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Arid and Semiarid Land Stewardship: A 10-Year Review of Accomplishments and Contributions of the International Arid Lands Consortium

Peter F. Ffolliott, Jeffrey O. Dawson, James T. Fisher, Itshack Moshe, Darrell W. DeBoers, Timothy E. Fulbright, John Tracy, Abdullah Al Musa, Carter Johnson, and Jim P. M. Chamie

Abstract

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The International Arid Lands Consortium (IALC) was established in 1990 to promote research, education, and training activities related to the development, management, and restoration or reclamation of arid and semiarid lands worldwide. The IALC, a leading international organization, supports ecological sustainability and development of arid and semiarid lands. Building on a decade of experience, IALC continues to increase the knowledge-base for managers by funding research, development, and demonstration projects, and special initiatives. The results from the scientific and technical projects enhance management and stewardship of arid and semiarid ecosystems for sustainable use, while maintaining the integrity of the ecological processes. The publication presents a review of the accomplishments and contributions of IALC's science and technical programs through a synopsis of the projects and initiatives. We group the projects and initiatives into soil and water resources development and conservation, land use and reclamation, processes enhancing the management of ecological systems, and inventorying and measurements techniques and monitoring.

Keywords: Arid and semiarid lands, land use, reclamation, soil and water resources, ecological systems, inventorying and monitoring

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Cover: Logo of the International Arid Lands Consortium showing the extent of arid and semiarid lands worldwide.

Arid and Semiarid Land Stewardship: A 10-Year Review of Accomplishments and Contributions of the International Arid Lands Consortium

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Preface

As President of the International Arid Lands Consortium (IALC), I am pleased to have been part of its first 10 years. This publication, *Arid and Semiarid Land Stewardship: A 10-Year Review of Accomplishments and Contributions of the International Arid Lands Consortium*, is a testament to those from different cultures and societies who are working together effectively in the interest of arid and semiarid environments. Scientists affiliated with IALC have shown a commendable ability to cooperate on projects and initiatives of mutual interest. Readers of this publication are encouraged to view this effort as one of ongoing collaboration and achievement.

Where will the next 10 years lead those involved in the scientific and technical programs of IALC? Much remains to be accomplished. We look forward to future collaboration with the entire Middle Eastern region and other arid and semiarid regions worldwide, as exists with our present partners in the Middle East. Water issues will continue to abound, increasing population pressures on limited natural resources will continue to grow, and the need to forge collaborative initiatives in sustainable economic development will persist. The IALC will continue to play a significant role in addressing these issues.

The Board of Directors is pleased to take this opportunity to recognize the diligent efforts of the Research and Demonstration Advisory Committee (RADAC) of IALC in preparing this publication. The RADAC is a peer-review committee that advises IALC's Board of Directors on funding projects and initiatives. I also want to thank the USDA Forest Service, Rocky Mountain Research Station for publishing this 10-year review of IALC's scientific and technical programs. The IALC's long-standing relationship with the Forest Service continues to be productive. The research, development, and demonstration projects and special initiatives discussed in this publication were funded largely by the USDA Forest Service and the USDA Cooperative State Research, Education, and Extension Service. We gratefully acknowledge the continuing support of and dedication to IALC by these organizations.

Kennith E. Foster

President, IALC

Contents

Chapter 1

Introduction

The International Arid Lands Consortium (IALC), established in 1990, promotes research, education, and training activities related to the development, management, and restoration or reclamation of arid and semiarid lands worldwide, with a focus on the Southwestern United States and the Middle East. IALC, a leading international organization, supports the ecological sustainability and development of arid and semiarid lands. IALC addresses the pressures on natural resources associated with shifting demographics and public expectations and concerns. Areas receiving IALC attention include the reallocation of water from agriculture to urban uses; endangered, threatened, and sensitive plant and animal species; and excessive exploitation and development of limited natural resources.

IALC's mission is to help people suffering from famine, overpopulation, disease, pollution, and the degradation and depletion of natural resources to improve their quality of life and the quality of life for future generations. IALC applies research and development, educational and training initiatives, demonstration projects, workshops, and technology-transfer activities to the development, management, restoration, and reclamation of arid and semiarid lands in the United States, the Middle East, and elsewhere in the world. IALC's member institutions and affiliate members, through their ongoing applied research efforts, support these activities.

Cooperation and Collaboration

IALC is a partnership of organizations dedicated to the Consortium's mission. Member institutions are the University of Arizona, New Mexico State University, the Jewish National Fund, South Dakota State University, the University of Illinois, Texas A&M University-Kingsville, the Desert Research Institute—University and Community College System of Nevada, and Jordan's Higher Council for Science and Technology. Egypt's Ministry of Agriculture and Land Reclamation, Under Secretariat for Afforestation is an affiliate member. Collaboration with cooperators from other institutions, including the USDA Forest Service, USDA Cooperative State Research, Education, and Extension Service, and similar institutions worldwide, is also promoted. Because the sum of resources offered by IALC surpasses anything that a single entity could offer, the efficient exchange of research, management, and technology-transfer mechanisms is enhanced.

IALC brings people and programs together in diverse areas, such as water resource development, conservation, and management; land-use planning and decision making; soil resource conservation and management; ecosystem processes; and inventory technology. Thus, IALC provides a broad basis for the coordination of activities in arid and semiarid land management and research. Funding for IALC, primarily from the Forest Service and Cooperative State Research, Education, and Extension Service, ensures that management and research experts are efficiently and effectively disseminating results.

Scientific and Technical Programs

Building on a decade of experience, IALC increases the knowledge-base for managers by funding research, development, and demonstration projects, and special initiatives. The results from the scientific and technical programs enhance management and stewardship of arid and semiarid ecosystems for sustainable use, while maintaining the integrity of the ecological processes. One evaluation criterion for proposals submitted to IALC is a link between the proposed effort and a solution to arid and semiarid land management

problems. IALC supports basic research, but the relevance of the research to management problems and situations must be clearly stated. The evaluation model derives from the United States' land-grant university tradition and reflects a commitment to public service at a practical level.

The Consortium's scientific and technical programs encourage projects with synergistic interinstitutional and international collaboration. Funding research, development, and demonstration projects and special initiatives ensures that scientists are conducting relevant research, and that their results are efficiently and effectively disseminated.

Research and Development Projects

IALC supports research and development projects that promote management for sustainable forests and woodlands, shrublands, grasslands, and agroforestry systems on arid and semiarid lands. These ecological systems include humans as biophysical and sociocultural components of ecosystems. A Board of Directors determines IALC's policies including research and development subject areas that are eligible for support. Traditionally, these areas are land reclamation, land use, soil and water resources development, soil and water conservation, water quality, inventory technology, ecosystem processes supporting sustainable management, enhancement of sustainable management of ecosystems, and the socioeconomic dimensions of these areas.

Many projects supported by IALC in its 10-year history concern the critical issue of biodiversity. Understanding the levels and scales of arid and semiarid land biodiversity continues to challenge managers attempting to sustain ecosystem functions, optimize the well-being of plant and animal species, and maintain niches for threatened, endangered, and sensitive species (Dawson et al. 1999, forthcoming). IALC also supports research and development that promote improved management of crucial soil and water resources in natural ecosystems and agronomic systems (Ffolliott et al. 2000). The Consortium has funded fifty research and development projects since 1993—when funding first became available. Some projects supported by IALC are completed, others are ongoing, while others have only recently been initiated.

Demonstration Projects

IALC's demonstration projects represent application of research and development results to the management of sustainable ecological systems. Demonstration projects must clearly identify the benefits derived and people served and link the available knowledge to those that are responsible for planning, management, and decision making at all levels of society. IALC-supported demonstration projects are sufficient in temporal and spatial scales to enhance the acceptance and application of the benefits obtained. It is also critical that the information or technology demonstrated or the educational goal sought is relevant to those living in the region.

Specific conditions that demonstration projects must meet to obtain IALC support are outlined elsewhere (Ffolliott et al. 1998). Since 1993, IALC has funded 16 demonstration projects, at varying stages of completion.

Special Initiatives

IALC special initiatives include workshops, conferences, Websites, training courses, and other technology-transfer activities. IALC actively participates with other organizations in supporting these initiatives. Members of the Board of Directors or the Research and Demonstration Advisory Committee propose special initiatives to complement IALC's scientific and technical programs.

Accomplishments and Contributions

To illustrate the historical scope and breadth of IALC's scientific and technical programs, research, development, and demonstration projects and special initiatives funded by IALC are listed in the appendix. A review of accomplishments and contributions of IALC to improved management and land stewardship of arid and semiarid lands is presented in the publication through a synopsis of the projects and initiatives. We group the projects and initiatives into the following categories: soil and water resources development and conservation, land use and reclamation, processes enhancing the management of ecological systems, and inventorying and measurements techniques and monitoring.

Chapter 2

Soil and Water Resources Development and Conservation

Research and Development Projects

Mitigating Effects of Sealing and Crusting of Soils

Sealing and crusting of soil surfaces is a major concern in arid and semiarid environments. Sealing reduces infiltration of water and inhibits the emergence and survival of seedlings. Agricultural crops must often be replanted due to failed emergence in sealed soils (Gardiner et al. 1996). Preventing the formation of sealing or controlling sealing strength is important to achieve a greater efficiency of water use, seedling emergence and survival, and agricultural crop production.

One way to mitigate sealing is to maintain a wet soil surface by frequently irrigating. However, the approach is expensive and wasteful. Another way to improve soil structure and aggregate stability is to add soil conditioners, such as polyacrylamides, to the soil surface. An IALC study hypothesized that polyacrylamides applied during crop planting will reduce soil sealing and improve water infiltration and seedling emergence. It was further hypothesized, in a companion IALC study, that gypsum will enhance the beneficial effects of polyacrylamides.

Studies

Greenhouse and field studies in Texas and Israel continue to evaluate the effectiveness of polyacrylamides and gypsum combinations on soil properties and the emergence and survival of agricultural crops (Levy et al. 1995, Gardiner and Carr 1999, Rapp et al. 2000). The influence of soil texture and the composition of exchangeable cations on seedling emergence and morphological characteristics were examined in greenhouse studies. While in ongoing field studies, gypsum is broadcast and polyacrylamides are applied in strips above the seeds at the time of planting. The emergence and survival of the seedlings, overall crop yields, and infiltration rates in the seeded rows were measured.

Results indicate that polyacrylamides reduce soil-crust strengths and improve hydraulic conductivity of Texas soils, with high sand and low silt contents in the greenhouse and field. Infiltration rates are doubled in sandy-clay-loam soil in the field (Gardiner and Carr 1998, Gardiner et al., 1998, Gardiner et al. 1999b). Repeated applications of polyacrylamides improve the persistence of these effects. The cactus extracts containing polysaccharides and polyacrylamides also improve the infiltration rate in soils, with high sand and low silt contents (Gardiner et al. 1999a). Other results indicate that applications of polyacrylamides increased evaporation from soil surfaces in an Israeli greenhouse study (Rapp et al. 2000). Emergence of shallowly seeded plant crops in Texas was usually unaffected by polyacrylamides. Applications of polyacrylamides and gypsum increased the emergence rate of onions in an Israeli field study.

Implications

Polyacrylamide applications reduced soil-crust strength, improved infiltration, and decreased erosion in many soils. However, seedling emergence in response to polyacrylamides and gypsum was inconsistent—emergence and survival of some seeded plant crops benefitted, there was little effect on other seeded plant crops, while still others were adversely affected.

Applying polyacrylamides with or without gypsum only to improve the emergence of small seedlings in crusted soils is not recommended (Gardiner and Carr 1999). Defining interactions among soil characteristics, infiltration rates, seedling emergence, and other factors needs further investigation.

Soil Contamination by Toxic Substances

Application of sewage sludge, heavy metals, and other potentially toxic substances to soil systems is common in many arid and semiarid countries. However, these applications present a risk to human health and the environment. The behavior of these substances is determined by their chemical reactions with inherent soil constituents. The most reactive substances are phyllosilicate clay materials and clay-sized iron (Fe) and manganese (Mn) oxides (Scott and Amonette 1988, Stucki 1988, Stucki and Lear 1989). Occurrences of the chemical reactions are attributed to their high specific-surface areas, cation exchange capacities, amphoteric surfaces, and oxidation reductions. Oxidation can affect soil-mineral properties.

Characteristics of soil-mineral properties vary in space and time because of seasonal or other cyclic oxidation-reduction processes, such as wetting and drying and warming and cooling, which involve microbial activities and alter oxygen supplies. Adding oxidation-reduction-active metals or organic compounds in sewage sludge that flows into a soil system promotes oxidation-reduction reactions with transition metals within the soil minerals. The oxidation-reduction reactions can alter the properties and behavior of the metal and organic compounds and the minerals themselves (Foth 1990). Consequently, these reactions are important to long-term soil quality and could modify the behavior of pollutants in the soil environment.

Studies

IALC continues to support studies at the University of Illinois and in Israel that characterize the surface, colloidal properties, and composition of Fe- and Mn-bearing soil minerals during and after oxidation-reduction reactions, which occur when sewage sludge and other contaminated water is applied. Changes in the oxidation state of transition metals in phyllosilicate clay materials and Fe and Mn oxides, which alter the nature, composition, and chemical behavior of soil-mineral surfaces and result in an active chemical environment at the mineral-liquid interface, were tested in a study. Surface chemical reactions related to Fe and Mn were measured in the laboratory and field investigation. Oxidation states and chemical compositions, cation exchange capacities, acidity swelling pressures, and absorption properties were also determined. A protocol to continuously measure the potential oxidation-reduction changes in a minimally disturbed field site that receives reclaimed sewage effluent or groundwater was also devised.

The study is increasing the available information about soil-clay properties and behavior under changing oxidation-reduction potentials. Particularly important is that the effects of oxidation on clay-organic surface interactions, the hydrophobic characteristics of these surfaces, and the clay-water surface interactions are better understood. This understanding improves our appreciation of the underlying mechanisms and reactions, which determine the behavior of water, organic material, nutrient irons, heavy metals, and other harmful substances in soil, when oxidation-reduction-active material is added.

Implications

The study is extending our knowledge of the physical-chemical processes that lead to the contamination of soil systems from the disposition of potentially hazardous substances, such as sewage sludge and heavy metals, into soils. These substances are influenced by their interactions with the constituents of the soil system. Phyllosilicate clay minerals and clay-sized Fe and Mn oxides play crucial roles in these interactions. High specific surface area, large cation exchange capacity and amphoteric surfaces, and active oxidation-reduction properties characterize the soil constituents. Applications of sewage sludge promote oxidation-reduction processes in soils by providing oxidation-reduction-active metals or organic compounds and surface water. This causes the alteration of soil properties and behavior of metal and organic compounds, which results in long-term effects on soil quality. Results from the study will help land managers prescribe improved land-use practices

and conservation measures through maintenance of non-contaminated and productive soils found in arid and semiarid environments.

Selenium Pollution of Subsurface Drainage Systems

Subsurface drainage water containing pollutants is a concern to planners and managers of irrigation projects, agriculturalists, and people living downstream of irrigated lands. Selenium, salinity, and sodium concentrations are potential pollutants of particular concern because of their long-term impact on water quality (Summers and Anderson 1986, National Research Council 1989). However, baseline information on the status of soil selenium and related chemicals before implementation of proposed irrigation projects is often unavailable. The IALC study was conducted to provide this information for an irrigation project in south-central South Dakota and then to use the information to estimate potential selenium and other chemicals discharges from the project area.

Study

Selenium, salinity, and sodium concentrations were measured to assess the potential impacts of these soil constituents on the quality of return-water flows from the proposed Lake Andres-Wagner Irrigation Project. Analyses of soil samples collected at specified depths and intervals along a 30-km transect indicated few general trends or consistent spatial structures in magnitudes of the chemical constituents sampled (DeBoer et al. 1994). A transfer function was developed to simulate the discharge of solutes, such as selenium, from a subsurface drain line. The function generated simulation results within a fraction of the time required for a comparable solution based on a classical flow technique (DeBoer and Warrick 1994, Warrick et al. 1995). The basic assumption of these simulation results was that either piston- or bulk-water flows control movements of selenium or other solute to the drain line. Influences of diffusion, dispersion, and chemical reactions in the soil must be defined before acceptable estimates of solute discharges from subsurface drainage systems are possible.

Implications

The analytical procedures developed in the study are important to planners and managers of proposed irrigation projects. From an environmental perspective, it is critical that we can estimate the magnitudes of selenium concentrations and other pollutants in drainage water from operational areas of irrigation projects. From a site-specific standroint, the applied results of these analytical procedures are valuable to the proposed South Dakota Lake Andes-Wagner Irrigation Project.

Atmospheric Carbon Dioxide Sequestration and the Global-Carbon Cycle

Carbon dioxide (CO_2) in the earth's atmosphere continues to rise at alarming rates (Schlesinger 1997). While the consequences of the rise are uncertain, the possibility of CO_2-induced global warming (greenhouse effect) is stimulating investigations of the global-carbon cycle and land management practices to mitigate effects (Schlesinger 1997, Lal et al. 1998). Soil-organic carbon is the largest terrestrial pool of carbon and soil-inorganic carbon (soil carbonate)—common in arid and semiarid soils—is the second largest terrestrial pool. More is known about the soil-organic-carbon pool than the soil-carbonate poon. Information that is missing about the soil-carbonate pool is the amount of $CaCO_3$ (calcium carbonate) sequestered in atmospheric CO_2. Unfortunately, data bases of total soil carbonates that contain primary, lithogenic, and atmogenic subgroups are insufficient. The latter soil carbonate subgroup is from the weathering of Ca-silicates and HCO_3 (hydrogen carbonate) and root and microbial respiration. Only atmogenic carbonate is a sink for atmospheric CO_2.

Study

The IALC study was initiated to learn about the atmospheric CO_2 sequestered by soil. Optical, x-ray mineralogy, and other methodologies are being used to vest the hypothesis that calcium isotopic signatures can separate primary and lithogenic $CaCO_3$ from atmogenic $CaCO_3$ and primary $CaCO_3$ can be separated from lithogenic and atmogenic $CaCO_3$. Relative proportions of the soil carbonate subgroups are being determined

for the soils of southern New Mexico and northeastern Jordan. These soils are well-suited for developing the necessary partitioning techniques because most of the soil-forming factors can be held constant by researchers to determine the source of calcium in $CaCO_3$—the exception is soil-parent material. Researchers can also hold soil-forming factors, other than climate and vegetation, constant to determine how much carbon in $CaCO_3$ is from C_3 plants, C_4 plants and the limestone parent material.

Implications

The study addresses the global carbon cycle information gap—the extent that arid and semiarid soils can sequester CO2 from the atmosphere into the calcium-carbonate system. Although the carbon pools in these environments are large, the fluxes to and from the atmosphere are poorly understood. In the future, these soils could be managed to sequester CO2 and mitigate impacts of the greenhouse effect, which could lead to carbon credits for these ecosystem managers. However, CO_2 sequestered by soil $CaCO_3$ must be quantified, and processes that lead to its formation fully known.

Function of Active Soil Organic Matter in Determining Soil Quality and Potentials for Land Reclamation

Active soil-organic matter is the portion of the soil body that is responsible for the formation of soil aggregates. Soil aggregation improves soil structure by reducing erosion, decreasing bulk density, and improving soil-biological functions by increasing porosity, aeration, and water movement. An improved understanding of the function of organic matter fractions in the sandy soils of arid and semiarid regions is the purpose of the IALC study. We hope to use knowledge of these fractions as an indicator of soil quality, which will enhance the ability to reclaim degraded arid lands. Managing these ecosystems to stabilize soils would improve their quality by promoting soil aggregation. Soil aggregation would be accomplished by comparing spatial patterns in soil-aggregate stability in perennial grassland and shrubland ecosystems and relating these patterns to vegetation; identifying soil-organic-matter fractions—loose, light, particulate, humin, and acid hydrolyzable carbohydrates—associated with soil macroaggregation; and identifying the probable sources of these fractions.

Study

Relationships between plant cover and the spatial variability in aggregate stability on perennial grassland and degraded mesquite (*Prosopis* spp.) shrubland sites are being established on the Jornada Experimental Range in southern New Mexico. General relationships among macroaggregate stability and location, plant species, and surface cover are being evaluated, while specific relationships involving aggregate stability, soil-organic-matter fractions, and plant species are being quantified for sites in perennial grass-shrubland transitions on sandy loam soil. At each study site, soils have been sampled at 3 depths beneath the shrub canopy and at a paired location in the adjacent bare inter-space for each of 5 perennial plant species. Soil-organic-matter fractions are determined for whole soil and stable macroaggregates. Fungal hyphal and cyanobacterial length density are also being analyzed, and the texture of all samples and iron oxide and carbonate contents of appropriate composites determined.

