture would be demonstrated with a solar photovoltaic array, solar hot water system, passive solar heating and cooling, rainwater harvesting system, improved water and irrigation systems, and proper treatment of water supply and wastes. If needed, seismic safety issues would be addressed with an onsite retrofit. A demonstration organic garden and agroforestry options and composting system would also be designed and started, with the goal of developing value-added products. The garden would help feed the team and would test varieties suited to local site conditions.

The soils science and hydrology/microclimatology students would establish a sampling framework and complete initial surveys of the area. Both would work with local teachers and students if possible to engage the community in the research. The public health/nutrition student would help keep the team healthy and would also work to better understand health problems and nutritional limitations in the local community.

The students and staff, truck, and tractor would be made available to help with community projects as appropriate. Funding would be provided to hire students from the local school or community to help with restoration research and implementation and gardening/facility operations.

Year 3. Work would begin on restoration projects and, as appropriate, economic development. The primary goal would be working with local stakeholders to develop two or three demonstration projects for restoration. Land tenure issues might be addressed as well. Restoration activities might include fencing springs and riparian areas to improve water quality and stabilize riparian ecosystems. It might also include water and soil conservation demonstrations using gabion dams, rock lines, terraces or swales. Business opportunities that could benefit the local community might also be explored, such as developing an organic certification for a local crop such as nopales (*Opuntia* (prickly pear) cactus pads) and developing value-added products such as cactus fruit syrup, goat cheese or organic mesquite flour and corn baking mixes. The project students and staff might also help start a garden at the local school.

The first annual open house and welcome to the community would be a fiesta, with food, music, and dancing. This type of annual cultural event has proved to be a critical factor in improving the interactions between the Mapami Biosphere Reserve and neighbours in the Chihuahuan desert.

Year 4-onward. Additional restoration projects (and economic development demonstrations) would be developed in partnership with the local community. Existing programmes that link business students with local vendors/producers in Chile and Mexico can provide valuable insights (see for example the *Proyección Social* 'Community Outreach' programme at the Universidad del Pacifico, Lima, Peru).

Restoration, demonstration efforts, and supporting facilities would be analysed using a standardized sustainability dashboard or scorecard (http://esl.jrc.it/envind/dashbrds.htm). Projects that have succeeded or appear likely to succeed would be replicated and promoted. Those that had failed to meet expectations would be revamped or dropped.

Note: the challenges caused by political instability and drug violence would need careful consideration in many areas. Even in the 1980s concerns about the *narco-trafficantes* (drug dealers) were common in much of northern Mexico and today it is much worse (Grant 2008).

long-term transdisciplinary restoration research and demonstration project in northern Mexico.

10.4.3 Funding

By my estimate, funding a study like this in the arid lands of a developed country like the United States might cost $5 million over 10 years. In Mexico and other developing countries, the cost would be considerably less. Secure funding for the long term, perhaps 10–20 years or more, is essential. The Long-Term Ecological Research sites of the National Science Foundation and a few development and conservation projects around the world have shown that long-term integrated research is invaluable. Inadequate funding, too little, too short, has hampered much of the research on ecological restoration and integrated development. Long-term funding is needed to ensure that students can complete projects and find continuing support for career advancement. Projects like this can provide meaningful change not only in the community where it is implemented, but throughout the region and for similar climate/cultural areas in other areas of the world. The benefits will also include new faculty and managers trained in systems analysis and arid and semi-arid lands restoration.

The World Bank and other international institutions are increasingly cognizant of the importance of economic incentives for improving land management, but this growing recognition has led to little improvement on the ground. The legacy of past economic colonialism through abusive loans and development programmes has also left a series of tragic consequences. The need for external funding support for the developing countries that will feel the most severe impacts of desertification and climate change is recognized in both the Climate and Desertification Conventions. The United Nations Framework Convention on Climate Change (UNFCCC) places particular emphasis on the responsibility of developed country parties for funding climate change mitigation and adaptation due to their disproportionate contribution to the problem of climate change (Lorimer *et al.* 2009). If we adopt a funding goal of just $5 per resident affected, we would have $1.25 billion to work with, enough for 5000 local, integrated, multidisciplinary, long-term management for restoration efforts.

Efforts to address the causes of desertification also require funding (Glenn *et al.* 1998). These would not be costly, but are politically challenging. While there have been many examples of worthwhile projects that have made technical improvements to agriculture in the drylands, there are few examples of the drylands being systematically considered in economic and trade policies, either nationally or regionally (Dobie 2001). Restoration of arid and semi-arid lands on a large scale will demand reform of these economic policy drivers. James F. Reynolds and coworkers have outlined the *Drylands Development Paradigm* for research that interlinks coupled *human–ecological systems* (H–E systems: Reynolds *et al.* 2007). This paradigm consists of five principles of particular significance in drylands and focuses on inter- and intrarelationships in dryland systems:

1. H–E systems are coupled, dynamic and co-adapting, so that their structure, function and interrelatioships change over time. Understanding dryland desertification and development issues requires the simultaneous consideration of both human and ecological drivers.