Preliminary results indicate that aggregate stability is lowest in the bare inter-spaces in all communities sampled and at all depths. A high temporal variability in aggregate stability, with higher stability occurring after the rainy season also exits. Aggregate stability is lower and there is increased spatial variability in soils that are frequently and intensely disturbed independent of their vegetative cover and composition. Glomalin and total protein are higher under mesquite shrublands, lower under grasses, and still lower in bare inter-spaces. The correlation is highest between easily extractable protein and total aggregate stability and lowest between sand-free aggregate stability and glomalin. Analyzing the data to completely defined these relationships and identify possible arid land reclamation measures continues.

Implications

Soil-organic matter plays a key role in stabilizing sandy soils in arid and semiarid regions. Studies in other ecosystems have shown that the contribution of soil-organic matter to soil structure depends largely on its

The Jornada Experimental Range is representative of the sensitive ecosystems in the Chihuahuan Desert and a site of several efforts in the IALC scientific and technical programs.

composition and distribution (Dutartre et al. 1993, Dalal and Bridge 1995). Results from the above study will help identify the key biotic and physical resources to manage to promote soil aggregation, optimize soil stability and productivity, and reduce the possibility of land degradation.

Water Harvesting and Treated Wastewater for Irrigation in Resources Development and Conservation

Many methods continue to be used to develop water supplies for people in the arid and semiarid regions. Irrigation with saline water, reuse of irrigation and treated wastewater, and water harvesting are examples. Without a permanent water source, a water supply for irrigation might be obtained through water-harvesting methods. Water harvesting involves collection and storage of the intermittent rainfall runoff until the collected water can be used beneficially. A distribution system is also needed to use the stored water for irrigation (Renner and Fraiser 1995a, 1995b, Brooks et al. 1997). Water-harvesting—used by people in the Negev Desert more than 4,000 years ago—continues to be used to establish trees and shrubs in plantations, growing food and forage crops, and watering livestock and wildlife on arid and semiarid lands. While water harvesting is ancient technology, people continue to explore ways to improve on the basic methods.

Studies

Limans (small earthen dams) were constructed for the past 50 years across ephemeral waterways of the Negev Desert to collect rainfall runoff. Trees and other agricultural crops are planted in the limans to capitalize on the water collected behind the dams. However, limans are closed hydrologic systems that accumulate sediments and dissolved salts. IALC supported a study to determine whether the accumulated salt deposits in the limans were significant enough to cause soil salinization and, if so, adversely affect afforestation efforts. The levels of salinization in soil profiles were described from limans representing a range of physiographic and climatic conditions in the Negev Desert. Soil samples were also obtained inside and outside the immediate area of the limans to analyze soil properties. Runoff water was collected upstream of the dams to estimate rates of salt inputs to the limans.

Despite relatively high salt inputs, analysis of these measurements failed to support the hypothesis that limans suffer from salt accumulations and consequent soil salinization. Salinity inside the limans was lower than in control trenches. Because the limans had been established in relatively leached alluvial flood plains, water infiltration and the accompanying leaching have been enhanced by tree roots and the sandy and gravel layers in the catchments. It was concluded that afforestation efforts with this low level of technology can be successful in establishing small groves of trees in the Negev.

Water harvesting and using treated wastewater (effluent) may increase water supplies to grow trees and crops in arid and semiarid regions (Stewart and Flinn 1984, Hopmans et al. 1990, Karpiscak et al. 1996). Researchers in an IALC study are evaluating the possibility of successfully growing trees by irrigating them with combinations of potable water, treated wastewater, and harvested rainwater (Karpiscak 1999, Karpiscak and Gottfried 1998, 2000). The study is also attempting to determine if trees take up harmful constituents in the treated wastewater or if there are any adverse impacts to soil irrigated with effluent.

Plantings of velvet ash (*Fraxinus velutina*), black willow (*Salix nigra*), Freemont cottonwood (*Populus fremontii*), eucalyptus (*Eucalyptus camaldulensis*), and Modell pine (*Pinus elderica*) in Arizona and Israel have been irrigated with potable water, treated wastewater, and harvested rainwater in amounts adjusted to account for seasonal transpirational losses of the trees. Survival and initial growth were monitored, nutrient uptake in leaves and stem tissue was assessed, and the chemical properties of the treated wastewater and the concentrations of soil minerals were analyzed. Initial findings indicate that, in comparison to irrigating with potable water, the survival and growth of some trees species were greater when irrigated with wastewater combined with water harvesting (Karpiscak 1999, Karpiscak and Gottfried 1998, 2000). Measurement of total biomass of the surviving trees remains to be done.

The feasibility of harvesting water for storage in the shallow aquifers of the eastern Badia of Jordan (Dutton et al. 1998) is being investigated in another IALC

Trees planted in a liman constructed in the Negev Desert to collect and store intermittent rainfall runoff behind the small earthen dam for survival and growth of these trees.

study. Although it is too early to report on the results of the study, study findings should improve the available information on hydrometeorological, hydrologic, and geochemical factors. These factors are expected to determine whether water harvesting is a feasible approach to mitigating the acute water shortages in Jordan and other countries that suffer from long-term water deficits.

Implications

Water harvesting offers a method of effectively developing the scarce water resources in arid and semiarid regions. In contrast to the development of finite groundwater resources, water harvesting uses the limited rainfall that occurs throughout the year (Renner and Fraiser 1995a, Brooks et al. 1997). Additionally, water harvesting is an inexpensive way to supply water to the resources and rural people who are removed from large-scale water development projects. Water harvesting is not a panacea—the uncertainties of rainfall, new management skills, and an efficient design must be considered.

Nevertheless, IALC studies will continue to further the technology necessary to apply water harvesting methods to growing trees and crops and storing water for livestock use and domestic needs. There are also advantages of using treated wastewater rather than potable water when irrigating some tree species. However, resolution of the possible health problems associated with wastewater irrigation is necessary before widespread applications of effluent are possible. Potential contamination of soils and plants, effluents polluting surface-water-delivery systems, and wastewater infiltrating to groundwater aquifers must also be addressed. Selecting trees and crops that wastewater least affects, choosing the appropriate irrigation technique—likely water harvesting—and adding decontaminates to the wastewater are also necessary.

Demonstration Projects

Sustaining Groundwater Quality Through Management of Nitrogen Fertilizers

There is increasing concern about the possible contamination of groundwater resources from nitrogen fertilizers applied to agricultural lands. For example, groundwater contamination by nitrate-nitrogen that is leaching through soils is becoming a serious problem in the irrigated Mesilla Valley of southern New Mexico. The large amounts of nitrogen fertilizer that agricultural producers are applying to onion, lettuce, chile, and other shallow-rooted crops have probably resulted in the greatest contamination (Lembke and Thorone 1980, Schepers et al. 1991).

However, only limited information on the mitigation of nitrate-nitrogen leaching to groundwater levels has been available to farmers. Therefore, IALC supported a demonstration project to show agricultural producers in southern New Mexico that they could use a known chloride-tracer technology for efficient nitrogen fertilization management. Using this knowledge, producers could then reduce nitrogen concentrations in the groundwater beneath their agricultural fields.

Demonstration

Farmers in irrigated portions of the Mesilla Valley participated in the demonstration project based on their farm management practices, and the likelihood that they would use chloride in irrigation water as a tracer to monitor their nitrogen fertilization management (Al-Jamal et al. 1998). Crop samples were taken at each participating farm to determine baseline crop nitrogen-to-chloride ratios and nitrogen fertilizer application efficiencies. After the chloride tracer was added to irrigation water, water and soil samples were taken below the irrigated field and the nitrogen-to-chloride ratios and nitrogen fertilizer application efficiencies were again determined. A user-friendly spreadsheet was made available to the farmers to help illustrate the observed efficiencies of their nitrogen fertilizer applications. Whether the farmers continued to apply the chloride tracer technology assessed success or failure of the demonstration effort.

Benefits

While the use of chloride tracers to evaluate nitrogen fertilizer application efficiencies is a proven research technology, it had never been applied at the farm-management level. However, none of the participating farmers chose to continue the use of the technology. Several felt that the cost of applying the chloride tracer

could outweigh the technology's benefits. Also, most of them believed that the problem of increased nitrogen concentrations in groundwater aquifers is a societal problem. Therefore, they felt that reducing their nitrogen fertilizer concentrations would give them only marginal benefits. Additionally, the farmers thought that the technology might cause some farmers to apply too little nitrogen fertilizer, which would reduce crop yields. These problems show that technology can be a sociological-psychological issue when trying to introduce it as an operational management tool.

Use of Wastewater to Grow Trees for Profit

Improper treatment and disposal of human wastes affect many communities in arid and semiarid lands by causing environmental degradation and declining public health. The situation exists in many small communities along the United States and Mexico border. The people in the area need effective wastewater treatment systems to reduce contaminants and a method of recycling the nutrients contained in their wastewater. One technologically viable solution is to apply wastewater to the landscape to grow commercially valuable short-rotation trees (Sopper et al. 1982, Page et al. 1983, Cole et al. 1986). This low-cost approach can safely recycle sludge and wastewater, while protecting the environment and providing opportunities for enhanced economic development.

Demonstration

An IALC demonstration project is exploring the feasibility of implementing the above technology in Ojinaga, Chihuahua, Mexico. The municipality is typical of many small- to medium-sized farming-based and economically-disadvantaged border communities. Currently, Ojinaga pipes its sewage into an anaerobic lagoon adjacent to the Rio Grande River where the solids separate from the waste stream. Those living in Ojinaga understand the need to mitigate the unhealthy situation. The demonstration project is intended to promote heightened environmental awareness, while solving local problems of wastewater treatment and disposal by using wastewater to produce fast-growing pulpwood trees.

Specialists in water and soil management, irrigation engineering, forestry, small business development, and community planning from the United States and Mexico are cooperating in 3 outreach efforts. One effort, targeted to school teachers, involves preparation of educational materials on environmental awareness and responsible management of the ecosystems within the Rio Grande River basin. Another effort focuses on expositions for the local farming community, school children and their families, neighboring communities, and representatives from local and state agencies. The exposition includes visual displays, tours of the project site, environmental awareness workshops, and literature on wastewater treatment-tree production systems and related small business development. A third effort is a conference to help local farmers determine if a cooperative pulpwood plantation irrigated by Ojinaja's wastewater is a viable economic option. The conference focuses on the advantages of community-driven cooperatives (Stanford 1994), opportunities for subsiding crop production, and community-shared financial and in-kind risk and equity.

Benefits

Increased public awareness about how to dispose of wastewater using environmentally sound and economically beneficial methods and learning about how to profit from growing pulpwood tree species are the benefits of the above demonstration project. Through binational educational and training programs and public relations, these benefits are shared with the people of Ojinaga and other small- to medium-sized communities along the United States and Mexico border. If successful, the project can serve as a model for wastewater treatment and disposal and the economic development of other local communities.

Controlling Desertification Through Savannization

Vast land areas in arid and semiarid regions are becoming desert-like because of over-exploitation of natural resources—a processes often exacerbated by climatic changes (Anaya-Garduno et al. 1994, Mouat and Hutchinson 1995). Increases in soil erosion and

decreases in land productivity and the diversity of plant and animal species characterize desertification. However, ecologically-sound management of lands threatened by desertification can stop and, sometimes, even reverse the desertification process. The Land Development Authority initiated the Savannization Project in 1986 to control desertification in Israel's northern Negev Desert (Sachs and Moshe 1999).

The focus of the project is to create patches of high productivity on desert landscapes that have low productivity by planting trees. Collecting surface water from the undisturbed surrounding area enriches the soil, which benefits the patches. By applying the water harvesting technique, further soil erosion is prevented and the collected runoff is used to irrigate the planted trees. The Savannization Project has successfully increased the biological productivity and diversity of land uses in the Negev and has helped to develop management practices of forester-sustained land uses. To transfer the knowledge from the Savannization Project to others, IALC has supported demonstration projects in Israel and in northern Chile. These projects teach the principles of savannization by demonstrating how understanding the ecological structure and function of desert landscapes can help people restore degraded areas that desertification threatens.

Demonstrations

Demonstration sites have been established at a research station in the northen Negev Desert to illustrate how ecological understanding is linked to savannization. One site shows the relationship between landscape components and surface runoff regimes. Here, participants conduct experiments in small-scale irrigation to determine and discuss the influence of shrub-covered and inter-shrub (crust) patches on runoff generation. A tour of the ongoing studies at the research station is another activity in the demonstration. Studies about the structure and function of small-scale landscape units, the effects of changes in patchiness on natural resources and species richness, and the responses of herbaceous plants and other natural resources to patch disturbances are visited.

Participants construct conceptual models of the processes and effects of savannization. They evaluate the reliability and reality of the relationships presented the models and explore the effects of grazing livestock, cutting trees, building fences, and other human-induced activities on ecological productivity and diversity. To conclude their visit, participants travel to a site away from the research station where the Land Development Authority is conducting savannization and other ecosystem-based management. Here, the participants are introduced to the management rationale of the models that they developed earlier. The historical and often incorrect uses of the ecosystem resources that have created excessive soil erosion and decreased plant and animal productivity and diversity are also explained.

A similar demonstration effort has been recently initiated in northern Chile. The principles and practices demonstrated to students, local farmers, and other clientele are based largely on Israel and Chilean techniques. Demonstration modules show the nature of biological productivity, water movement, and plant and animal diversity in shrub and inter-shrub patches, the functional relationships between surface runoff and the 2 patch types, and how ecologically sound management practices affect water harvesting and tree growth.

Benefits

A better understanding of the processes that limit the production and diversity of plants and animals on these landscapes is needed for effective ecosystem resource management. Demonstration projects on savannization show that it is not the lack of water, soil, and nutrients but the availability of these resources to plants, animals and other biotic elements that affect the production and diversity of desert land (Shachak et al. 1998, 1999). The existing water, soil, and nutrient-resource base that biotic elements in the ecosystem do not use because they escape from the ecosystem is demonstrated. However, through savannization and similar efforts to create patches of high productivity on arid and semiarid lands of low productivity, the existing water, soil, and nutrients from the undisturbed surrounding areas are effectively captured to grow trees or benefit other biotic elements. The net effect is an increase in plant and animal productivity and diversity and a reversal of the processes leading to desertification.

Controlling desertification in the Negev Desert through savannization efforts and other tree planting activities has been successful in many instances.

Water Conservation by Drip Irrigation

The effectiveness of drip irrigation in crop rotation schemes, including alfalfa, is the focus of this recently initiated IALC demonstration project in southern New Mexico. Traditional methods of irrigating agricultural crops in the Southwestern United States include inefficient flood and sprinkler systems. Effective irrigation methods and water conservation measures are needed for irrigated agriculture to remain profitable and environmentally acceptable. Recent innovations in drip irrigation technologies, such as improved drip-tape designs, have enhanced the usefulness of this low-water agricultural irrigation system (Bucks et al. 1988, Powell and Wright 1993, Camp et al. 1995, 2000, Hanson et al. 2000). Demonstrating the benefits, costs, and proper agronomic management practices of subsurface drip irrigation are key to promoting long-term water savings.

Demonstration

A drip irrigation system has been installed at New Mexico State University's Agricultural Science Center to illustrate subsurface drip irrigation practices. All system inputs (labor, water, and maintenance) and outputs (alfalfa and rotational-row crop production levels) are being monitored for future water conservation and the economic analysis of this alternative irrigation practice. An enterprise budget for alfalfa production using drip irrigation is generated to help encourage acceptance of the technology and to indicate the changes in farm management required to sustain alfalfa production in the common crop rotations schemes of the region. Workshops and study tours are also being conducted.

Benefits

Alfalfa is produced on most of the land irrigated for agricultural production in New Mexico—a state where water conservation is important. The IALC demonstration project shows how water savings and economic benefits can be obtained by using buried drip irrigation systems rather than flood or sprinkler irrigation. Reducing the water needed for profitable agricultural production should help to restore in-stream flows and improve groundwater availability.

Improving Water Quality and Environmental Conditions Using Integrated Pest Management

An effective way to control plant pests is to use a combination of chemical, biological, and mechanical control methods—known as integrated pest management (IPM). Implementing IPM practices often prevents the adverse impacts from the continuous use of pesticides, eliminates or reduces resistance to particular pesticides, and provides a backup control system if other methods fail. Building on a training program in the Middle East, researchers from the University of Illinois began an IALC demonstration project in 1994 to educate farmers on the West Bank and Gaza about the detrimental effects of excessive pesticide use. Pesticides have caused deteriorating water quality, environmental degradation, and health problems for farming communities in these fragile areas.

Demonstration

A survey was used to obtain information about the farmers, their farms and households, major constraints to agricultural production, farm management practices, decision making within the households, and the technology used to produce greenhouse and field crops. Attention was also given to pesticides use, farmer knowledge of pests, methods of pest control for crop management systems, exposure of farmers to pesticides, and exposure effects. The surveyors found excessive pesticide application, which confirmed earlier research findings and observations. Farmers determined pesticide use through trial and error applications that were based on untested information provided by dealers, other farmers, and nongovernmental organizations. In response to the heavy use of pesticides, researchers from the University of Illinois proposed a farmer education program focusing on safe and effective pesticide use and initiation of IPM technology. The purpose of the program was to teach farmers how to implement effective IPM programs, which would lower their input costs while sustaining agricultural diversity, improving water quality, slowing environmental degradation, and reducing health risks. The farmers will need effective follow up from research and extension programs to adopt fully and continue to use the information.

Benefits

Farmers on the West Bank and Gaza should attain higher water quality, less environmental degradation, sustainable agricultural crop production, improved personal health, and increases in incomes by adopting the pest control methods offered by IPM techniques. Improved knowledge of IPM technology will also enable efficient use of limited land, water, and other natural resources by farmers, agricultural managers, and other stakeholders.

Transferring Technology to Improve Soil Management on Erodible Lands

No-till agriculture can reduce surface-water runoff and soil loss from wind and water on highly erodible soils. Carefully planned no-till systems also increase farm profitability (Lamb et al. 1985, Reicosky and Lindstrom 1993, Ismail et al. 1994). Annually, up to 145,000 ha of highly erodible landscapes in central South Dakota are converted from grasslands to agricultural croplands because of expiring Conservation Reserve Program (CRP) contracts with the U.S. Department of Agriculture. Farmers need information about no-till agriculture to minimize soil and water degradation for successful land conversion. The information is transferred to the farmers through on-farm demonstration activities supported by IALC.

Demonstration

The advantages and challenges of no-till agriculture are transferred to farmers through on-farm demonstrations, sharing experiences of no-till farmers, and relevant research studies. Farmer-led discussion groups provide a forum to discuss no-till agriculture. Training materials have been developed for extension agents, agronomic consultants, and others involved in no-till technology transfer. Workshops for technology-transfer specialists focus on practical applications of no-till technology to farm enterprises. Teams of experienced researchers, practitioners, and technology-transfer specialists have organized and conducted these demonstration efforts for the general farm audience.

Benefits

Effective and responsive methods of transferring information about soil management technology on highly erodible lands are enhanced through the demonstration project. Technology-transfer specialists, a no-till farming network to facilitate information exchanges, and research feedback mechanisms are the main benefits of the project. Many demonstration efforts concentrate on farmers in central South Dakota that could convert grasslands to croplands at the expiration of their CRP contracts. Most of the CRP lands are on highly erodible soils within watersheds that drain into the Missouri River where sediment loads and the sedimentation process are acute problems. No-till agriculture is the primary conservation practice being promoted in the area.

Web Site on Arid and Semiarid Soils

Proper soil management requires understanding the complex nature and properties of soil resources in relation to the environments in which they are developed. The fragility of ecological systems in arid and semiarid environments makes proper soil management imperative. Too often, improper management practices so degrade these soils that they cannot be reclaimed even after decades of careful use (Ffolliott et al. 1995, Squires and Sidahmed 1998, Joyce et al. 1999). Relevant, accurate, and timely information on the nature and properties of soils formed in arid and semiarid regions must be available to soil scientists, land developers, resource managers, and decision makers when planning for future conservation and sustainable use of soils and other natural resources in these regions. IALC supported a demonstration project in the United States and Israel specifically to achieve the goal through Website technology.

Demonstration

A Website (http://www.ag.arizona.edu/OALS/IALC/soils/home.html) has been developed by an interdisciplinary and international team of experts to provide an informational base about the nature and property of arid and semiarid soils and to establish links to other relevant sites (Casler 1996, 1997). A slide-tape

educational program titled, *Classification, Properties, and Management of Arid Soils*, has been adapted and posted to the site, along with supplementary information. Soil-survey information, maps, and publications of organizations responsible for soil management in arid and semiarid environments are also posted to the Website. A "Guide to Resources," which includes a directory to print publications, multimedia sources, databases, and maps, was prepared and is included on the site. The Website provides special "Educational Sites for Kids and Teachers," with links to many related national and international sites—it is important that children begin to appreciate the need to manage soils and other natural resources at an early age properly. Some information in the module has been translated into Hebrew and future translation into Arabic is a possibility.

Benefits

The Website provides instantaneous, germane, and requested information about arid and semiarid soils to people any time from anywhere in the world. Efficient and timely accessibility of information is important to planners, managers, and decision makers as they attempt to mitigate the effects of and meet the natural resource needs of increasing numbers of people who are moving into arid environments.

Special Initiative

International Symposium on Sustainable Water Management and Wastewater Recycling

Topics important to sustainable water supplies in arid and semiarid regions include implementation of technologies for irrigation with fresh and saline water, irrigation technology, rain-fed agriculture, use of sewage effluents in irrigation, groundwater protection and management, and the legal aspects of water management. The purpose of the international symposium held in Israel in May 1995 was to provide a forum for deliberating these topics, identifying relevant issues, and developing recommendations and strategies in relation to 3 areas. The areas were policies and strategies for the integrated management of land and water resources, research and development for improving water use efficiency, and national-level capacity building for integrated land and water resource management.

Symposium participants were from 30 countries and included program directors and administrators of water and wastewater facilities, irrigation districts, and other government activities related to sustainable water management. At the beginning of the symposium, participants listed and prioritized the most important water issues in their countries. The list was compiled and distributed to attendees to provide a perspective for presentation of the background papers and discussion of issues. Working groups were formed to develop recommendations and present strategies on policies and action plans for the integrated management of land and water resources. A steering committee was created to suggest continuing actions to maintain the momentum initiated by the symposium.

Chapter 3

Land Use and Reclamation

Research and Development Projects

Water Use by Dryland Oaks

Part of the needed knowledge on the ecological functioning, hydrology, and management of oak woodlands in arid and semiarid regions is water transpiration by individual and stands of oak trees. Transpiration by oak trees affects the water budget of the oak woodlands and the responses of other components of these ecosystems. Tree harvesting and subsequent tree regeneration change the proportions of water contributed to other parts of the hydrologic cycle. Additionally, questions about how oak trees adjust their water demands to establish, survive, and grow on relatively dry sites in the region exist. In the Southwestern United States and northern Israel, an IALC-supported study has helped to increase our understanding about the adaptability of dryland oak species to ecosystem processes centering on transpiration by these trees.

Study

The heat-pulse technique estimated transpiration (Swanson 1994) in 2 adjacent stands of Emory oak (*Quercus emoryi*), a drought-deciduous tree in southeastern Arizona, and stands supporting Tabor oak (*Q. ithaburensis*), a deciduous oak, and Kermes oak (*Q. calliprinos*), an evergreen oak in northern Israel. Firewood had been selectively cut in 1 stand sampled in southeastern Arizona in 1980. Because firewood harvesting had last occurred 100 years ago on the other stand in Arizona, it represented unharvested conditions. Transpiration of 5 mature trees (60 years and older) was estimated in the first stand, while the transpiration of 5 mature trees and 5 postharvesting stump sprouts were measured in the second stand. Sapflow measurements obtained biweekly for 18 months on all of the sample trees were converted into estimates of transpiration. Eight oak trees were measured for 72- to 240-hour periods at each of the 2 stands in northern Israel. These sapflow measurements were also converted into estimates of transpiration on a daily and annual basis.

Only small differences in daily transpiration were discovered among the mature Emory oak trees on either of the stands sampled in southeastern Arizona (Ffolliott and Gottfried 1999, 2000). However, differences in transpiration existed between the mature trees and the postharvesting stump sprouts. Average daily transpiration for the 18-month study by a mature tree in stands was nearly 17.5 L, while 4 L of water were used daily by individual postharvesting stump sprouts. On a per-hectare basis, the mature Emory oak trees in the unharvested stand transpired about 1,900 L of water annually. In comparison, the mature trees and postharvesting stump sprouts (collectively) transpired 3,150 L of water annually in the harvested stand (Ffolliott and Gottfried 1999, 2000). Average daily transpiration for Tabor oak trees in northern Israel was 47 L, while that for Kermes oak trees was 28 L (Gottfried et al. 1999).

Mature Emory oak trees in the unharvested stand in southeastern Arizona transpired 190 mm of water—about 45% of the annual precipitation—while mature trees and postharvesting stump sprouts stocking the harvested stand transpired 315 mm of water (Ffolliott 2000). The total amount of transpiration by the large number of postharvesting stump sprouts occupying the harvested site is the presumed reason for the finding (Ffolliott and Gottfried 2000). About 40% of the annual precipitation falling in the stand containing the deciduous Tabor oak trees in northern Israel was transpired, and nearly 70% in the stand supporting the evergreen Kermes oak trees (Gottfried et al. 1999). The

Selected harvesting of fuelwood has been a traditional land-use activity in the oak woodlands of southeastern Arizona.

difference between these 2 species is attributed to the length of their respective growing seasons.

Implications

In the oak woodlands of southeastern Arizona, firewood cutting removes approximately 10% to15% of the mature oak trees. Even this low level of harvesting results in vigorous stump sprouting (Touchan and Ffolliott 1999). Therefore, harvesting Emory oak trees will probably affect the water budget of the harvested stand. Less water will be available to recharge groundwater aquifers, produce streamflow, or, depending on soil-moisture conditions, help other plants grow. That there is less precipitation available to recharge groundwater aquifers or produce streamflow after tree harvesting is contrary to the common observations of water yields increasing following the thinning or clearing of forest communities (Megahan and Hornbeck 2000). Continuing research is focusing on the effects of thinning dryland oak trees on transpiration rates. The results of the research should provide a basis for understanding how oak woodlands in arid and semiarid regions can be sustained under severe environmental conditions.

Status of Sensitive Bird Species in Desert Grasslands

The Southwestern Borderlands of the United States cover a unique and unfragmented landscape of mountains and valleys that contain exceptional biodiversity. The area is home to diverse plant and animal species that are rarely found in the United States. It was within this setting that a group of local ranchers met in 1990 to express their concern about the increasing encroachment of trees and shrubs onto otherwise productive grasslands and brainstorm a solution to the problem. Thus, the Southwestern Borderlands Ecosystem Management Research Project, headed by USDA Forest Service Rocky Mountain Research Station, was established to provide a scientific basis for developing and implementing comprehensive ecosystem management in the area (Edminster and Gottfried 1999, Gottfried et al. 2000). The evolving management effort includes strategies for sustaining natural processes, improving the productivity of woodlands and grasslands, providing wildlife habitats, maintaining an open landscape, and sustaining a viable rural economy and social structure. As a contribution to the Southwestern Borderlands Project, IALC supported a study to evaluate the status and management opportunities for sensitive birds species in the area.

Study

Many studies have focused on grassland bird conservation, but the area of focus has been the plains grassland of the Midwestern United States. Less attention has been centered on bird species of desert grasslands of the Southwestern United States. The study was designed to determine how sensitive bird species and assemblages of birds distribute themselves across a vegetation gradient in the desert grasslands of southeastern Arizona and southwestern New Mexico.

Systematic observations and monitoring efforts in the range of conditions encountered in the Borderlands area formed the field basis for the study (Downard 1998). It was found that the presence of woody plants affected the occurrence and distribution of individual and assemblages of bird species. Sites with less than 10% woody plant cover had proportionally larger populations of upland bird species. Sites with less than 20% woody plant cover supported semidesert grassland bird communities (Morrison 1999). Greater seasonal shifts in bird species richness were observed on sites with greater woody cover. Relationships between birds and specific plant species were also noted. Total bird abundance varied little between seasons except at sites with little woody cover.

Implications

A prescribed burning program and lower livestock-grazing intensities will create a mosaic of diverse plant communities that would support the greatest bird-species diversity in the Borderlands area. Prescribed burning and changes in livestock-grazing intensities will also promote a diversity of native rodent species, which will affect vegetative composition and serve as an important food source for many wild predators. Optimizing bird diversity and small mammal populations, while simultaneously achieving the desired goals of cattle production, will require prediction models that incorporate biological information, such as that obtained in the study. The models will also define costs for and tradeoffs between the benefits derived from various management activities.

Decision-Support Systems for Improved Arid and Semiarid Land Management

Many decision-making techniques are available to planners, managers, and other decision makers. Linear programming with a single objective is the basis of a relatively simple decision-making model. Assumptions of linearity for the objective function and associated constraints are inappropriate for complex problems of management, however. Problems most commonly confronted by managers of arid and semiarid lands involve most objectives. For example, minimizing the costs of a water management practice, while simultaneously maximizing the benefits from forage production, wildlife habitats, and soil and water conservation. It is also likely that the set of such objective functions will be subjected to most linear and nonlinear constraints. Complex but realistic problems can be analyzed with decision-making models based on multiple criteria decision-making (MCDM) methods

(Anderson et al. 1994, Yakowitz and Hipel 1997, and El-Swaify and Yakowitz 1998). IALC supports studies to formulate and test integrated and effective decision-support systems for strategic land-use planning and tactical management practices on arid and semiarid lands.

Studies

IALC studies consisted of efforts focusing on development of computer-based tools to apply in desert, rangeland, and wetland and riparian (streamside) ecosystems in the Southwestern United States and Middle East. Deciding the proper management activities in these ecosystems is critical because their structural integrity and ecological functioning can be easily lost if improper or inappropriate practices are initiated.

A decision-support system to assess land suitability for management practices was formulated as an MCDM problem and linked to a geographic information system (GIS) for detailed spatial analysis in one study (Mendoza 1997, 2000). Alternative MCDM methods to combine factors affecting land suitability for management into a model to evaluate habitat suitability for wildlife species in a spatial format were developed. Desert tortoise (*Gopherus flavomarginatus*) was selected as the basis of the model and decision-support system because of its endangered status in the Southwestern United States. The decision-support system represents a model that can be easily transformed into a user-friendly tool to evaluate land suitability about other natural resource management considerations.

Understanding the spatial relationships between livestock-grazing patterns on rangelands and landscape characteristics is necessary to evaluate the impacts of livestock grazing on natural resource values and to select the most appropriate management program. However, determining optimal sustainable livestock stocking rates is difficult because factors that influence forage production, effects of livestock grazing on erosional processes, and impacts of management on the functioning of rangeland ecosystems can change dramatically over a landscape. To help resolve the problem, IALC supported a study to develop a GIS that integrates spatially distributed landscape factors controlling livestock-grazing intensities into estimates of optimal sustainable stocking rates for rangeland management scenarios (Guertin et al. 1998, Mendoza and Guertin 1999, Cate 2000, Guertin and Mendoza forthcoming). The system, called RANGEMAP, is a tool that addresses resource production and conservation that enables managers to modify existing livestock-grazing management practices to sustain the environmental quality of rangelands.

A decision-making system for managers of wetland and riparian ecosystems has also been developed. The system links a groundwater model with other hydrologic and ecosystem-based models. Linking the models addresses the impacts of the proposed interventions on the ecosystem's plant-water relationships and determines the interactions between surface water and groundwater resources on plant species seeded to rehabilitate the ecosystems (Ostfeld et al. 1998, Lansey et al. 1999, Ostfeld et al. 1999). GISs provide visualizations of the static results obtained by the system. The system has been applied to a riparian ecosystem in the Southwestern United States that is being rehabilitated by identifying suitable plants to evaluate alternative planting schemes and groundwater levels. The system has also been applied to Lake Hula in northern Israel to determine the appropriate schedule and magnitude of releases through canal systems to maintain groundwater levels necessary to sustain vegetation in a restored wetland. In both cases, the system was a valuable and effective approach to operational decision making.

Implications

Decision-support systems help people make better choices for ecosystem conservation, sustainable use, and management. While the decision-support systems supported by IALC centered on habitat suitability, livestock stocking rates, and plant-water relationships, they can also be applied to a wide selection of other management topics. Arid and semiarid land management decisions can be thoroughly examined before implementation to facilitate administration that meets societal demands for natural and economic resources on a sustainable basis. Operational decisions to accommodate short-term needs can also be analyzed from a long-term and systems-wide perspective.

Public grazing lands in the Southwestern United States provide forage for livestock production and a variety of other multiple-use values.

Demonstration Projects

Improved Management of Public-Grazing Lands

Managing public-grazing lands in arid and semiarid regions requires continuing forage production and use data, preparing resource status reports, and keeping up-to-date on information about the applicable environmental laws and regulations. Satisfying these and other informational requirements affects rangeland managers and the ranchers receiving the grazing permits (Holechek et al. 1989). Additionally, managers must consider changing grazing allotment boundaries, rangeland management practices and improvement policies, and the permittees. Managers have routinely collected information about the changes, resulting consolidations, and relevant management factors. However, the information is often poorly organized and lacks an effective and user-friendly storage and retrieval system. The situation frequently leads to lost records, duplication of efforts, and wasted time and financial resources.

Demonstration

An IALC demonstration project is helping to improve management of public-grazing lands in the Southwestern United States. The project is assembling

historical and current information on the management of a representative amount of livestock-grazing allotments in central Arizona (Hutchinson and Blake 1999). The Forest Service has collected the data and information for more than 50 years and, recently, the University of Arizona has joined the effort. An interdisciplinary team of managers from the Forest Service and extension workers and information management specialists from the University of Arizona are facilitating access to the data and information through the World Wide Web and CD-ROM technologies. The team is also creating a model database, a user interface, and a database template to bring the information to planners, managers, decision makers, and local ranchers in a user-friendly package to promote learning, analysis, interpretation, and planning. Through these efforts, the team is facilitating enhanced public knowledge and understanding of public-grazing land issues in relation to environmental regulations.

The availability of the Website and the CD-ROM products is announced at meetings, conferences, and workshops, where they are also demonstrated. Depending on the audience, demonstrations focus on the different attributes of the electronic products. At workshops involving management personnel, the demonstrations provide an overview of the entire data-management system but center on how to use the template to organize data sets. Demonstrations for students, teachers, and other educators address the analysis of data and other information to solve rangeland management problems. The usefulness of the Website and CD-ROM products is also presented at locally-led advisory committee meetings and Cooperative Extension conferences and workshops.

Benefits

Organizing the information in electronic formats furnishes a case study on the planning process used by the Forest Service and other federal agencies to develop livestock-allotment grazing plans that meet society's needs. The database template provides a model for people to build their own data-management systems that meet specific needs. As a result, the template maximizes the benefits of past financial inputs, offers new planning opportunities, and facilitates compliance with federal laws and regulations pertaining public-grazing lands in the Southwestern United States (Hutchinson and Blake 1999). The variety of delivery mechanisms available ensures that the broadest constituency possible is included in the clients served. Managers planning and implementing land-use practices on public grazing lands, researchers testing and validating predictive models of forage growth and livestock use of forage biomass, students and teachers learning about the ecological processes of livestock production, and decision makers selecting the best course of action from a set of alternatives benefit from the project. The products and benefits of the demonstration project reach beyond Arizona and the Southwestern United States because livestock production is a traditional land-use of many societies in arid and semiarid environments.

Dissemination of Watershed Management Information

Watershed managers throughout the world are formulating and implementing actions that manipulate natural and human resources for specific objectives. Watershed management on arid and semiarid lands is often difficult, however, because water supplies and inherent resource productivity levels are limited. In addressing the difficulty, watershed management research in the Southwestern United States has led to a better understanding of the hydrology, ecology, and land-use potentials of the region's watershed lands (Baker 1999, Baker and Ffolliott 1999). The research has helped to establish management guidelines to satisfy the needs of a growing population in the region. However, the research efforts and their benefits to improved land stewardship are not widely known nor readily accessible. An IALC demonstration project has been undertaken to increase the accessibility of the information and to help planners, managers, and decision makers improve management decisions and effectively involve the public in the decision-making process.

Demonstration

The University of Arizona and the Forest Service undertook a collaborative technology transfer effort to deliver research results and other information generated by the Beaver Creek Project in north-central Arizona

(Baker 1999) to a diverse public (Baker and Young 2000). A key part of the project consisted of bringing the information to the public through the World Wide Web. A Website (http://www.ag.arizona.edu/OALS/watershed) was developed to feature Beaver Creek-related references as examples of successful and unsuccessful projects in regional watershed management (Baker and Ffolliott 1999). The home page titled, "Watershed Management in the Southwest," includes topics on watershed management practices, order forms for references on watershed management practices in the Southwestern United States, and an interactive learning package on watershed management practices.

Other technology transfer mechanisms are also available. A telephone system gives callers recorded two-minute messages on sustainable management practices for watershed lands in arid and semiarid environments. Field trips to Beaver Creek sites introduce students, teachers, and the public to forest, wildlife habitat, and rangeland management practices and to the importance of watershed condition and function. The three-pronged technology transfer effort optimizes information transfer on issues concerning watershed management on arid and semiarid lands to interested stakeholders.

Benefits

Clientele who have benefited from the increased availability of watershed management information include practitioners in the region, throughout the United States, and other countries; students, teachers, and other educators in high schools, colleges, and universities; and others interested in sustainable resource development and conservation. By bringing field-tested data and other information to people in formats that can be used for learning and decision making, the demonstration project is providing a valuable service to planners, practitioners, and educators concerned about future land stewardship. Technology transfer methods that have been developed are being expanded to make other hydrologic, ecological, and economic data sets collected on other watersheds in the Southwestern United States available to researchers, managers, educators, and decision makers (Baker et al. forthcoming). Included in these continuing efforts is research from watersheds in mixed conifer forests and chaparral shrublands.

Special Initiatives

International Workshop on Arid Lands Management

The purpose of the workshop, held in Israel in June 1994, was to establish the state-of-knowledge on the functioning of arid and semiarid land ecosystems, and their proper and sustainable management. IALC and other institutions at the workshop that support research and development on these ecosystems used the information to review the state-of-knowledge and to decide where best to allocate resources. Information was also distributed to managers to use in their management planning and programs. The workshop featured more than 250 participants specializing in ecological and climatological relationships, management planning and implementation, and mitigating or combating desertification. Invited papers on selected topics were presented; participants held discussions on population, community, and ecosystem management; and field trips were conducted to demonstrate how technological breakthroughs in desert management and combating desertification in Israel might be globally applicable.

Invited and volunteer papers from the workshop discussions and a capstone synthesis paper on research and management implications formed the basis for a book titled, *Arid Lands Management: Towards Ecological Sustainability*, which has become a reference for planners, managers, and decision makers (Hoekstra and Shachak 1999a). Topics of chapters in the book include an ecological framework for conservation and sustainability; ecosystems of deserts and their management; land use and management of arid and semiarid lands in the Southwestern United States, northern Mexico, the Negev, and Australia; and planning, simulation, and operation research approaches to management. A concluding chapter presents a synthesis of research and management opportunities and implications about sustaining the functioning of fragile ecological systems in arid and semiarid lands. The book is a source of information for policy makers, representatives of legislative bodies, and interested segments of societies of countries in arid and semiarid regions where desertification is an issue.

International Symposium and Workshop on Desertification in Developing Countries: Why Can't We Control It?

Desertification is occurring in many arid, semiarid, and dry subhumid regions of the world. The *World Atlas of Desertification* shows that soil degradation leading to desertification is a problem in developed and developing countries (United Nations Environment Programme 1992). The symposium and workshop, held in October 1994 in Tucson, Arizona, addressed the issue of desertification in developed countries and what can be done to control it. Participation was limited to about 150 scientists and land managers from 15 countries concerned about the increasing threat of desertification. Participants focused on monitoring and assessment techniques and mitigative interventions. While many lessons had already been learned about desertification, organizers felt that the participants should concentrate their efforts on the successes from a few countries and distill the information into a transferable format for extrapolation.

Key papers presented at the symposium and workshop were published in a book titled, *Desertification in Developed Countries* to facilitate dissemination to a wide audience (Mouat and Hutchinson 1995). Book chapters address social, economic, political, and institutional factors that have resulted in successful interventions; monitoring and assessment of the magnitude and severity of desertification in developed countries and worldwide; and techniques tried to halt or reverse the desertification processes. Recommendations on how to combat the effects of desertification and other forms of soil degradation common in arid and semiarid environments are also presented.