2. A limited suite of 'slow' variables are critical determinants of H–E system dynamics. Identifying and monitoring key 'slow' variables are particularly important in drylands where highly fluctuating 'fast' variables often mask fundamental change related to slow variables.

3. Thresholds in key slow variables define different states of the H–E systems. The costs of intervention rise nonlinearly with increase in land degradation or the degree of socio-economic dysfunction. Managers should adopt the precautionary principle.

4. Coupled H–E systems are hierarchical, nested and networked across multiple scales. Drylands are often distant from economic and policy centers and have difficulty influencing policy drivers.

5. The maintenance of a body of up-to-date local environmental knowledge (LEK) is key to functional co-adaptation and restoration of H–E systems. The Drylands Development Paradigm also addresses the needs of research, management, and policy communities.

10.5 PERSPECTIVES

The world's drylands are beset by problems of overuse and mismanagement, and most are experiencing declines in ecosystem health and productivity. Growing human populations and changing economic structures can add further pressure to fragile lands (Depner 2011). Desertification is causing increasingly severe

Figure 10.8 Project manager Dr Laura Jackson at the restoration research farm near Eloy, Arizona, explored options for restoring abandoned farmland. Simple techniques of water harvesting hastened recovery, but the project also illustrated the challenge of working on long-term problems with short-term funding. (Photograph by David Bainbridge.)

problems for local communities and families and despair with the suicide of more than 200 000 farmers in India in a little over 10 years (Sainath 2009). It leads to unnecessary suffering, migration and displacement, and unrest. Water is perhaps the most critical concern, but desertification also involves equally pressing concerns about food, economics, justice and biodiversity. These problems are all expected to become worse as climate change disrupts rainfall and stream flow in arid and semi-arid lands (Ribot *et al.* 1996; Lorimer *et al.* 2009). Solving these problems demands an understanding of ecological and cultural histories because they develop over time and almost always involve subtle or not so subtle signals and incentives that encourage people to do the wrong thing. Historical insights can help us plan policies or developments that restore ecosystem structure and function, protect and restore endangered species and ecosystems, and improve the quality of life today and for future generations.

Restoration research has improved our understanding of the ecological issues involved in restoration, but this has done little to improve management. Successful restoration in protected areas has been possible, but the key challenge today is improving management of areas in use by addressing the ecological and socio-economic causes of desertification. This effort will benefit from setting sustainability goals, better understanding less disturbed reference ecosystems, developing and demonstrating restoration approaches, ensuring funding for long-term research and addressing the potentially critical impacts of climate change (Figure 10.8).

We must address the complex problem of desertification and restoration of arid and semi-arid lands with intelligence, commitment and compassion (Bainbridge 2007a). Solutions are likely to be very different from one area to the next, reflecting the cultural, administrative and political differences present even when ecological factors are similar. Restoration is both possible and essential and can help protect vulnerable ecosystems and communities from increasing risks from global climate change while contributing to the development of viable eco-economies (Brown 2001, 2005; Critchley 2010).

The costs of ecological restoration are not insignificant, but the cost of not acting will be higher in terms of human suffering and ecosystem damage. Combining restoration and improved management can provide multiple benefits. As Scherr and Rhodes (2006) note, 'Synergies can be delivered by enhancing coordination and complementarity between existing conservation and production strategies. Diverse stakeholders need to be collectively engaged in designing and delivering strategies that simultaneously address the challenges of meeting goals for rural livelihoods, food security and environmental sustainability' (p. 23). Well-funded restoration efforts in protected areas can be undertaken with optimism and expectation for success. Restoration projects for lands actively being used or exploited or abandoned lands have been less common and demand much more attention. If a range of options that previous research has suggested are 'best bets' are tested and evaluated on each project arid and semi-arid lands, restoration projects can avoid repetitive failures and improve restoration practices more rapidly.

Solutions that halt and reverse desertification can be found, but they won't reveal themselves without much improved, long-term, transdisciplinary research and demonstration at field, community, and regional levels. Restoration can improve the outlook for people and the environment and reduce the risks of ecosystem collapse and extensive migration. This is made even more important by the added stress of climate change with rising temperatures, less rainfall, reduced streamflow and more extreme weather events. Healthier and more productive ecosystems from improved management are more resilient and reduce the risk of ecosystem collapse.

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