International Symposium and Workshop on Connecting Science with Community Action in Combating Desertification

A symposium and workshop on desertification was held in May 1997 in Tucson, Arizona, to explore methods of linking science to community action. The initiative was a follow-up to the above 1994 symposium and workshop on desertification, however, this initiative included a wider audience of scientists, managers, and community action specialists. An outcome of the 1994 activity was the realization that there was a gap between the scientists researching the processes, causes, and effects of desertification and the people daily facing its effects. Therefore, the 1997 initiative focused on exploring and evaluating the methods for linking the science to community action. Another focus was to review interventions and other programs to combat desertification at the local level by examining the successes and failures and extracting lessons.

Twenty of the papers presented at the symposium and workshop, including research-oriented papers, regional case studies, and community action studies, were published in a special issue of the Journal of Arid Environments (Mouat and McGinty 1998). The papers embody the concept that desertification and soil degradation are inseparable from sustainability. People know something about the processes, causes, and status of desertification in the world, but to successfully combat it, human interventions must be applied before the processes and causes lead to irreversible situations. Participants at the symposium and workshop concluded that carefully planned community action supported by science can help reverse the processes and attain a level of sustainability.

International Training Workshop on Ecological Systems

The training workshop, held in November and December 1995 in Israel, was presented to managers, policy makers, scientists, and academics from 20 countries containing arid or semiarid regions who were interested in sustaining ecological systems. Topics presented included soil-water-plant-nutrient relationships; animals in desert and desert-like conditions; and appropriate agriculture, agroforestry practices, afforestation, and livestock-grazing practices. There was a special emphasis on participation of men and women in management and implementation of programs focusing on these topics at economic levels ranging from subsistence to a market-oriented economy and sustainable economic and regional growth. The format consisted of formal lectures, open discussions, and visits to agricultural production and industrial manufacturing enterprises, water harvesting projects,

afforestation interventions, and restoration sites. Trainees prepared reports that linked management and development practices considered in the training workshop to proposals that addressed these practices in ecological systems in their respective countries. The reports were presented to trainees and staff in a plenary session at the conclusion of the workshop. An evaluation made by the trainees at the end of the training workshop ranked the topics and other activities of the initiative in relation to their importance to the trainees.

Technical Training Course on Mitigating Risks to Conservation and Sustainable Use of Water and Other Natural Resources

The course, held May and June 1999 in Jordan and Israel, for trainees from Jordan, the Palestinian Environmental Authority, and Israel, concentrated natural climatic variability when planning for management of water and other natural resources. The format consisted of formal lectures and informal

Participants in a technical training course on natural resource management in the Middle East viewing ecological conditions affected by drought and desertification processes and discussing what might be done to mitigate these degraded conditions.

discussions, laboratory sessions, and field trips. Trainees learned about the basic concepts and principles of natural resource management practices, the techniques and applications of dendrochronology (tree-ring dating) to generate information on climatic regimes, applications of stochastic generators of the climatic regimes when planning for conservation and sustainable development of water and other natural resources, and the importance of local participation when planning natural resource management. A key outcome from the course was the identification of issues for cooperation among countries affected by drought and desertification and a prioritization of the issues for possible follow-up actions. Course modules were chapters of the training manual prepared for the initiative (Touchan et al. 1999). The training manual has been widely distributed to interested organizations and people in the Middle East since course completion. An evaluation made by the trainees at the end of the initiative indicated that the technical training course was a success, had met anticipated expectations, and could be a model for future collaborative efforts.

Land Management Workshop

IALC hosted a special initiative titled, "IALC Land Management Workshop: A 10th Anniversary Celebration of USFS, CSREES, Israel, and IALC Partnerships," in November 1999 in Reno, Nevada, to update government land managers and others on the activities and accomplishments of IALC's scientific and technical programs. The focus of the workshop was on water and watershed management; seedbanks and crusts; wildlife, grazing, and ecology; and decision-support systems. A panel of scientists considered each focus area by presenting IALC-sponsored research and development projects and supporting demonstration projects (International Arid Lands Consortium 1999). A group discussion followed the presentations. Most of the 70 participants that attended the workshop were researchers and administrators from the respective IALC-member institutions. Others included representatives from the Forest Service and Cooperative State Research, Education, and Extension Service. The initiative successfully brought together researchers and managers from the United States and Israel to share their expertise and experiences in building a global community of planners, managers, and decision makers dedicated to improved stewardship of arid and semiarid lands.

Chapter 4

Processes Enhancing the Management of Ecological Systems

Research and Development Projects

Impacts of Water Capture on Plant Virus Vectors

Water that is captured and remains in natural depressions can influence the character and dispersal patterns of the vectors of plant viruses. In turn, the water can spread into agricultural croplands near the catchments and impact crop production (Irwin and Ruesink 1985, Irwin 1991). The significance of these events on sites in Israel with high-input agriculture is the focus of the IALC study. The study is designed to clarify the effects of natural water catchments on populations and the dispersal patterns of leafhoppers, aphids, whiteflies, and thrips, which are potential vectors of plant viruses in the region.

Study

Three sites at about the same elevation within 1 km of each other with different water-capture potentials were selected for study. Their differing ability to capture water has resulted in differences in plant characteristics. One site supports more grasses, annual flowers, and Acacia trees than the second site, while the third site was essentially bare. Liquid-filled yellow pans and malaise traps were used to sample insects in the spring of consecutive seasons. The pans attracted specimens flying in the plant boundary layer (>10 m above ground), while the traps collected specimens within the surface boundary layer (<10 m above ground), thereby sampling movements of the vectors throughout the site habitats.

Results to date suggest that aphids and whiteflies are abundant on sites that captured less water and leafhoppers and thrips are abundant on the site with more water. These differences were greatest following a winter with heavy rains and minimal following a winter with almost no rainfall. No temporal (seasonal) off-setting of flight activities was detected among the 3 sites. The results suggest that nearby water-capture regimes do not off-set the life cycles of the vectors. Most flight activity of the insects occurred in the spring—flight patterns of aphids and trips peaked earlier than those of leafhoppers and whiteflies. The 3 sites differed in the numbers and types of insect vectors observed in relation to the amount of water they receive.

Implications

The study is improving the understanding of the effects of captured water on the life cycles of potential vectors of plant viruses. While further analysis of the data will be made, findings to date have implications for management of agricultural crops adjacent to sites of natural water catchments. If the availability of water affects the types, abundance, and flight patterns of insect plant vectors, a holistic form of management might be necessary to minimize the occurrence of plant viruses that reduce the productivity of threatened agricultural crops.

Climate Change, Allometry, and Tree Hydraulics

The rise in atmospheric CO_2 anticipated by the end of the 21st century is expected to increase air temperature and atmospheric vapor-pressure deficits. Managers of forests, woodlands, and plantations are concerned about the effects these increases might have on trees. The most relevant allometric component controlling

water transport for trees is the ratio of biomass allocated to photosynthetic tissue (leaves) relative to water-conducting tissue in the stem (sapwood) (Running 1980a, 1980b, Holbrook and Sinclair 1992). Within the genus *Pinus*, trees decrease the ratio of biomass allocated to leaves relative to sapwood in response to rising air temperature and atmospheric vapor-pressure deficits. Therefore, these climatic changes could alter the water relation of trees and forests of this genus. In Nevada, stands of ponderosa pine (*Pinus ponderosa*) in a desert-to-montane transition gradient were used in the IALC study to determine the effects of climate-related shifts in biomass allocation on the water relation of mature trees.

Study

Researchers used published values to test a theoretical prediction that ponderosa pine trees decrease their investments in leaves relative to sapwood as air temperature and atmospheric vapor-pressure deficits increase (DeLucia 1999). From these predictions, researchers found that desert ponderosa pine trees would have higher rates of water transport per unit sapwood area than montane ponderosa pine trees because of larger diameter tracheids in the sapwood (Maherali and DeLucia 2000b). The low ratio of biomass allocated to leaves relative to sapwood and the higher sapwood conducting efficiency should lead to an increase in hydraulic conductivity and higher transpiration rates in desert trees.

Desert and montane trees should have similar vulnerability to xylem embolism and soil-to-leaf water potential gradients during the growing season (Maherali and DeLucia 2000a). Despite relatively higher allocations to sapwood, desert and montane ponderosa pine trees would not differ in their reliance on stored water reserves. A loss in foliage storage capacity offsets gains in sapwood water-storage capacity through high allocation to sapwood in desert trees. The advantage of the high allocation to sapwood in warm, dry environment is increasing the hydraulic conductivity to prevent xylem embolism induction. A growth chamber study revealed that there were no interactions between elevated temperature and CO_2 on water transport in ponderosa pine seedlings. Similar to their mature counterparts in the field, seedlings reduce the ratio of biomass allocated to leaves relative to sapwood and have higher hydraulic conductivity in response to elevated air temperatures and atmospheric vapor-pressure deficits.

Results from the study suggest that rising air temperatures and atmospheric vapor-pressure deficits could exert more influence on tree-water relations than elevated CO_2 in a future climate (DeLucia et al. 2000, Maherali and DeLucia 2000a, 2000b). A common garden study showed that although populations of desert and montane ponderosa pine trees differed genetically, none of the variability was associated with ecotypic divergence. Therefore, differences in water relations of desert and montane trees might be related to phenotypic plasticity. Consequently, phenotypic plasticity of a species, with respect to its adaptation to changes in temperatures and water relations could determine the composition of future forests under the warmer conditions resulting from elevated atmospheric CO_2.

Implications

A doubling of atmospheric CO_2 concentration—considered stable for the last 100,000 years—is predicted to increase global air temperatures about 4° C in the next 100 years (DeLucia 1999). The CO_2 rise will be unprecedented and raises the question of how will long-lived trees respond to the climate change. What physiological and morphological characteristics will produce the most robust trees in the future is not known. However, inferences drawn from the study about combinations of traits that could be adaptive to climatic changes increases our understanding of the capacity of future forests to fix atmospheric carbon and survive. The knowledge should help managers select ecologically adapted genotypes for wood production and other purposes in warm and dry environments that are similar to that studied.

Modifying Toxic Compounds in Leguminous Trees

Fodder from leguminous trees is part of the roughage diets of livestock in many arid and semiarid countries. While the fodder is not necessarily a nutritional dietary component, it is used when nutritional forage is unavailable. However, anti-nutritional effects of

leguminous fodder can be alleviated through modification of rumen microbial populations by isolating, culturing, and reintroducing microorganisms capable of transforming anti-nutritional compounds into susceptible ruminants (Gregg and Sharpe 1991, Gregg 1995). The IALC study used two approaches to obtain these modifications. Isolating and characterizing rumen organizations capable of modifying known anti-nutritional factors was one approach, while identifying anti-nutritional factors in leguminous trees with potential value as fodder was the other.

Study

The hypothesis tested was that microorganisms from ruminants adapt to diets containing leguminous fodder modify or degrade anti-nutritional factors better than rumen populations from livestock fed conventional roughage diets. Researchers from the International Livestock Research Institute, Addis Ababa, Ethiopia, and the University of Illinois developed the hypothesis concerning the effects of feeding fodder from the *Acacia angustissima* to sheep. *A. angustissima* is a tropical legume, which could be a fodder tree (Hocking 1993), although the fodder is toxic to sheep.

Completed laboratory experiments and experiments in progress are testing the validity of the hypothesis. Metabolic transformation by rumen inocula of 3 classes of anti-nutritional factors in leguminous fodder—mimosine, tyramine, and ferulic acid—indicated that there was no difference in the rate or extent of modification when sheep were fed leguminous-supplemented or conventional roughage diets. Organisms that modify anti-nutritional factors of leguminous fodder were present in rumen populations in Africa and the United States. Isolating cultures of these organisms is possible, which could be useful in developing rumen inocula.

A bioassay was conducted on rats to identify and evaluate anti-nutritional factors present in diets of varying amounts of *A. angustissima* and comparative diets of *A. augustissima* and alfalfa. Other experiments will be conducted to determine whether anti-nutritional effects of *A. augustimmisa* are due to the presence of phenolics or whether a synergistic effect between the phenolics and unidentified compounds exists. DNA collected from fecal samples will be analyzed to assess the antimicrobial effects of the phenolics present. In vitro incubations of phenolic containing plant extracts, with previously isolated bacteria, will help identify organisms capable of detoxifying the anti-nutritional factors of *A. angusissima.*

Implications

While limited to 1 leguminous tree species and 1 class of livestock, results from the study should further our understanding about toxic compounds in leguminous trees, their potential effects on livestock, and what might be done to make it palatable. Leguminous trees are multi-purpose because they provide wood resources for local uses, are a source of human food, and provide shade for livestock. Many species also symbiotically fix atmospheric nitrogen needed in nutrient-deficient ecosystems. Knowing about the fodder resources of these trees allows for their efficient and varied use.

Genetics and Propagation to Improve the Management and Culture of Plant Resources

Many IALC research and development projects continue to focus on improving planting stock through genetics and other techniques to increase yields and qualities of plants valuable to people, develop plants that can do well in adverse environments, and produce plants for special uses, such as conservation planting or agroforestry practices. However, other world regions have received more research and development efforts to improve planting stock than the arid and semiarid regions. IALC is addressing the deficiency by supporting studies that will increase knowledge about how genetics and other improvement techniques can conserve plant resources in arid and semiarid environments.

Studies

Cacti produce food crops efficiently under dry conditions. However, cacti as a food crop occurs mostly in areas where they are indigenous. The objective of a cactus breeding study supported by IALC in southern Texas was to combine cold hardiness, low seediness, high yields, and high sugar concentrations to produce high quality, adaptable, appealing cacti food crops (Chavez-Ramirez et al. 1997, Parish and Felker 1997, Wang et al. 1997, Felker et al. 1998, Wang et al. 1998,

Wang et al. forthcoming). Seeds from crosses of native Texas spiny (*Opuntia lindheimerii*) and several commercial spineless fruit varieties that are found in Mexico and elsewhere were obtained for the study. The native variety is cold hardy in southern Texas, and it was expected that progeny from crosses with the native and non-cold hardy Mexican varieties would have the desired cold hardiness and fruit quality.

Among the promising crosses was one between a spineless, large, red-fruited variety, with small seeds, high yields, a dwarf-compact shape, good disease resistance, and average sugar concentration. An outcome of the breeding effort was a clone of a spiny yellow-fruited variety, with excellent firmness and a high sugar content. Unfortunately, the clone is too tall to harvest efficiently and has disease problems. All of the crosses between the 2 Chilean clones were noteworthy because they had the greatest sugar concentration and lowest seed size. While these clones are low yielding, combinations of the clones with high-yielding varieties should result in genotypes with desirable food production characteristics. When compared to citrus, cacti is more cold hardy, requires less water, and its fruits are ripe when citrus is not. Techniques for emasculation, hybridization, and germination have been developed to promote cacti as a food.

IALC also supported a study to improve propagation of Rocky Mountain juniper (*Juniperus scopulorum*) and eastern redcedar juniper (*J. virginiana*). The purpose of the study was to help nurseries meet production levels by identifying factors critical to rooting stem cuttings. Identifying factors enables manipulation to help ensure successful rooting for conservation plantings in the Great Plains (Wagner et al. 1992). Factors known to affect rooting (adventitious root formation), which were investigated, included genotype, mother-plant growing conditions, cutting type and position, exogenous growth-regulator application, and dormancy level or collection timing. Stem cuttings from known sources planted in a Great Plains Agricultural Council provenance trial were studied to determined genetic variability within the species. To evaluate the effects of mother-plant growing conditions, cuttings were collected from sources in South Dakota, Nebraska, and New Mexico to provide climatically distinct growing environments. Cutting type and position experiments examined differences between juvenile and mature cuttings and the location on the crown where the cuttings originated. Another experiment was accomplished to investigate the effects of exogenous hormone applications. Collection dates in March, April, June, or July, and October assessed dormancy level or collection timing.

Overall, the stem cuttings studied did not root well. Variability in stem rooting was observed within and among species, collection site, and individual trees. Cuttings from some individual trees did root well for one or more collections (Wagner et al. 1994). Cuttings from younger trees (less than 3-years old) generally rooted well. These experiments indicate that there is some underlying genetic control on the ability of Rocky Mountain juniper and eastern redcedar stem cuttings to produce adventitious roots. However, there may be potential for large-scale vegetative propagation of these important trees to meet the nursery demands for juniper stock for use in conservation plantings.

Scientific and practical benefits are expected from a study to increase knowledge about the population and individual genetics of Mediterranean pines. Pine forests in the Middle East, and other arid or semiarid environments, respond to global warming according to their ability to withstand increasing drought (DeLucia et al. 2000). Additionally, identification of genes and genotypes of pine, with particular abilities to withstand drought, should be applicable in afforestation efforts where conditions are too dry for pine cultivation. Researchers in Israel and the United States are using two approaches to identify genes and proteins induced by drought stress in Allepo pine (*Pinus halepensis*), a species with renowned resistence to drought (Korol and Schiller 1996, Schiller and Cohen 1998). One approach is using young seedlings to examine proteins induced by water stresses. Seedlings are subjected to stress by withholding water or to a slowing induction by subjecting them to varying concentrations of glycerol. They observed that total protein content in roots of seedlings subjected to rapid stress was reduced to 20% within 18 hours. The protein content of hypocotyls decreased at a slower rate. Coomassie staining of total proteins separated by SDS-PAGE did not show differences between stressed and unstressed seedlings. However, SDS-PAGE of hypocotyl boiling-stable proteins

facilitated identification of bands induced by the stress treatments. When biotin was incorporated into the proteins produced during treatments, additional proteins induced by stress were detected. The various bands reached their maximums at different stress levels. An antibody to a peptide in LP3 has also been used to examine induction of dehydrins. The antibody was not specific and reacted with several proteins between 15 and 90 kDa. Some bands decreased or increased during stress treatments.

The second approach uses six-month-old seedlings and differential screening of a cDNA library to isolate the clones of induced genes. The library is made using roots of stressed seedlings and was screened using probes generated from stressed and unstressed roots. Of the 21,500 clones examined, 156 that represent genes induced by water stress were identified. Fifteen of the identified genes have been sequenced and northern blot analyses were used to examine the expression of 7 of those genes. The genes induced by stress included those encoding a LEA-like protein (late-embryogenesis-abundant), a lignin biosynthetic enzyme (4-coumarate CoA ligase), a cyclophilin, an endochitinase, a sucrose synthase-type protein and some that were not similar to previously identified genes. Next, the study will determine if any of the characterized genes encode the induced proteins that were identified in the first approach.

Climate changes will likely create many challenges for ecologically-sound management of arid and semiarid lands. Climatic changes could encourage further aridification in the Middle East and Southwestern United States. Anticipated water stresses could affect specific plant communities by causing displacements and extinctions. Although a significant amount of theory exists, there is little evidence that core populations of plants will be more resistant, equally resistant, or less resistant to climate changes than peripheral ones. An ongoing IALC study is revealing whether there are genetic variabilities in sensitivity to environmental stresses between core and plant peripheral populations—particularly in those predicted to increase through desertification. Predictions of which plant populations will be biogenetic resources are possible as well as predictions on the roles of drought-responses of genes involved in adaptive functions. To test the hypothesis that the genetic complexity for drought-response genes is greater in peripheral than core plant populations, structures of gene families for drought-responsive and nonresponsive genes are being evaluated. The evaluation is occurring in 2 species, *Dactylis glomerata* and *Trifolium purpureum*, with core populations in the Mediterranean region and peripheral populations in the desert-to-nondesert transitions in Israel.

Standard molecular biological procedures in samples of each of the 2 species in 3 core populations and 3 peripheral populations are measuring genetic variability in the 2 plant populations. The diversity of drought-inducible genes, drought-repressible genes, and genes, with transcript levels that do not change in response to drought, will be studied. Testing for survival will measure the drought-resistance physiological attributes of individual plants into drought by relating leaf-water potential to transpiration and water acquisition from the soil. Analyses will be done to determine if genetic variability for any of the drought-inducible genes is greater in peripheral than core populations. The study is significant because the results from the native plants could be directly translated for use in studies on crop plants. If complexity of the gene families for drought-inducible genes is greater in peripheral than in core populations, the hypotheses proposing positively adaptive functions for these genes will be supported.

Implications

The importance of improving planting stock for conservation and improved food and forage production for humans, livestock, and wildlife on arid and semiarid lands is evident. As shown by the IALC studies through carefully conducted research and development, plant yield and quality can be improved. Additionally, the studies have shown that plants can be developed that can sustain themselves on harsh sites, under extreme environmental stress, and that plants can be adapted for special uses. These studies are benchmarks because of the increased knowledge obtained about improving planting stock for species and regions not previously investigated. One particularly important benefit of genetically improving planting stock, accomplished by these studies, is that once the desired change is obtained, it can be maintained for many generations through careful planting-stock management. Genetic material

identified through screening or developed through plant-breeding programs can be kept intact through improved methods of vegetative propagation.

Nitrogen, Productivity and Soil Biota in Desert Ecosystems

Deserts, which cover more than 15% of the earth's land surface, are expected to increase significantly in areal extent with increasing CO_2 levels and global warming. When lands that are sensitive to desertification processes are also considered, nearly one-third of the earth's land surface is likely to be subject to the combined nitrogen, water, and other stresses addressed in the IALC study. The capabilities of these lands to sustain human activities will be tied to the productivity of the plants growing on them. While plant productivity is related to available soil moisture, high year-to-year variations in soil moisture are difficult to correlate with annual rainfall inputs (Bottner 1985, Keift et al. 1987, Hartley 1997). A major reason for these variations is the soil's nitrogen status, including the amount of extractable nitrogen available in the plants and the amount tied up in soil biota. Under the best of circumstances, the complex fluxes between soil-nitrogen pools are poorly understood. This is the case in arid ecosystems where the fluxes can change quickly following rainfall.

Study

Soil samples have been collected in the Negev Desert in Israel and on the Jornada Experimental Range in southern New Mexico to determine how total nitrogen, soluble nitrogen, and plant nitrogen pools in desert soils change with time and following rainfall events. How observed changes in nitrogen relate to plant productivity and follow populations of arbuscular mycorrhizal fungi, heterotrophic bacteria, and soil nematodes are also being evaluated in the 2 ecosystems. The ecosystems vary in amount and pattern of rainfall inputs received, and both are under stress from livestock grazing.

While analysis of the study data is incomplete, the following findings have been reported. Halophytes in the Negev are arbuscular mycorrhizal fungi and the levels of colonization are positively correlated with organic matter and soil moisture. The rapid changes in species richness and trophic structure indicate that Nematode communities also respond to soil moisture Arbuscular mycorrhizal colonization rates on the Jornada Experimental Range are consistently higher than those in the Negev and are positively correlated with soil moisture—similar to that the Negev. Distributions of heterotrophic bacteria on the Jornada are high near established plants and when soil moisture is high. As predicted, on both study sites the responses of arbuscular mycorrhizal fungi and heterotrophic bacteria are not as dramatic following a second and third rainfall event. Researchers are waiting for additional laboratory analyses to identify correlations between biotic communities and nitrogen levels.

Implications

Results from the study will provide a better understanding of the interactions among nitrogen pools, plant productivity, and populations of soil biota in the desert ecosystems of Israel and the Southwestern United States. Once available, these results can be translated into inputs for planning management and use of plant communities to sustain livestock grazing and other human-induced activities on desert lands and lands sensitive to desertification. Increasing areas of the earth's land surface are falling into this category.

Patchiness and Ecological Flow Effects on Ecosystem Functioning

Seemingly bare surfaces of many soils throughout arid and semiarid regions of the world are actually mosaics of macrophytic patches of shrubs and herbaceous plants. These plants are growing in soil mounds and microphytic (biogenic) patches of algae, mosses, lichens, bacteria, and cyanobacteria that are growing on soil crusts. Due to the limited amount of water, soil, and nutrients available to organisms of these patchy ecosystems, patterns of spatial heterogeneity at the landscape-level develop (Zaady and Shachak 1994, Shachak et al. 1999). The distinguishing features of the heterogeneity are the spatial distributions of soil, rock, shrubs and other herbaceous plants within the matrix of soil crusts

formed by the microphytes. When an abiotic or biotic variable shows 2 discrete states at a single level of resolution, the spatial heterogeneity is called patchiness (Shachak et al. 1999). The patchiness of arid or semiarid landscapes controls population abundance, species richness, biomass accumulations, and flows of water and nutrients in the ecosystems. IALC supports studies to learn about the character of natural and human-made patchiness, ecological flows, productivity, and diversity of patchiness on arid and semiarid landscapes.

Studies

The studies are designed to understand the relationships among patchiness, microbiotic crusts, ecosystem resources, productivity, and diversity better. The studies also intend to show the implications of these relationships for management of arid and semiarid lands and the effects of patchiness on the cycling of nutrients and other resources. Additionally, the research hopes to indicate redistribution of these ecosystem resources in the deserts of Israel and Southwestern United States. Methodologies used by researchers in the studies have been presented elsewhere (Zaady et al. 1996, Offer et al., 1997, Shachak and Lovett 1998, Monger and Kidron 1999, Dawson et al. forthcoming) and, therefore, are not elaborated here. However, some significant findings from these studies are presented.

Trends in species diversity with respect to harvesting shrubs, scalping vegetation, and spraying herbicides and relationships among patchiness, water flow, and plant responses in the Negev have been revealed in 1 study. Harvesting shrubs causes the size of the macrophytic patches to increase, while there is a decrease in the size of microphytic patches. The trend results from the dispersal pattern of seeds on the area. A large seed bank can accumulate in the macrophytic patches in spring and summer. Without competing shrubs, a high germination rate of herbaceous plants exists on the soil mounds of macrophytic patches and in the interface between macrophytic and microphytic patches. This promotes an increase in the macrophytic and decrease in microphytic patches.

A predictive model, developed by the researchers, shows that the increase in macrophytic patches and a decrease in water-shedding microphytic patches results in increased runoff interception by the macrophytic patches (Shachak et al. 1999). Removal of aerial portions of the shrubs alters patch quality, increases patch size, and increases total surface area covered by macrophytic patches. This causes an increase in water retention and water availability for plant growth. The net effects of harvesting shrubs are increases in species richness and variation in composition of both patch types.

After scraping to remove above-ground vegetation and expose the soil surface, *Atractylis serratuloides* was the first shrub to colonize the area. When these shrubs grow, soil accumulates and forms a mound under the shrub canopy. The soil mounds enable herbaceous plants and *Noaea mucronata* shrubs to become establish. Development of the 2 shrubs, *A. serratuloides* and *N. mucronata*, allows for soil accumulation and an increase in the size of macrophytic patch. The scraping treatment creates large microphytic patches and an increase in the ratio between the microphytic and macrophytic patches. The high proportion of micophytic patches preventing infiltration of surface water and explains the relatively high runoff generation and low water retention following the treatment. Patchiness modification by scraping, and its effect on water flow, helps to explain the decreases in species richness in both patch types, compositional variations, and patch type differences. Spraying with the herbicide Simazine eliminates all herbaceous plants and *A. serratuloides.* Areas sprayed usually become inhabited by only *N. mucronata.* Without herbaceous plants on the soil mounds, the mounds disintegrate and the soil erodes. These processes cause a decrease in the size of the macrophytic patches and an increase in the size of microphytic patches.

The accumulation of soils is a limiting resource in desert ecosystems. However, loose soil mounds in macrophytic patches can permit relatively high production of annual plants. In another study, depositions of atmospheric particles on macrophytic and microphytic patches were measured in the Negev to determine to what extent atmospheric particle depositions are responsible for soil-mound formation (Offer et al. 1997). Fine particles consisting mostly of mineral dust are deposited at similar rates in macrophytic and microphytic patches. However, coarse particles from plant detritus

The patchiness of the Negev Desert and other deserts of the world influences on-site water retention and, as a result, the water available for plant growth.

are deposited at greater rates in macrophytic than in microphytic patches (Zaady and Shachak 1994, Zaady et al. 1996). Coarse particles have higher concentrations of carbon and nitrogen than fine particles. Typical soil mounds take up to150 years to develop. Therefore, ecosystems that are slow to recover from disturbances, such as overgrazing by livestock, excessive firewood cutting, or herbicide applications, reduce the abundance of macrophytic patches.

Depositions of dust, organic matter, and feces, and their redistribution by runoff in the Negev, have also been studied in relation to patchiness and rainfall. Higher accumulations of these dry depositions observed in the winter are probably due to climate and biological activity (Offer et al. 1997). Depositions of dust are higher in soil-crust patches than under shrubs of macrophytic patches. Contrary to popular theory, shrubs do not act as dust traps but instead as umbrellas that prevent dust deposition underneath shrub canopies. Soil erosion that is higher than dust deposition indicates that the ecosystem is in a state of soil accumulation, although the soil accumulations are nonuniform. Runoff redistributes dust deposits so that the rate of soil accumulation under the shrub is higher than that on the soil crust. The difference in soil accumulation is responsible for creating differences between the flat crusts and soil mounds under shrubs (Shachak and Lovett 1998). Patchiness from dry deposition, and its redistribution, is the main controller of productivity and diversity of the ecosystem.

In the Chihuahuan Desert of the Southwestern United States, occurrences of fragile physical crusts on soil surfaces are more common than those of microbiotic crusts. A finding from an IALC study indicates that microbiotic crusts are confined to stable soils on sites protected from soil degradation, while physical crusts are on almost any bare soil (Monger and Kidron 1999). Microbiotic crusts are often found on the sheltered leeward sides of quartz dunes that mesquite has stabilized (*Prosopis* spp.) shrubs. Their scarcity in bare sandy areas suggests that they are vulnerable to soil erosion and are burial by sand. Microbiotic crusts generally cover gpysiferous sands, which are less extensive in the Chihuahuan Desert than quartzose sands. The microbiotic crusts are distributed in a patchy pattern reflecting microclimatic patterns of modified temperature, moisture, and soil erosion, which creates a habitat where the crusts can flourish.

The roles of large herbivores and burrowing animals on patch dynamics and crust retention are being analyzed in an IALC study that has recently been initiated in Israel and the Southwestern United States. Information on plant consumption rates and preferences of animals and crust disruptions at varying animal densities will enable managers to optimize livestock stocking densities as a vegetation and water management tool.

Implications

Patch manipulations can be a management tool to preserve productivity and diversity of the landscape, restore desertified areas, and increase their productivity and diversity. Patch manipulation involves either a change in the ratio between microphytic and macrophytic patches or the addition of human-made patches. Since the IALC-supported studies entailed manipulations that changed the ratio between microphytic and macrophytic patches, results of these studies provide predictions of how changes in patchiness could be used to manage productivity and diversity as discussed below.

Harvesting shrubs in the Negev increases plant-species diversity. High germination of the herbaceous plants on the patches and the interface soil mounds between the macrophytic and microphytic patches occurs without competing shrubs in the macrophytic patches. This promotes a relative increase in macrophytic and a decrease in the microphytic patches. Increases in macrophytic and decreases in microphytic patches result in increased in runoff. However, extensive scraping, which contributes to runoff, decreases ecosystem productivity and diversity. Scraping can also be a restoration tool when management wants to restore the successional species and create landscape mosaics. Although in the short term, herbicide use increases runoff, it is not recommended as a management tool to increase water-harvesting potential. Herbicides can kill microphytic communities and crust disintegration increases infiltration of water into the soil, which decreases runoff. Spraying herbicides also reduces ecosystem productivity and diversity. Most of the plants and animals are eliminated from sites sprayed with herbicides.

Because soil mounds are crucial for annual plant germination and growth, and because annual plants are the major source of productivity in arid and semiarid ecosystems, the results of the IALC studies suggest that these ecosystems are slow to recover from disturbances. Disturbances, such as overgrazing by livestock or excessive firewood cutting, reduce the abundance of macrophytic patches. Shrubs should be maintained in the ecosystems to promote productivity and biological diversity. However, some shrub turnover increases the productivity and diversity of annual and perennial plants in macrophytic patches.

A managerial problem that remains is how to determine the optimal amount of livestock grazing, firewood harvesting, and other interventions to maintain a desired ratio between macrophytic and microphytic patches. Knowing the optimal amounts will help to achieve site productivity, diversity, and water production. Nevertheless, these IALC studies are helpful to planners, managers, and decision makers contemplating rehabilitation efforts to improve the functioning of degraded arid and semiarid ecosystems.

Increased Ecosystem Productivity and Species Diversity

Knowing how a species reacts to changes in ecosystem productivity through processes such as competition is essential to effective ecosystem management and conservation. Increased productivity typically decreases species diversity (Rosenzweig 1971, Elseth and Baumgardner 1981, Bergon et al. 1990). Researchers in a recently initiated IALC study have proposed 3 hypotheses to explain the declining phase of productivity patterns in the Sonoran Desert of the Southwestern United States and the western Negev Desert in Israel. The hypotheses are intertaxon competition, habitat heterogeneity, and intrataxon competition. However, the hypotheses provide conflicting predictions that are being explored experimentally in the study.

Study

The occurrence and relative abundance of ants, birds, and rodents depends on seed enhancement in their habitats. Directing seed enhancement for a single group is evident by changes in population abundance of related populations, changes in overall species diversity of that taxon, and lower populations and increased food of other taxa. To test the validity of these predictions, researchers in the Sonoran Desert are using electronic seed feeders to drop precise amounts of seed 30 minutes after sunrise for ants and birds, 30 minutes after sunset for nocturnal rodents, and 30 minutes after sunrise and 30 minutes after sunset for ants, birds, and rodents. Concurrently, researchers in the western Negev Desert have established 10 seed feeders on 5 experimental plots—4 have manipulative treatments and a control. Seeds are dropped in the Negev using the Sonoran Desert schedule. The sunrise feeders drop seeds through meshed trays so that only ants have access and drop seeds from lifted trays so that only birds have access. When completed, these experiments will allow the researchers to evaluate the effects of increased seed enrichment on species diversity.

Implications

Why species diversity is often low when ecosystem productivity is high remains elusive. However, the study is examining the mechanisms controlling species diversity by altering food supplies to 3 key components of desert ecosystem—ants, birds, and rodents. Understanding about these mechanisms should help managers avoid diversity declines and improve species diversity in changing desert environments.

Habitat Fragmentation and Management of Ecological Systems

The effects of human-caused habitat fragmentation on wildlife have been widely studied in forest ecosystems. Habitat fragmentation results in landscape patchiness that changes the habitat conditions for wildlife species (Morrison et al. 1992, Patton 1992). However, little is known about the patchiness and scale of the patchiness of wildlife habitat in arid and semiarid ecosystems. IALC supports studies that examine the influence of habitat fragmentation and patch alterations on communities of sexual *Cnemidophorus* lizards inhabiting the Negev and Chihuahuan Deserts of Israel and the Southwestern United States. Lizards contribute

significantly to the functioning of these ecosystems because they occur in high densities, are predators of arthropods and prey for larger vertebrates, and are burrow diggers.

Studies

Studies include the impact on lizards when highly productive patches are added, how urbanization and desertification alter lizard densities, and the impacts of livestock grazing on the diversity and abundance of lizards. Why habitat fragmentation affects sexual *Cnemidophorus* lizards more than pathenogenetic species of the same genera is also being investigated. Direct observations, food-abundance analysis, and trap-release-recapture techniques are used to assess small-scale habitat preferences, which reflect habitat fragmentation and alteration, urbanization, and desertification. Impacts for management of the ecological systems studied can be inferred from the preliminary findings of the species-level processes. The abundance of lizards is similar in both deserts. However, human disturbances, which include excessive livestock grazing, urbanization, and activities to restore desertified areas, resulted in a change in the lizard-species composition in both localities. While these disturbances did not significantly alter species richness, lizard densities decreased with the increase in soil compaction attributed to livestock grazing. The density change likely results from the destruction of burrows or the inability of lizards to construct burrows in compacted soil.

A follow-up IALC study is focusing on learning about the effects of habitat fragmentation on sexual *Cnemidophorus* lizards and associated ecological processes at both the community and population levels to gain a higher-order perspective. Results from the study should lead to a better understanding of the influence of human-caused disturbances on ecosystem functioning and management. The benefits and costs of current management of the ecological systems will be evaluated considering the effects on the indigenous fauna.

Implications

Habitat alteration by human disturbances is a concern to managers of arid and semiarid lands. These alterations often lead to habitat fragmentation, which influence the sustainability of wildlife populations and other natural resources in the affected areas. It is important to understand how habitat alterations and fragmentation impact ecosystem processes at species, community, and population levels to properly manage these resources. The continuing study represents a contribution to achieving understanding.

Soil Seed Banks in Rangeland Management

The persistence of annual forage species under conditions of highly fluctuating temperature and limited moisture environments depends on soil-seed bank maintenance (Evenari et al. 1982, Kemp 1989, Maranon and Bartolome 1989). When annual forage is used as the primary production component on fragile arid and semiarid rangelands, knowing the extent that existing soil-seed banks of annual forage species can be depleted without causing lasting negative effects on the production of primary biomass and biological diversity of the plant communities is important. IALC supports studies to learn about the role of soil-seed banks in arid and semiarid rangeland management, the effects of soil disturbances and vegetation dynamics on the seed banks, and the effects of livestock grazing on the germination of seed banks and the newly-recruited forage species.

Studies

Effects of livestock grazing on the composition of seeds in soil banks and plant recruitment were determined from sites in grazed and ungrazed exclosures in the Negev Desert. Germination of seeds comprising the soil-seed banks was determined through laboratory tests in Israel—germination of artificial seed banks—and Utah—dormancy tests and hydrothermal modeling. Findings from the study indicated that the effects of livestock grazing on soil-seed banks and newly-recruited plants are habitat independent (Perevolotsky and Seligman 1998, Sternberg et al. 2000). Livestock grazing changed the overall balance of the palatable and less palatable species of annual plants in the seed banks and in the resulting vegetation on the productive sites. However, livestock grazing did not affect the less productive sites. Effects of livestock grazing on the composition of soil-seed banks and on the resulting vegetation also appeared dependent on the inherent habitat productivity.

Assessing the relative importance of soil-seed bank components and soil disturbances in determining the diversity of annual forage species following small-scale soil disturbances in the Negev Desert is the focus of another study currently in progress. The seed-bank components studied are external seed rains from outside the soil disturbance, internal seed rains from seeds produced within the disturbance, and residual ungerminated seeds from previous years. Soil disturbances are sunken and raised mounds. The study emphasizes learning about plant density, species richness, and the equatability of vegetation on disturbed patches. The number and abundance of species in the seed-bank composition, the microclimate and soil moisture regimes of patch-specific conditions, and the complexity of the seed banks relative components are the factors used. Initial results from the study suggest a rapid recruitment of dense populations of plants from soil-seed banks in the rainy season. However, there is little indication that high temperatures or light inhibits germination of seeds on top of exposed soil crusts. Seed dispersal and subsequent predication cause vegetation differences rather than differences among species germination rates.

The objectives of another study concern the ecological mechanisms that regulate germination timing, the prediction of germination outcomes, and the effects of livestock grazing on soil-seed bank composition and outcomes. The effects of interannual variations in rainfall patterns on soil-seed banks, vegetation, and biomass production are being investigated (Allen 1999). Microenvironments that prevail in seedbeds during and immediately after rainfall events that favor or prevent germination are also being studied to determine the effects of intermittent moisture on germination and dormancy loss. Simulation models of seed dormancy and loss are being developed and refined to predict seed-bank germination on rangelands under livestock grazing. These models will be validated with data from the Negev and information from transplant experiments and artificial seed banks.

Implications

Soil-seed banks are often the sole source of germination stock to sustain the rangelands for livestock production. However, livestock grazing causes short-term changes in the relative balance of forage and non-forage species. Long-term changes are currently unknown. Knowing the occurrence and success of the germination of seed-bank components can lead to predictions of plant-species dominance in communities due to changing weather patterns. The introduction of plant species to enrich rangeland vegetation or attain other rangeland management objectives—for example, ecological restoration—must consider the presence, quantity, and quality of seeds in soil-seed banks, and their behavior following rainfall events of known magnitudes. Understanding the timing of germination for species comprising the seed banks can produce better decisions about locations that offer the greatest potential for achieving desired management results.

Plant Invasion and Introduction Effects on Ecosystem Properties

A major challenge facing the managers of arid and semiarid lands is arresting desertification and, when and where possible, restoring ecosystem productivity and diversity. However, effective and economically efficient methods to attain these management goals are difficult to implement because of inherent habitat heterogeneity and patchiness that exists at different spatial scales. Planned or unplanned plant invasions, and the effects of these invasions on indigenous fauna and fauna, compound the situation. IALC supports studies to learn about plant invasions on ecosystem functioning and properties.

Studies

Banner-tailed kangaroo rats (*Dipodomys spectabilis*) are mound-building heteromyid rodents that inhabit the desert grasslands of the Southwestern United States. Mounds built by these rats differ from their surroundings in vegetative and hydrologic features and soil-nutrient contents (Best 1988, Best et al. 1988, Waser and Jones 1989). Active mounds are kept free of vegetation by activities of the rats and, therefore, the rats influence local vegetation (Anderson 1999). Researchers are modeling the role of these mounds as they pertain to the invasion of mesquite (*Prosopis* spp.) shrubs onto grasslands in the Chihuahuan Desert of

southern New Mexico. Observational and experimental studies have been accomplished to formulate a predictive model in which the role of kangaroo-rat mounds is analogous to that of tree-fall gaps in patch-dynamic models of forest ecosystems. The kangaroo-rat model promotes hypotheses that feeding the preferences of banner-tailed kangaroo rats affect local vegetation by retarding mesquite shrub encroachment, that kangaroo rats can suppress mesquite shrub establishment near active mounds, and that mesquite seedlings are established preferentially on abandoned mounds. The validity of these hypotheses is being evaluated in the study.

The introduction of trees and shrubs to arid or semiarid landscapes to counter desertification can increase productivity of the planted area and create a new habitat type that could increase species richness. Researchers in another study are determining the effects of planting trees and of shrub invasions on biodiversity in arid and semiarid environments by examining the effects on predacious spiders. Spiders are abundant, diverse, and an integral part of ecosystem functioning because of their role as arthropod predators in the food chain. Spiders are also sensitive to changes in habitat structure and are easy to monitor. Studies on the effects of planting trees and shrub invasions on spider densities and species richness are underway. Researchers in Israel are comparing tree-planted or savannized sites to natural shrublands in the Negev Desert, while other researchers in southern New Mexico are comparing shrub-encroached sites with natural shrublands on the Jornada Experimental Range. The results of the comparisons will increase our understanding of the effects of tree planting and shrub invasions on a key species group and biodiversity in similar arid and semiarid environments.

For more than a century, cheatgrass (*Bromus tectorum*), a winter annual that is native to western Europe, has aggressively invaded the sagebrush ecosystems of the Great Basin in the Western United States. Livestock overgrazing and occurrences of uncontrolled fire have propelled the invasion. Cheatgrass has dominated the widespread transformation from a diverse shrub-perennial steppe to annual grasslands (Mack 1981, 1986). The phenology of the species temporally and spatially redistributes water and other resources on the invaded landscapes. The primary objective of a recently initiated study is to quantify the ecosystem-level consequences of cheatgrass invasions, and the effects of remediation practices on area-based energy fluxes and evapotranspiration. The hypothesis is that the postfire dominance of cheatgrass arrests natural plant succession in Great Basin sagebrush ecosystems by redistributing water and other resources in time and space. The focus on water is because of its overriding control on the reestablishment of native vegetation.

Implications

Findings from these studies will increase our knowledge and understanding of the processes and effects of planned and unplanned plant invasions on ecosystem functioning, properties, and multiple-use management of arid and semiarid lands. Tree, shrub, and herbaceous plant invasions often cause a conversion from a vegetative community, such as desert grasslands, to a less productive shrubland. Knowledge of the causal mechanisms for these invasions, and how they affect local flora and fauna, contribute to sustainable ecosystem management for livestock production and to the sustainability of wildlife habitats. However, effective and economically efficient methods to arrest desertification and restore ecosystem productivity and diversity can be difficult to implement because of the inherent habitat heterogeneity and patchiness encountered at different spatial scales.

Demonstration Projects

Ecological Processes Enhancing Sustainable Livestock Grazing

Raising livestock is a traditional land use in arid and semiarid region. Unfortunately, desertification is possible where overgrazing occurs and improvement of livestock-grazing practices on overgrazed rangelands is often recommended (Anaya-Garduno et al. 1994, Squires and Sidahmed 1998). Importantly, the improvements must be acceptable to the herdsmen's way of life and must be sustainable and compatible with other land uses. An IALC demonstration project has been initiated in Israel to instill in local Bedouin

Increases in invasive shrubs on overgrazed rangelands in arid and semiarid regions reduce the capacities of these rangelands to sustain livestock production.

pastoralists an awareness and understanding of sustainable livestock grazing for long-term human and environmental benefits.

Demonstration

A farm that serves as a research site to improve sheep production in typical Bedouin pastoral systems is the location for demonstrating the benefits of sustainable sheep grazing systems to students and educators, local pastorales, managers, and scientists. Sites have been established on the farm to represent the environmental aspects of the locale, factors controlling forage productivity, effects of livestock grazing on vegetation and soil resources in these habitats, and a Bedouin farming operation from a herder's perspective. Additionally, visitors to the farm develop an integrated model of the structure, function, and management of a Bedouin livestock-grazing system.

Information about environmental parameters (meteorological measurements, runoff, and erosion patterns), vegetation characteristics (biomass, species diversity, and seed-bank dynamics), ecological features (changes in landscape mosaic, organic matter, and sediment flows across the landscape), and rangeland-improvement methods (mineral amendments and herd movements) on the first demonstration 4 sites is presented to so that participants can develop an integrated livestock-grazing model at the fifth site. The project is helping participants to understand the linkages between ecology and livestock-grazing management. From these linkages, participants develop a working model of the structure, function, and management of a Bedouin farm centering on livestock production.

Benefits

Livestock grazing is a way to economically exploit rangelands. However, improper livestock-grazing practices can cause rangeland destruction, particularly in potentially desertified ecosystems. In properly implemented and sustainable grazing systems, livestock are manipulated to meet a designated purpose, such as meat, milk, or hide production, for compatibility with other land uses. The demonstration project illustrates the benefits of properly implemented and sustainable livestock-grazing systems by teaching about the structure and function of livestock-grazing systems; the effects of climate, habitat, and livestock grazing on inherent vegetation and soil properties; the principles of sustained livestock management in ecosystems threatened by desertification; and the relationships among rangeland management, economic benefits, and human cultures in arid and semiarid regions of the world.

Survivors in the Sand

Increasing public awareness and interest in natural resources, and their management issues, is critical to the conservation, sustainable use, and management of arid and semiarid lands. The role of research and development and effective public education, involvement, and cooperation is also crucial to the success of planned interventions. IALC supported preparation and dissemination of a video called *Survivors in the Sand* to help meet the above needs, and to bring IALC's educational role to its public and private cooperators.

Video

Media specialists from New Mexico State University and public and private land managers and scientists in the United States, Israel, and Australia helped to prepare the video. The nature of natural resources, and their management issues, in the Southwestern United States, the Negev Desert, and the Australian Outback have been documented in the video through on-site interviews and supporting film archives. Among the topics presented are land reclamation; conservation of water, endangered species, and other natural resources; and sustainable ecosystem management. The 1-hour video focuses on prevailing management conflicts and concerns by presenting the perspectives of managers and scientists who daily devote their attention to ecological sustainability.

Through its widespread distribution, *Survivors in the Sand* has received a high level of attention. Collaboration with IALC member institutions, their cooperators, and other organizations has led to widely viewed telecasts of the video in the 3 featured countries. The video was released to the Public Broadcasting System for distribution in the United States and the Israeli Discovery Channel and ABC for distribution in Australia. Additionally, the video has been distributed through

the Smithsonian Teacher Training Program as a part of the Digital Desert Library. Events centering on the video's release were a focal point for public education and participation. *Survivors in the Sand* has won awards at the New York International Film and the Columbus International Film and Video Festivals.

Benefits

Survivors in the Sand had generated awareness of, interest in, and support for arid and semiarid land management issues and practices. The video provides insight to managers and other clientele on the potentials for conservation, sustainable use, and management of land, water, and other natural resources on arid and semiarid land. *Survivors in the Sand* also identifies approaches to land use that are precedent-setting in technology and social involvement. The video helps planners, managers, and decision makers understand the importance of supporting research, effective management, and public involvement in land stewardship.

Special Initiative

Biodiversity in Drylands: Research, Management, and Demonstration

Arid and semiarid regions, collectively called drylands in the initiative, are undergoing accelerating changes due to land-use and climatic pattern shifts. The changes are affecting the distribution and abundance of species, populations, and habitats and the diversity of organisms within ecosystems (Hoekstra and Shachak 1999a). Drylands are also experiencing accelerating changes in their biodiversity. To promote integrative and comparative research and management and to facilitate a network of demonstration center that focus on dryland biodiversity and its management, an international workshop titled, "Biodiversity in Drylands: Research, Management, and Demonstration Needs" was held in Israel in June 1999. The workshop brought ecologists, managers, and educators to the Negev Desert to foster effective interactions about biodiversity and the ecological complexes of biodiversity at the organism, ecosystem, and landscape scale. The role of a demonstration network in advancing biodiversity research and management was presented to participants as they visited study sites where management applications of the respective research efforts shown were considered.

Papers on biodiversity, linking biodiversity at the population and community level with ecosystem and landscape diversities, management of biodiversity, and applications of scientific and management knowledge on biodiversity in demonstrations were available to the participants (Blaustein Institute for Desert Research 1999). Subsets of participants representing ecologists, managers, and educators reviewed and revised the papers for inclusion in the book *Biodiversity in Drylands* to be published by Oxford Press (Shachak et al. forthcoming). The book will be a useful reference to conservation, restoration, and ecosystem management personnel, students, and academics who are interested in advancing research, management, and demonstration of dryland biodiversity.

Chapter 5

Inventorying and Measurement Techniques and Monitoring

Research and Development Projects

Influence of Plant Characteristics Determined by Remote Sensing of Vegetative Communities

Satellite imagery shows a contrast in the reflectance values from the Negev Desert side of the Israeli-Egyptian border to the Sinai side. Because the Negev has been managed under a conservation policy, while the Sinai has been open to livestock grazing and other plant harvesting activities. Therefore, the Sinai has less vegetative cover and a higher surface reflectance (Otterman 1974, 1977, 1981, Tucker et al. 1985, Holben 1986, Townshend and Justice 1986). However, the difference in reflectance values cannot be attributed solely to the differences in vegetative cover. One hypothesis is that microphytic (biogenic) soil crusts exhibit reflectance characteristics similar to lower (smaller) plants in the vegetative communities. An IALC study tested this hypothesis and developed a remotely-sensed optical index to detect the extent of microphytic communities on arid soils. Another study is analyzing the impacts of temporal variations in the character of higher (larger) and lower plants on the spatial variability of their reflectance values.

Studies

To determine the effects of biogenic crusts on satellite-based spectral indices of surface reflectance, ground measurements were made of the spectral reflectance of mobile sands, biogenic crusts, and *Artemezia*—a species that represents macrophytic vegetative reflectance in the region. A diagnostic tool to identify cyanophyte within soil crusts using remotely-sensed images was developed. Spectral reflectance measures made under several conditions showed that the spectral characteristics of the phycobilins in the crust caused the higher reflectivity of soil crust in the blue region of spectral values. Analyses to determine whether high Normalized Difference Vegetation Index (NDVI) values are caused by microphytes, which cover rock and soil surface in undisturbed areas, indicated that the NDVI response of lower plants could be similar to higher plant responses. Using the spectral response of biogenic crusts, a spectral index was developed from a normalized difference between the red and blue spectral values of the imagery. The unique spectral features of cyanobacteria crusts were analyzed relative to the visible spectroscopy, near-infrared spectroscopy, and shortwave infrared regions of the spectrum in relation to bare soil (sand) under varying moisture conditions. This analysis showed that when biogenic crusts are wet, their NDVI values can approach 30% and the phycobilin pigments in the crusts contribute to the higher reflectance in the blue spectra. Finally, the optical properties of the various microphytic crusts were also examined under wet and dry conditions and at a range of viewing angles.

Additional vegetative indices, including the first derivative spectral index, soil-adjusted vegetation index, and the perpendicular vegetation index, decoupled the influence of the soil background on the NDVI values from the photosynthetic signal detected on the satellite imagery. All of the soil crusts showed increased photosynthetic activities when wet. The result of all of the analyses in this study has been a better understanding of impacts that soil crusts have on vegetative indices obtained from satellite-sensed images. The hypothesis that soil crusts produce NDVI values that are similar to

vegetation was verified. Using the spectral response of soil crust in the blue region, a soil-crust index was also developed to distinguish between high-order vegetation and soil crusts in desert ecosystems.

The second study is dealing with the difficulties of temporal changes in the vegetation state and soil-rock signature used to discriminate vegetation from a soil or rock background. These difficulties were encountered in the earlier study that attempted to detect and monitor temporal changes in vegetation along the Israeli-Egyptian border by multispectral imagery. Field- and satellite-based measures of surface reflectance obtained in rainy and dry seasons have been related through the Linear Mixture Model (Ichoku and Karnieli 1996) to estimates of vegetation cover and densities from ground plots (McAuliffe 1990). This was done to estimate the overall spectral signal that higher and lower plants and bare surfaces reflected. Spectral responses are mixed by their percentage of cover to simulate the anticipated responses from the red and near-infrared spectroscopy spectral bands from satellite imagery from June 1995 to June 1998. NDVI values were calculated from the reflectance values from the satellite images and composites were made monthly.

Analysis of field-based measures of surface reflectance shows that the high reflectance of bare surfaces observed in rainy seasons is similar to that in dry seasons. Reflectance of the biogenic crusts during the rainy season is similar to that of higher plants, while reflectance of biogenic crusts in the dry season is similar to that of bare surfaces. Using the field-based measures of reflectance, researchers calculated the relative contributions of the different surface components to the overall NDVI values. Analysis of the satellite data shows a significant spectral difference between the Negev Desert and Sinai for the study period, with the Sinai showing much higher reflectance. Correlation analyses between NDVI values and rainfall show a relatively high level of variation in the NDVI values for the Negev throughout the year and higher rainfall amounts result in higher composite NDVI values. The NDVI values for the Sinai remain relatively constant throughout the year.

Implications

The first study has resulted in a better understanding of the impacts that soil crusts have on vegetative indices obtained from satellite-sensed images. Results from these studies indicate that satellite-based remotely-sensed information can identify significant differences in plant characteristics and vegetative communities on desert landscapes. Use of satellite images, with estimated responses of vegetative changes to climctic conditions, allow predicted and satellite-based NDVI values to be noted and evaluated. This information helps managers detect disturbed areas on a landscape, determined the nature of the disturbance, and identify possible mitigation measures.

Monitoring the Effects of Wildlife Herbivory on Vegetation by Remote Sensing

A major cause of desertification is overgrazing of vegetation by livestock, which cascades into losses of soil resources, plant productivity and diversity, and ecological functioning of the site. An approach to restoring desertified ecosystems is to replace the livestock with indigenous herbivores that are valuable to people. However, the effects of the replacement, or, in the case of the IALC study, the reintroduction of herbivores on vegetation and other rangeland resources, should be monitored to enable the appropriate adaptive management to proceed. The study was designed to analyze the effects on vegetative-cover richness and to predkct future effects of the initial decade of reintroduction of the Asiatic wild ass (*Equus hemionus*) to the Negev Desert using ground-survey methods.

Study

Livestock were removed from large portions of the Negev Desert in the 1950s because their historical overgrazing had led to a decline in rangeland health and a preponderance of non-palatable plants. Attempts to fill the void in the Negev's herbivory led to reintroduction of the Asiatic wild ass—an inhabitant of the Negev Desert in Biblical times but extinct by the early 20th century—to the Central Negev Desert in the 1980s. The primary purposes of this reintroduction effort included restoring native fauna, ameliorating effects of moderate livestock grazing on plant diversity, and promoting ecotourism (Safriel et al. 1999). The study was designed to analyze the effects of the initial decade

of the animal's reintroduction on the region's plant cover, predict future effects by ground-survey methods (McAuliffe 1990, Camargo 1993), and explore applications of remote-sensing technology to monitor these effects. The discussion here focuses on exploring remote-sensing technology to monitor the reintroduction effects.

Spring and fall LANDSAT 5 Thematic Mapper images for a wet and a dry year were analyzed. None of the vegetation indices calculated for the images, including the NDVI and the Transformed Soil Adjusted Vegetation Index, were significantly correlated with the mean plant cover for non-grazed and grazed study plots (Safriel et al. 1999). Failure to detect differences between non-grazed and grazed conditions was attributed to the overall low ground cover relative to soil cover and variability in the rocky soil type. The situation caused a high noise-to-signal ratio that overshadowed the herbivory effects on plant cover. However, differences in vegetation indices found between seasons and years suggested that changes in plant cover due to rainfall patterns could be detected by remote sensing.

Implications

The inability to detect small declines or other changes in plant cover will probably lessen the usefulness of remote-sensing technology in analyzing the effects of herbivores on the ecology of deserts or on sites subjected to desertification. Small declines in plant cover—5% in a humid region—with a 50% plant cover, might be ecologically insignificant. However, the same decline in a desert that has a 15% plant cover can be ecologically significant. Safriel et al. (1999) concluded that the remote-sensing technology used in the study does not offer great promise in avoiding ground-survey methods to measure or monitor the effects of wildlife herbivory in a desert or desert-like vegetation.

Regional Indices of Global Climate Change

Land-water interfaces of temporary and seasonally flooded wetlands are ecotones between upland and aquatic ecosystems. These areas could be highly sensitive to global-climate changes (Mitsch and Gosselink 1986, Poiani and Johnson 1991, Stakhiv and Major 1997). Freshwater wetlands are aquifer discharge or recharge areas and function as sinks for sediments, nutrients, and contaminants that flow off a landscape. Therefore, the fluxes of materials and energy through land-water interfaces are directly linked to upland processes. IALC supported a study to learn about the spectral reflections and biological integrity of land-water interfaces of seasonal wetland basins. Additionally, the study sought to link the observed changes in the conditions of the basins to regionalized climate changes.

Study

Relationships between ground and satellite measurements of seasonal wetland basins were established, differences in seasonal wetland attributes along an arid-to-semiarid gradient were quantified, and changes in seasonal wetland conditions were linked to spectral signatures in a regional climate change scenario in the study. Ground measurements were made to describe the physical, chemical, and biological attributes for wetland basins along selected precipitation gradients in South Dakota and Israel (Troelstrup 1999). Physical attributes measured at each basin were area, depth of inundation in the basin, and average annual precipitation. Chemical attributes included benthic organic matter, dissolved oxygen content, nitrogen species (nitrite, nitrate, and ammonium), total and dissolved organic phosphorus, and specific conductance. Biological attributes were occurrences and abundances of vegetation species, stem densities, dry-weight biomass, and occurrences and abundance of invertebrate taxa. For each basin, satellite measurements of reflectance were estimated with LANDSAT Thermatic Mapper imagery. These measurements included greenness, NDVI values, and wetness indices. Correlation and regression analyses were done to define relationships between ground measurements and satellite indices of landscape conditions.

Climate was the major factor governing the physical, chemical, and biological attributes of the wetland basins studied. A significant finding, however, was that several LANDSAT Thematic imagery indices were significantly correlated to several physical and biological attributes (Troelstrup 1999). For example, brightness values were correlated with annual precipitation, basin

depth, substrate strata, specific conductance, nitrate-nitrogen ratio, vegetation-stem density, and biomass of the vegetation for wetlands in South Dakota. NDVI indices were correlated with the biomass of the vegetation for wetlands in both South Dakota and Israel. Much of the variability in the NDVI values was explained through a multivariate model of vegetation biomass, annual precipitation, and inundation depth of a wetland.

Implications

Study results could be used to detect regional climate changes and to evaluate efforts to mitigate the effects of climate changes on freshwater-wetland basins. Climate changes occur over long periods. Therefore, the impacts of climate changes on local flora and fauna might be undetected for decades. Additionally, ground monitoring of physical, chemical, and biological attributes of a wetland basin as a change-detection technique is expensive. Consequently, only a few basins can be monitored to detect the level of changes required to produce statistically significant results. To detect the effects of climate changes on a regional scale reliably, the ability to analyze changes in the physical, chemical, and biological attributes of many wetland basins at the regional scale is desirable. The study showed that relationships exist among the physical, chemical, and biological attributes of wetland basins; the land-water interfaces that are sensitive to changes in the global climate; and indices from satellite images. The images can establish baseline attributes for wetland basins on a regional scale. Future satellite images can be analyzed to determine if significant changes in wetland basin attributes have occurred. This comparison provides an indication of regionalized climate changes that will help managers anticipate future terrestrial conditions and will facilitate development of effective management practices.

Monitoring Large Rainfall and Runoff Events, Flooding, and Other Outlier Events in Remote Areas

Monitoring the availability of water resources in arid and semiarid regions is critical to efficient land management and restoration efforts. However, in remote areas, frequent representative sampling of large rainfall and runoff events, flooding, and other outlier events is difficult and costly because of the extreme variability of the occurrence of these events. On large areas of many watersheds, encountering extreme or outlier events on one or more isolated watershed in sparsely monitored areas was more likely than on a single well-instrumented watershed (Renard 1970, Singh and Woolhiser 1976, Morin and Sharon 1993). Identifying and analyzing data from these isolated watersheds could significantly reduce the time and cost of obtaining long-term data from a single instrumented watershed that might not represent the larger area. Researchers in several IALC studies have explored, or are exploring, the feasibility of developing methodologies to acquire, analyze, and document data obtained during large rainfall and runoff events and flooding events in sparsely monitored, remote areas rapidly and cost-effectively.

Studies

The coastal plain of central Israel, the Negev Desert, and the Walnut Gulch Experimental Watershed in southeastern Arizona were the sites for most of the studies. Research at the first site centered on validating radar-based estimates of rainfall for a 400-km^2 area that is 30 km south of Tel Aviv. For the large storm that occurred on November 29, 1991, point measurements of the rainfall were obtained from 5 ground-based rain gages, while radar-based estimates of the rainfall amounts were generated for 1 km^2 grids across the study site. Ground-based measurements of rainfall calibrated the radar-based estimates of rainfall from this storm by using the Window Probability Matching Method (Rosenfeld et al. 1994). Comparisons were made between measurements of rainfall from the ground-based rain gages and estimates of rainfall obtained by applying the calibrated Window Probability Matching Method for a series of storms from November 28, 1991, to December 4, 1991. While the Window Probability Matching Method has been successfully used elsewhere (Rosenfeld et al. 1994), results from this study did not show it to be a superior than existing algorithms for estimating large rainfall amounts falling on remote areas.

Another study applied the Window Probability Matching Method to calibrate radar-based estimates of rainfall to point measurements from ground-based rain gages. This was accomplished to obtain accurate information about the areal extent and intensity of rainfall events in central Israel during the rainy seasons of 1995 to 1996 and 1996 to 1997. Thirteen tipping-bucket rain gages in a radial strip up to 80 km from a radar site at Ben Gurion Airport, near Tel Aviv, and 56 standard rain gages from the coastal plain to the Judea and Samaria Mountains collected the rainfall amounts. The rainfall amounts calibrated the radar data, which was collected at 1 km^2 resolution and 1-minute intervals during the rainfall events. By using the Window Probability Matching Method, accurate synchronization of the timing of rainfall to radar data was achieved with measurements obtained in the tipping bucket rain gages. Two large rainfall events were selected for analysis. The first storm of 45 mm of rainfall occurred in 2 days —January 15 and 16, 1997. The second storm of 80 mm occurred in 3 days—February 21, 22, and 23, 1997.

Study results show that the Window Probability Matching Method is only practical when enough recording-rain gages with 1-minute recording capabilities, such as tipping bucket rain gages, are used with a well maintained and highly accurate radar system. Unfortunately, there were not enough recording-rain gages in the study and maintenance problems with the radar system were encountered. The results show the difficulties associated with obtaining accurate information on large-rainfall events in remote arid and semiarid regions.

A recently initiated IALC-supported study is exploring the structure and dynamics of rainstorms that cause flooding in the Negev Desert. Researchers are developing a database of atmospheric and hydrologic conditions associated with previous flooding events, categorizing conditions associated with major storm events, identifying atmospheric processes at a scale that produces flooding, and developing predictors of regional flood occurrences. About the latter, ground truth and remote-sensing data will be integrated to help determine the structure and dynamics of meso-scale rainfall systems to search for recurring patterns that indicate interactions with terrain features. Mechanisms linking meso-scale structures to hydrologic efficiencies induced by the terrain features will be identified for specified watersheds. Based on this knowledge, a set of predictors for flood occurrences will be developed and tested with independent data sets.

Researchers at Walnut Gulch are focusing their efforts on the uncertainties associated with the indirect measurement of peak streamflow-discharges levels that represent large-runoff events and flooding. The Walnut Gulch Experimental Watershed encompasses 12 sub-watersheds that contain meteorological and hydrologic monitoring stations. The sub-watersheds range in area from 2 to 150 km^2. In one study, channel reaches near recording-stream gages on the sub-watersheds were selected as sites for the indirect measurement of peak streamflow-discharge rates. The 1993 monsoon season of July to early September—the study period—was unusually dry and only moderate streamflows occurred. Nevertheless, 4 independent runoff events that were large enough to obtain indirect peak streamflow discharge measurements occurred. The high water marks left after the cessation of streamflow were noted for each channel reach. Peak-flow estimates were calculated from water surface profiles and post-flow channel geometries. Estimates of uncertainty associated with the indirect peak streamflow-discharge estimates were developed. Unfortunately, because the uncertainty analysis was based on only small runoff events, its extrapolation to larger runoff events and flooding is limited.

By comparing the efficacy of the power-law radar-rainfall relationships (Marshall and Palmer 1948) from the United States to those in Israel, researchers from the United States and Israel are attempting to improve the algorithms used when estimating rainfall rates from radar data. Additionally, researchers are developing a predictive methodology to represent rainfall and runoff on relatively small watersheds in arid and semiarid regions. The study sites are the Walnut Gulch Experimental Watershed and several small watersheds in the Negev Desert that are located within radar coverage from the Ben Gurion Airport. Data sets for rainfall and runoff amounts will be collected; ground-based and radar-based estimates of rainfall amounts will be made; and physiography, stream networks, vegetative cover, and land-use on the watersheds

studied will be obtained. Once the information is assembled, rainfall intensities will be estimated from the radar data at various temporal and spatial scales with the power-law relationship. The Window Probability Matching Method (Rosenfeld et al. 1994) and other methods will determine the appropriate temporal and spatial scales of rainfall data. The scales can predict streamflows from storm events of differing intensities and durations. Watershed scales and characteristics will also be examined to determine if correlative relationships exist.

Implications

Results from these studies are providing insight about how to estimate the character of large runoff events, flooding, and other outlier events on lands with little or no ground-based monitoring. While these results may not be applicable to a wider range of conditions than those studied, the methodologies developed could be expanded to accomplish this goal. Once fully developed and tested methodologies are available, their applications could help managers implement land-use practices and mitigation efforts to minimize the risk to life and property from extreme meteorological and hydrologic events.

Dust Emissions and Desertification Implications

Loss of particles from soil surfaces by wind erosion can exacerbate desertification. Fine particles (<50 mm in diameter) removed from soil surfaces represent a disproportionately high amount of nutrient loss when compared with the loss from coarser soil grains (Zobeck and Fryer 1986, McTainsh 1989, Offer and Goosens 1990). Controlling the loss of soil particles is critical to maintaining the sustainability of arid and semiarid ecosystems. An associated environmental problem is the size and mass of the resulting concentration of airborne dust, which affects human health. Dust emissions also affect soil resources, the atmosphere, and the socioeconomic conditions of people living in affected areas. To develop a better understanding of the processes that govern dust emissions from dryland surfaces, IALC is supporting a study to collect baseline information on dust emissions with known precision through field measurements. The field measurements will enhance the predictive capability of the dust emission model previously developed by Berkofsky and McEwain (1994).

Study

Researchers are measuring dust emissions on the playa surface of Owens Lake, California, a site highly susceptible in late winter and early spring. This area is the largest single source of dust emissions in North America (Bach et al. 1996, Nickling et al. 1997). A 10-m suspended sediment sampling tower, with 5 aerosol monitors and 5 anemometers that are vertically distributed along the tower and a wind vane on the top, collects airborne dust during emission events (Gillies and Berkofsky 1999). The aerosol monitors are constructed to facilitate orientation with wind from any direction to obtain mass dust-concentration measurements. Particle distribution is measured with an optical counter during emission events. Saltation activity is monitored with 6 energy sensors in an array around the tower. Data are collected at 1-second intervals and averaged over 15-minute intervals because of the unsteady effects of the airflow.

Improved simulations of Berkofsky's and McEwain's (1994) dust emission model using physically-based descriptions of the relationship of wind speed to dust emissions, the response of the emissions to changing surface-roughness conditions during erosive events, and the evolution of the particle-size distributions of suspended sediments are being developed. This information is based on source data from the field measurements taken at Owens Lake. Although the study continues, more than 20 hours of data have been collected at Owens Lake during 33 hours of erosive events. These data sets have been assembled into a database to guide development and testing of the dust emission model. Many improved descriptions of dust emissions have already been incorporated into the model, which can predict the change of wind components in the transition layer, friction velocity, the change of the aerodynamic roughness, and dust concentrations near the ground and at the top surface layer. A module that incorporates particle distribution of suspended dust into the simulation procedure has also been included to improve its predictive capacity. The Berkofsky and McEwain (1994) model is interactive and user-friendly.

Implications

The study will provide an enhanced model to managers of areas susceptible to dust storms so they can obtain reliable simulations of the potentials for dust emissions from a minimal amount of input data on soil types, surface conditions, and wind characteristics. The simulations will allow people to plan and manage land uses that prevent or mitigate against hazards posed by dust storms better. The enhanced model will be used in a prognostic capacity to determine how losses in fine particles can vary as a function of climatic change, human forces, or combinations thereof that could lead to desertification.

Monitoring Behavior of Ungulates by Acoustic Telemetry

Wild ungulates interact and affect many human activities in arid and semiarid regions. As medium- and large-sized herbivores, wild ungulates influence ecosystem processes, thereby, attracting management attention (Schleidt 1980, Patric et al. 1982, Cohen 1986, Hodeler and Bullock 1997). A new technology for remotely monitoring the behavior of desert ungulates using sound is being developed in a recently initiated IALC study. Acoustic telemetry is a potentially powerful means of accurately monitoring a wide range of behavioral patterns, especially those associated with feeding activities, of wild ungulates and other mammals.

Study

An acoustic telemetry system is being tailored to fit desert mule deer (*Odocoileus hemionus eremicus*) in Southwestern United States and Nubian ibex (*Capra ibex numiana*) in Israel. Subjects will be equipped with microphone transmitters, and their sounds recorded by a suitable receiver-recording system for interpretation and analysis. Captive animal trials to test and calibrate the telemetry system in relation to the animals' behavior will be done first. Field tests with free-ranging animals will be conducted with desert mule deer in the Sonoran Desert and with Nubian ibex in the Negev Desert. Phases of this study include developing equipment to monitor sounds generated by captive and free-ranging animals, assembling a catalog of captive deer and ibex activity-sounds and a video for interpreting recorded field sounds, developing field applications and refining the telemetry system with free-ranging animals in their natural habitats, and producing guidelines for management purposes and future acoustic telemetry applications.

Implications

Once developed and tested, acoustic telemetry will enable remote monitoring of feeding activities and other behaviors of free-ranging wildlife ungulates in their natural habitats. Knowledge of food preferences, feeding times, and other feeding habitats is essential to manage arid and semiarid ecosystems for sustainable wildlife resources and other multiple benefits effectively. Acoustic telemetry is also a unique expansion of biotelemetry capabilities for research programs.

Demonstration Project

Information Visualization for Management of Arid Lands Vegetation

When evaluating management options on arid and semiarid landscapes, managers are confronted with 2 scale-dependent issues. First, relevant research conducted on small-scale and often homogenous plots must be extrapolated to larger, heterogeneous landscape management units. Second, the time scale of management impacts is commonly beyond the managers' abilities to replicate. For both issues, replications and statistical analyses help to ensure the desired precision at a particular point in time, but they do not necessarily represent the dynamics of the management unit.

The goal of the IALC demonstration project was to measure landscape elements over a broad spatial and temporal scale to allow management models to incorporate data appropriate to specified scales in the decision-making process. Use of an information visualization system to manage vegetation on arid landscapes was demonstrated. Broom snakeweed (*Gutierrezia sarothrae*), a perennial non-forage plant found on rangelands of the Southwestern United States, was used for the initial demonstration. However, the tools

developed are adaptable for many problems associated with management of arid and semiarid landscapes.

Demonstration

The initial phase of the demonstration project involved compiling a database of all available research on broom snakeweed. The database was linked to maps, aerial photographs, and other information to provide site-specific and management-oriented information that typifies the rangelands in southern New Mexico. Using 2 software programs, PHOTO-CATALOG SYSTEM (PCS) and LINKER, which researchers at the Physical Science Laboratory at New Mexico State University (Haynes and Sanderson 1999) developed, the linkage was accomplished. PCS allows a user to capture, archive, and display images. Photo sets can be logically organized by physical location or set relationships in a time sequence using the program. PCS functions in standalone applications, or it can be used in with a database browser. LINKER permits the visual correlation of spatial or temporal data, such as photographs, satellite imagery, geographic information system layers, databases, and spreadsheets.

The information visualization system shows how the above tools develop visual databases that traverse data sets in spatial and temporal domains. The system also demonstrates that these tools spatially and temporally connect related information in a format that is easily recognizable and tailored to a user's preferences. A demonstration disc has been prepared to show the ability of LINKER to connect to a wide range of information and computer software packages.

Benefits

Landscape-scale management models require information that is not easily obtained from small plots or linear extrapolations from time-dependent census data sets. In addition, the dynamics of ecosystem resources are not linear, and their rate of change is a function of many inputs. To overcome these problems, photographic databases from 1940 to the present helped in developing applications of the demonstrated information visualization system with broom snakeweed. The ability to couple historical information with the results of experiments conducted on a small scale at a specific point in time is a powerful tool that will help people understand the landscape changes that can result from different management activities. Based on this understanding, managers can select the best course of action. Managers, researchers, and others interested in viewing this demonstration can contact the IALC office at 1955 E. 6th Street, Tucson, Arizona 85719-5224, USA; ialc@ag.arizona.edu (email).

Chapter 6

Synthesis of Accomplishments

Thematic Summaries

Soil and Water Resources Development and Conservation

The inherent problems associated with soil and water resources affect sustainability and variability in arid and semiarid ecosystems. IALC addressed some important issues related to the development and conservation of these natural resources under different climatic conditions in the Southwestern United States, the Middle East, and Chile. Scientists from these countries have exchanged views and collaborated in research and development and demonstration projects to help make information available for improved resource management. To enhance the dissemination of information and data needed for research and demonstration activities to all stakeholders, IALC has supported outreach activities through publications, conferences, and training courses.

IALC orients its research and development projects to soil and water resource development and conservation to help people understand what causes losses in soil productivity and to synthesize methods to reclaim soil and water resources. Results from these efforts have provided managers and land owners with ways to overcome existing or anticipated limitations in soil and water resources. The findings can be directed to local, regional or even global issues. The role and importance of arid and semiarid land soils in carbon sequestration are not fully known. Nevertheless, land management agencies are being pressed to report management impacts and strategies potentially useful to offset carbon emissions. IALC research and development efforts near completion will contribute fresh insights and innovated analytical tools for addressing management impacts and strategies. For example, conserving fresh potable water for critical uses is an important water reuse issue. Managers, therefore, must understand the associated agricultural crop and environmental health risks posed by the various types of water that can be locally available. Research has extended our knowledge of physical-chemical processes that lead to the contamination of soil and water systems.

IALC demonstration projects are providing managers and the public with information and instruction about local, regional, and global conservation and sustainable use. Arid and semiarid soils and water databases, developed through the demonstration projects, are a critical resource and a common reference available to the international Web-based community. In the Middle East, a West Bank demonstration project that raised awareness about the hazards associated with mishandling pesticides and other agrochemicals, provided immediate benefits to people needing health protection. The integrated pest management technology presented by the same program improves the likelihood that crop production will continue to be efficient as dependence on agrochemicals is reduced. The Negev Desert savannization project gives managers an opportunity to understand the concepts from work that has received international recognition for its originality and contributions to the advanced theories of ecosystem functioning. Most notably, the demonstration shows that barren landscapes can capture sufficient soil and water resources to support and attract biodiversity, while also attracting and sustaining human settlement.

Demonstration efforts supported by IALC also teach people in small communities along the Rio Grande River between the United States and Mexico how to construct wetlands to reduce biological and chemical contaminants that pose serious risks to human health. Short-rotation tree plantations provide a water treatment approach within the community's economic reach. The

tree-plantation wetland approach will also stimulate economic development because there is a need for wood fiber, transportation infrastructure, labor, and capital. The project also demonstrates application of a model for public participation in environment and development decisions affecting rural communities. In the Southwestern United States, less than 1% of irrigated agricultural cropland uses drip technology to conserve water. Low use of drip technology in the region continues despite improvements in engineering technology, which eliminated or greatly reduced the problems that most farmers found objectionable. A demonstration project in New Mexico that is showing people how to use drip irrigation technology to produce a regionally important agricultural crop, is of interest among farmers who are facing water shortages.

IALC sponsored an international symposium on sustainable water management and wastewater recycling. The symposium provided a forum for attendees to deliberate topics, such as the appropriate technologies for irrigation with fresh and saline water, use of sewage effluents in irrigation, and groundwater protection and management. Program directors and administers of water and wastewater facilities, irrigation districts, and other government activities related to sustainable water management from 30 countries attended the symposium. Attendees developed recommendations and presented strategies on policy and action plans to help integrate land and water resource management on arid and semiarid lands. Momentum generated by the participants in this symposium is continuing under the leadership of a steering committee.

Land Use and Reclamation

Understanding the effects of land-use practices on water transpiration by indigenous plant communities and assemblages of sensitive bird populations is a focus of IALC research and development projects. Fifty percent or more of the annual precipitation that falls on oak woodlands in the Southwestern United States and northern Israel is lost through transpiration. Increased transpiration following fuelwood cutting in the Southwestern United States—a historical land use in the region—is attributed to the many vigorous postharvesting stump sprouts. Usually, tree removal increases water yields. However, in the Southwestern United States, tree harvesting results in less available precipitation to recharge groundwater aquifers or to produce streamflow. Elsewhere, the presence of woody plants affects the occurrence and distribution of sensitive bird species in the Borderlands area of the Southwestern United States. Sites with less than 10% woody-plant cover have larger populations of upland bird species, while sites with less than 20% woody-plant cover support grassland bird communities. Mosaics of diverse plant communities that differ in composition and structure should, therefore, support the greatest bird-species diversity. Managers have proposed prescribed burning and alternatives in livestock-grazing intensities to obtain these desired mosaics.

A major thrust of IALC research and development concerns developing computer-based systems to improve decision-making processes for desert, grassland, wetland, and riparian ecosystem management in the Southwestern United States and Middle East. Managers of these ecosystems generally confront problems that involve several objectives. For example, minimizing the costs of some water management practices while maximizing forage production, with a set of objective functions that are subject to many constraints, such as limited funding, a restricted land base, and a requirement to satisfy the objectives within a specified period. Managers can effectively analyze the problems with decision-support systems, such as those developed by researchers supported by IALC. While the specific themes of these systems centered on habitat suitability, livestock stocking rates, and plant-water relationships, the decision-support systems developed are applicable to a wide selection of management topics.

In this category, IALC demonstration projects are producing information in easily accessible formats for use by managers of arid and semiarid lands. For example, they have developed a database template for managers to build their own local database systems for planning and tool effective and environmentally sound livestock's management practices on public grazing lands in the Southwestern United States. The database systems help researchers validate predictive models of forage growth and use patterns, students and teachers learn about the ecological processes of livestock production, and decision makers select the best action from a set of alternatives.

Because water supplies and inherent natural resource productivity are limited on arid and semiarid lands, IALC supports development of a Website to bring people field-tested data and other information from the Southwestern United States. Titled the "Sustainable Management of Arid and Semiarid Watersheds," the format of the site encourages learning and helps in decision-making. The site includes topics, references, and an interactive learning package on watershed management practices. Researchers are expanding the technology transfer methods so that hydrologic, ecological, and economic data sets from the Southwestern United States will be available to researchers, managers, educators, and decision makers in other regions.

IALC-sponsored workshops, symposia, and training courses have been organized and conducted about arid and semiarid lands management and the effective management of impacted ecological systems; desertification in developed countries; connecting science with community actions to combat desertification; and mitigating the risks in planning for the conservation and sustainable use of water and other natural resources in arid and semiarid regions. IALC's research, development, and demonstration agendas were reinforced and expanded during the 1994 conference and workshop on arid lands management (Fisher et al. 1999, Hoekstra and Joyce 1999, Hoekstra and Shachak 1999b). The accomplishments and contributions of IALC's scientific and technical programs reviewed in this publication are in response to this agenda.

Sustainable management of watersheds in arid and semiarid regions is necessary to protect limited water supplies and retain natural resource productivity.

Processes Enhancing Ecological Management

IALC research and development activities help to determine how livestock grazing, tree planting, shrub occurrence and control, microphytic soil crusts occurrence, and burrowing animals are influencing plant diversity, nutrient distribution and productivity, and water capture. The high proportion of support for research and development projects relating to biological diversity and productivity of plants and animals, and their functional relationships, reflects the fragility of biodiversity in arid and semiarid land ecosystems. IALC has also funded research and development on genetic and physiological determinants of drought hardiness and the productivity of coniferous trees, fruit-producing cacti, and native populations of herbaceous plants. Results from the studies have provided a basis for selecting, breeding, and genetic modification of plants that tolerate aridity and heat. An improved understanding of genetic diversity and phenotypic plasticity of arid and semiarid land plants is helping to predict the effects of global climate change and habitat destruction on populations of plants and associated organisms.

Research and development efforts supported by IALC have contributed to our understanding about how habitat fragmentation, livestock-grazing patterns, and shrub invasion effects species diversity and the ecology of desert lizards and arachnids. The important role of small mammals in soil-patch development and maintenance has also been clarified. Studies on ungulates focus on anti-nutritional factors in leguminous shrubs and development of telemetry to track animals. The effects of landscape-level processes, such as habitat fragmentation and desertification on ungulate and predator diversity and population dynamics, are research and development areas that have not been addressed.

Less research and development have been focused on methods for ecosystem restoration, the effects of exotic plant and animal invaders, and impacts of recreation, mining, and military activities, and pollution on arid and semiarid lands. However, in the future, these areas will be likely be important. IALC has also been unable to support studies about cultural heritage preservation, including archaeological sites, and pastoral lifestyles and traditions. Research and development on these topics should be encouraged.

An IALC demonstration project in Israel is focusing on sustainable livestock-grazing practices. The effort will help local Bedouins improve their grazing practices to sustain forage and livestock productivity near their settlements. Settlement patterns of the Bedouins have resulted in localized overgrazing of livestock that must be mitigated to ensure rangeland sustainability. Researchers, students, and agriculturalists from the Middle East and other arid and semiarid regions of the world visit this unique demonstration site to learn about environmentally sustainable livestock production.

The video *Survivors in the Sand* was televised to diverse audiences throughout the world and has received many awards. The video successfully delivers the IALC message and that of others concerned with the conservation and sustainable use of the natural resources on arid and semiarid lands.

IALC helped to sponsored a conference in Beer Sheva, Israel, in June 1999 to promote integrative and comparative research and management of arid and semiarid ecosystem biodiversity. Ecologists, managers, and educators gathered to increase the effective interactions about biodiversity and ecological complexes of biodiversity at the organism, ecosystem, and landscape scale. They also formed a network of demonstration centers to advance research and management of biodiversity, and its ecological complexes.

Inventorying and Measurement Techniques and Monitoring

Assessment of the condition of arid and semiarid lands is an onerous task for land managers for many reasons. First, in arid and semiarid areas, management units are large and often cover a diverse array of ecotypes. In addition, subtle changes in a wide array of physical conditions can frequently result in long-term impacts on the sustainability of the natural and human environments of the land. The impacts include localized human disturbances, such as altering the composition of surface soils or denuding vegetation, and regional climate alterations, such as slightly reduce precipitation or increased temperatures. Finally, disturbances on arid and semiarid lands are long-term—recovery usually involves significant management inputs and it occurs over extended periods. Therefore,

development of tools that can provide improved inventorying, measurement, and monitoring techniques are beneficial to managers.

A variety of IALC-supported projects are focusing on developing improved ways to assess the risk that humans pose to the ecology of arid and semiarid environments, and the hazards that these environments pose to humans. Research and development projects that concern the impact of human activities on the environment, usually focus on the response of vegetative systems to livestock grazing and agroforestry activities. For example, researchers have learned that field-based inventorying and monitoring is often unable to detect subtle changes in landscape conditions. Additionally, intensive inventorying and monitoring of small representative areas are not representative of the overall condition of the larger landscape. Therefore, techniques are needed to provide a wide spatial assessment of land surface conditions and to be comparable to temporal data sets that exist for decades or longer.

Through IALC-funded efforts, researchers developed a variety of techniques to help accomplish the above goals. The primary technologies are based on developing algorithms for LANDSAT imagery. The algorithms were specifically tailored to assess vegetative and soil conditions in arid and semiarid regions. Methods to assess the conditions and capabilities of large land areas were also obtained. Since images are available from the 1980s, a large database exits to perform trend analyses about future assessment, planning, and management of arid and semiarid lands.

IALC research and development projects about the risk to human health from arid and semiarid land environmental conditions focus on flood hazards and dust emissions. Meteorological events in these regions occur sparsely and randomly in space and time. Therefore, intensive inventorying and monitoring of selected drainage systems will probably not yield representative relationships between meteorological conditions and the hydrologic responses of drainages. Additionally, these efforts will not yield useful information about the frequency of large-runoff events that pose the greatest flood risk. Therefore, conventional flood-risk analysis techniques based on long-term stream-flow monitoring along with ground-based precipitation monitoring do not give managers the appropriate information to determine the risk of flooding. To overcome this difficulty, several IALC projects have examined using radar imagery with advanced watershed monitoring and modeling efforts to predict the occurrence and frequency of flooding events. The analysis techniques give managers the information necessary to prevent human development and habitation of areas that are prone to flood hazards. Additionally, the techniques give managers the ability to develop mitigation strategies for flood hazards in arid and semiarid areas.

Although the research and development projects have produced useful management approaches and tools, the study results also provide inventorying and monitoring insight into future research needs on arid and semiarid lands. With increased sophistication in field- and satellite-based remotely-sensed technology, innovative analysis techniques are needed to process remotely-sensed data for application to arid and semiarid land management issues. Research and development efforts must focus on advances in remotely-sensed technology and synthesis of information through development of analytical procedures and predictive modeling. Research and development into the above areas will give managers ways to assess the condition of larger land areas using the same resources. Doing so will be a cost effective and reliable way to assess the condition of arid and semiarid lands.

Other Comments

IALC has discovered that to obtain research results with limited funding, it is necessary to foster collaboration between scientists and leverage the resources of major universities and experimental centers that focused on arid and semiarid land studies. Scientists and institutions with limited research resources benefit by collaborating on funding policies. By investing in outreach, greater management impact is achieved than by focusing on research and development. Sustained efforts in research and development that relate to IALC's mission are often incubated at the research centers of IALC's member institutions. The centers are found at the Jacob Blaustein Institute for Desert Research; Ben-Gurion University, Negev Desert; Sede Boker Campus,

Israel; Jornada Experimental Range, New Mexico State University, Las Cruces; and the University of Arizona's Santa Rita Experimental Range south of Tucson. At these centers, it is possible to access land for research and demonstration projects, conduct long-term studies under protected conditions, and use an extensive base of historical research. Infrastructures and personnel at such established facilities are unique. Personnel often have an advantage when competing for grant funds because leveraging more research per unit of funding is possible due to the wealth of research resources that exist. The research centers are important to advance research about improving arid and semiarid land stewardship globally.

Many planners, managers, and other practitioners are unable to access current research journals, reports, or personnel. They can, however, benefit from IALC's demonstration projects from funded research and development projects and related workshops, training sessions, and technology-transfer mechanisms. IALC efforts help link theoretical research to management applications using the interdisciplinary perspectives of biological, physical, and social scientists—people who are not usually involved in research and development projects. Additionally, IALC programs foster opportunities for communication and collaboration between theoretically-based ecologists and scientists in rangeland science, wildlife and watershed management, forestry, and related social scientists. Basic and applied research and development linked to application demonstration promotes improved land stewardship by identifying the roles of sustainable natural resource management on arid and semiarid lands and by recognizing the functioning of the environments' critical ecosystem components. Understanding the importance of sustainable natural resource management is necessary for long-term human benefits and for the conservation and preservation of the natural heritage of arid and semiarid ecosystems. Ultimately, its contributions to the sustainability of arid and semiarid land ecosystems that support human settle will measure the success of IALC-sponsored research and development projects.

Chapter 7

The Future

Challenges

IALC continues to provide unique opportunities for collaboration and creativity in basic and applied research and development. IALC experience confirms the importance of an external peer-review process to ensure that limited funds are spent efficiently and to maintain sponsor credibility. Fostering international collaboration has benefited researchers, students, and institutions through increased research innovation and productivity. Curiosity and self-interest drive researchers to pursue topics that are scientifically interesting, current, and likely to result in the dissemination of novel, worthwhile, and useful scientific findings. IALC successfully screens a diversity of research and development topics and, through its peer-review process, supports proposals of timely relevance.

Where technologically-based economic development and urbanization supplants traditional pastoralism and other traditional land uses on arid and semiarid lands, problems of livestock overgrazing, ineffective water conservation, excessive recreation impacts, unwise mining operations, and pollution have emerged. These problems require careful research and planning to improve the balance between humans and their natural resource systems. Efforts to restore and preserve natural and cultural heritage, sustain intensive agricultural enterprises, and maintain biological diversity must, therefore, be increased. The consequences of overpopulation and resource degradation are dire and will challenge future political, economic, and scientific leaders.

Research and development must continue to focus on critical issues. The results of research and development projects must be efficiently and effectively disseminated. IALC sponsors are interested in technology transfer to countries and regions with the greatest need. The importance of scientific and technical programs demonstration projects concerns IALC. However, more proposals have been submitted for research and development projects than for demonstration projects in the 10-year history of IALC—perhaps reflecting a shortage of outreach educators. This disparity also reflects a trend in the privatization of outreach and development services that were, in the past, provided by government agencies.

Transferring needed technology to arid and semiarid land managers and local landowners will remain a priority of IALC. Preparation and distribution of policy briefs and synthesis papers and other means of technology transfer, including technical training courses and workshops, are particularly useful to managers. Therefore, IALC should develop mechanisms to fund these and other policy-oriented research and development projects that are useful to managers. Planning and managing to mitigate the conflicts and problems that occur at the urban and wildland interface also deserve increased attention.

Options for Meeting the Challenges

Future options for IALC include continuing to operate as in the past, periodically focusing on selected critical initiatives, increasing scientific and technical activities about the human dimension of arid and semiarid land stewardship, and emphasizing applied, adaptive, and other research and development efforts that have immediate management applications. Each option has advantages and disadvantages.

This publication highlights some successes that IALC's scientific and technical programs have experienced during its 10-year history. IALC's peer-review process is a model for other similar programs funded by

the U.S. Department of Agriculture. Funded proposals are recognized as practically and scientifically important by the best scientists in IALC-member institutions. Consequently, the portfolio of funded studies reflects national and international priorities for research, development, and application. Because of IALC's strengths and resources, limited grant money has often leveraged greater production than would otherwise be possible. Member institutions waive indirect cost reimbursement and make available research centers and personnel to support IALC programs directly and indirectly. IALC funding allows researchers to initiate innovative, new projects, or to add important elements to ongoing research and development projects, thereby, attracting proposals from a large pool of scientists.

However, current scientific and technical programs have a maximum grant amount that is often insufficient to support graduate students at collaborating institutions. Because funding levels have not substantially increased, expanding the membership or scope of IALC might be impossible. The limited size and special requirements of grants limit their attractiveness to potential applicants. Additionally, there are always fewer applicants for demonstration projects than for research projects, which limits the impact of IALC's scientific and technical programs.

By periodically focusing on a single research and demonstration topic might help IALC to have a greater, more visible impact and a better-coordinated effort than under the current program. Because of the breadth of IALC's mission, the diversity of topics addressed annually is significant, which disperses the influence of the available funding over many problem areas. The disadvantages of this thematic approach include the possibility that IALC could have difficulty attracting many quality proposals from its member institutions. If the area of focus selected for emphasis is one in which some member institutions lack expertise, the institutions could leave IALC, or lessen their involvement in IALC's scientific and technical programs. If this were to occur, some of the best IALC scientists would not have the opportunity to guide IALC by submitting proposals that reflect their collective judgment and experience.

A review of completed IALC projects provides only minor support for narrowing the program boundaries. Despite the challenges posed by de-facto requirements for multinational teams, diverse disciplines, researchers, developers, and demonstrators have made significant, often breakthrough, contributions. Under the existing framework, all IALC member institutions in the United States have participated in funded projects and the list of participating institutions in Israel, Jordan, and Egypt continues to grow. Most important, participation is based on each institution's capacity to direct its strength and unique assets for IALC projects. By overly constraining the solicitation process to arrive at a program theme, institutional participation would suffer, and the opportunity to expand the expertise and skills of IALC's best scientists, and their member institution's programs, would be lost.

All arid and semiarid land problems are based on social and economic conditions. Therefore, the emphasis and integration of research, development, and demonstration into the human dimension of arid and semiarid land stewardship are important. Although the mission statement of IALC does not specifically address social science, IALC welcomes proposals on the human dimension of arid and semiarid land stewardship. Incorporating social science membership in IALC and clearly describing research and development priorities in these fields are essential. The need for socioeconomic assessments of research, development, and demonstration efforts is often apparent, but frequently lacking in IALC grant proposals. However, even without a high level of social science projects, the efforts of IALC cover a wide range of disciplines. To avoid greater dispersion of efforts and impacts and to expand efforts into the human dimension of arid and semiarid land ecosystem health and management, additional funding or changing IALC's scope is needed.

Emphasizing research and development that have immediate management applications is a desire of both researchers and managers. Showing immediate practical benefits from IALC's scientific and technical programs would fulfill our social contract and justify our support. IALC's management-oriented clients would benefit in real time, and the benefits to society would accrue quickly. With more immediate successes, much needed direction and advice from managers would increase. Incorporating more dialogue and collaboration between managers and researchers will better serve the inhabitants of arid and semiarid lands.

Many significant problems of arid and semiarid land stewardship require time, effort, collaboration, money,

and political action beyond the scope of IALC. Solutions to these problems require a mixture of basic and applied research and development from many organizations. IALC's scientists—especially junior scientists—must conduct both basic and applied research or emphasize basic research or development in their personal portfolios to establish their institutional programs and succeed in their careers. Therefore, an emphasis on applied research might discourage some of IALC's brightest and most productive scientists from submitting grant proposals. In academia, applied research is not considered as prestigious as basic research and development, which is an attitude that must be overcome to attain an applied and adaptive focus in IALC's scientific and technical programs.

The future will require IALC to be flexible and innovative. Policies and approaches that increase flexibility and foster innovation and collaboration must continue. IALC's members cooperate, collaborate, and contribute within a framework of shared interest in and concern for the viability of arid and semiarid land ecosystems worldwide. A framework that is supportive of member and client needs to generate support and address critical problems of arid and semiarid land stewardship better is essential to the continued success of IALC.

Recognizing the human dimensions of natural resource management practices is increasingly important to effective arid and semiarid land stewardship.

Chapter 8

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Appendix

IALC Funded Projects 1993–2000

1993

Research and Development Projects

- Arid Lands Water Resources Monitoring for Outlier Events on Ungauged Watersheds Using Radar Rainfall Measurements
- Collection of Cold-Tolerant Opuntia Fruit Clones in Northern Mexico and their Field Evaluation in Texas and Israel
- Propagation of Juniperus for Conservation Plantings
- Relationship Among Desert Patchiness, Resources, Production and Diversity: Implications for Rehabilitation of Desertified Environments
- Simulation of Selenium Discharge from Subsurface Drainage Systems
- Soil Salinization Induced by Runoff Collection in Small Forested Limans in the Negev Desert
- Transpirational Control in C_3, C_4, and CAM Plants

1994

Research and Development Projects

- Effects of Polyacrylamide on Infiltration of High-Sodium Water
- Effluent and Water Harvesting for Irrigation in Agroforestry Production Impact of Water Capture on the Dynamics of Plant Virus Vectors
- Patchiness and Nutrient Cycling in Arid Lands (U.S. and Israel)
- Role of Lower Plants in Remote Sensing of Arid Lands Vegetation Dynamics

Demonstration Projects

- Design, Build, and Bring On-Line an IALC Component of the Arid Lands Information Network
- Planning an IPM Demonstration Project to Help Improve Water Quality and the Environment in the West Bank and Gaza

1995

Research and Development Projects

- Estimation of Areal Distribution of Rain Intensities by Radar and Rain Gauges
- Spectral Reflectance and Biological Integrity of the Land-Water Interface
- Water Use by Tree and Shrub Forms of Dryland Oaks
- Wildlife Rangeland Monitoring by Remote-Sensing of the Negev Desert

Demonstration Projects

- Arid Lands Video Demonstration Outreach Project
- Information Visualization for the Management of Arid Lands Vegetation

1996

Research and Development Projects

- Capturing High Water–Use Efficiency in Cold Hardy Fruit Cacti
- Climate Change, Allometry, and the Hydraulics of Arid Land Trees
- Decision Support System for Arid Land Wetland and Riparian Zones
- An Integrated Management and Decision Support System for Arid Lands
- Redistribution of Resources in Drylands of the U.S. and Israel
- Role of Seed Banks in the Management of Semiarid Rangelands Under Grazing
- Ruminal Manipulation to Modify Toxic Compounds in Leguminous Trees
- Southwestern Borderlands Grassland Ecosystem Restoration

Demonstration Projects

- Developing a Sustainable Groundwater Management System from Decreased Nitrogen Use
- Developing a World Wide Web Resource on Aridic Soils of the U.S. and Israel

1997

Research and Development Projects

- Disturbance, Seed Banks, and Vegetation Dynamics of Desert Annuals
- Drought-Responsive Genes in Plant Populations from Desert Habitats
- Effects of Habitat Fragmentation And Patch Alteration on Desert Lizards
- Effects of Polyacrylamide and Gypsum on Seedling Emergence
- Influence of Water Deficit on Gene Products in *Pinus Halepensis*
- Microbiotic Crusts: Their Nature and Establishment in Israel and New Mexico

Demonstration Projects

- Savannization: Linking Ecological Understanding and Applications
- Management of Semiarid Watersheds: Technology Transfer

1998

Research and Development Projects

- Banner-Tailed Kangaroo Rats and Shrub Invasion in Desert Grasslands
- Effect of Redox Processes on Soil and Water Quality I
- Nitrogen, Productivity, and Soil Biota in the Chihuahuan and Negev Deserts
- Physically Active Soil Organic Matter: Key Factor in Arid Lands Reclamation?
- Predicting Seed Bank Germination in Semiarid Rangelands Under Grazing Management
- Remote Sensing Techniques Specific to Vegetation Detection in Arid Regions

Demonstration Projects

- Forest Systems for Wastewater Treatment and Economic Sustainability
- Integrated Technology Transfer: Soil Management for Erodible Lands
- Savannization: Demonstration Project in Chile

1999

Research and Development Projects

- Atmospheric CO_2 Sequestration by Soil $CaCO_3$ in Jordan and New Mexico
- Dust Emissions from Drylands Implications for Desertification
- Effect of Increased Productivity on Species Diversity
- Effects of Habitat Fragmentation and Management Practices on Desert Lizards
- Influence of Savannization and Brush Invasion on Spider Diversity
- Water Use and Growth in Dryland Oaks: Effects of Coppice Thinning

Demonstration Projects

- Improved Management of Public Land Grazing Allotments: An Information Resource
- Land Application of Wastewater for the Creation of Man-Made Forests in Egypt
- Water Conservation through Drip Irrigated Alfalfa Cropping Systems

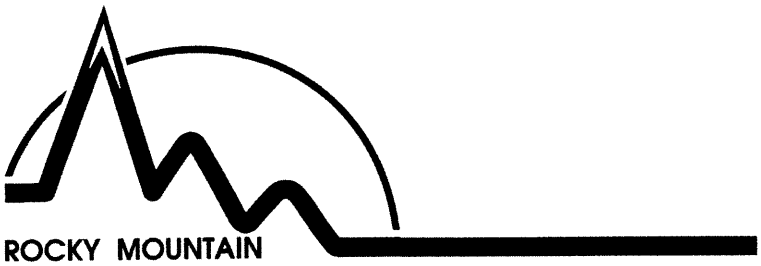
2000

Research and Development Projects

- Ecosystem Consequences of Cheatgrass Invasion in the Great Basin
- Effect of Redox Processes on Soil and Water Quality II
- Factors Controlling Microbiotic Crusts: Negev and New Mexico
- Feasibility of Water Harvesting and Storage in Shallow Aquifers in the Eastern Badia of Jordan
- Monitoring the Behavior of Desert Ungulates by Acoustic Telemetry
- Radar Scaling and Runoff Prediction Models in Arid and Semarid Basins
- Soil Disturbance by Animals: Soil Genesis and Patch Dynamics
- Structure and Dynamics of Rainstorms Inducing Floods in the Negev

Demonstration Projects

- Ecological Processes Enhancing Sustainable Grazing in Semiarid Ecosystems
- Management of Semiarid Watersheds - Phase 2: Decision-Making Tools and Technology Transfer



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