Chapter 7. An Ecosystem Approach for Establishing an Environmental Monitoring Program for the U.S.-Mexico Border Region

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Introduction

In the early 1990s, the U.S. border patrol increased enforcement activities in urban areas along the U.S.-Mexico border. As a consequence, immigration of undocumented individuals and drug traffic shifted to more remote areas of the international border. Much of this activity was redistributed to U.S. public lands that were established to protect biological diversity, including rare and endangered wildlife species and unique plant communities. The shift in locations of cross border violations that had resulted ecological damage to these public lands, including parks, refuges, and tribal lands, prompted the U.S. Department of Homeland Security (DHS) to expand border infrastructure, including construction of new and improved fences, roads, off-road vehicle barriers, and lighting, as well as increased helicopter patrols.

An Act of Congress in 2006 **(The Secure Fence Act of 2006** (Pub.L. 109-367) provided for construction of new fence and infrastructure projects, and allowed the Secretary of Homeland Security to waive consideration of existing environmental, cultural and public health and safety laws, notably the National Environmental Policy Act (NEPA). In some cases, construction of border infrastructure, changing agriculture and grazing patterns, and increased human traffic has altered stream channel morphology and increased flooding, increased the number of foot trails and rates of hill-slope and stream erosion, and impacted cultural and biologically important sites. Less obvious and largely unknown are the effects of unauthorized transit, border infrastructure, and enforcement activities on wildlife species that historically used areas that span the border. Public concern over these issues has triggered development of strategies to better integrate the need for border security with natural and cultural resource protection. Therefore, in 2008 DHS and the Department of the Interior (DOI) initiated discussions to develop a border-focused environmental monitoring strategy.

In 2009, DOI requested that the U.S. Geological Survey (USGS), its science bureau, assume leadership in developing an environmental monitoring strategy to evaluate the effects of border security activities. On 2 December 2009, the Good Neighbor Environmental Board (GNEB), an independent advisory board to the U.S.

President and Congress on the U.S.-Mexico border issue coordination, issued an advice letter[1] that offered 12 recommendations related to monitoring changes and mitigating impacts associated with construction of border fencing and roads such as obstructing the normal flow of rivers and assessing impacts to cross-border wildlife movements and migration corridors. In addition, the GNEB report suggested annual funding targets for monitoring, research, and mitigation of the environmental impacts of the border fence. In December 2009, a Listening Session for the Border Fence Monitoring and Mitigation Project was sponsored by Congresswoman Gabrielle Giffords (D-AZ) to solicit comments and recommendations from land managers and environmental organizations. Following the Listening Session, the USGS hosted a workshop to:

1) Define specific land-management issues and concerns, and
2) Based on input from stakeholders and land managers, develop/propose a pilot study as part of a monitoring strategy necessary for a scientifically defensible assessment of the effects and consequences of the U.S.-Mexico border security activities on representative ecosystems.

The goal of this chapter is to describe elements necessary to develop a monitoring program for the U.S.-Mexico border region using a multidisciplinary ecosystem-level approach that considers the range of scales and ecological drivers associated with border–related activities. An ecosystem-focused monitoring program would allow a more complete understanding of the kind of future research efforts necessary to properly evaluate the consequences of activities along the US–Mexico border.

Factors and metrics to monitor along the border

There are a considerable number of environmental resources within the region of the U.S.-Mexico border that could potentially be influenced by the present infrastructure and border activities. During a December 2009 meeting, DOI resource managers and stakeholders identified a number of critical factors that need to be included in a monitoring program (Table 1). Managers identified a series of factors after conducting an assessment of the potential influences of border activities on the habitat including general damage to vegetation and other aspects of wildlife habitat; the degree of fragmentation of wildlife habitat and movement

[1] See Sidebar 2 in this book.

corridors; the vulnerability of the region to the introduction and spread of invasive species; air and water contaminants; wildlife mortality and displacement; modifications of wildlife behavior, particularly for threatened and endangered species and species of special concern, such as impacts of lights on plant phenology and wildlife behavior; and difficulties in habitat restoration in damaged areas and protection of habitat improvements. Following the lead of the National Park Service Ecological Integrity Framework (Unnasch *et al*. 2009), we recognize that for a given resource area, the number of resources or their indicators that would be monitored would be refined to a manageable and relevant set.

Conceptual ecological models

The first step in creating a monitoring strategy is development of a conceptual model of the ecosystem. Conceptual models are used to represent complex systems, including system components, interactions, and processes. The conceptual model should rest on knowledge of the resource, the setting, associated species, natural communities and other aspects of the ecosystem. The resulting model represents a set of assumptions about how the focal ecological resources "work," their defining characteristics, the interrelations among characteristics, critical environmental conditions, and ecological drivers. These assumptions serve as the basis for hypotheses that both guide management and monitoring, and highlight gaps in knowledge that require additional investigation (Unnasch *et al.* 2009).

Table 1. Recommendations provided by managers at the listening session on essential elements for a monitoring program of the U.S.-Mexico Border Region.

1. Changes in landscape use (monitor uses as well as direct and indirect effects)
a. Examine changes at the border and many miles north (up to 100 miles)
b. Includes wildlife, human use, routes and roads

2. Connectivity and fragmentation issues
a. Roads
b. Barrier types
c. Off road use
d. Flyways
e. Lights

3. Hydrology: changes in overland flow, sediment movement, water flow, geomorphology, and erosion that occurs at the fence or as result of the fence

4. What are impacts from illegal activities on DOI mission and management (responsive actions that affect budget, time?)

5. Roads, including impacts from construction (both legal and illegal), traffic, and foot trails
a. Number of roads and trails
b. Activity levels on roads
c. Water quality
d. Species movements

6. Riparian Systems: human activity and effects – breaking down of infrastructure, pollution, trash, livestock, other biological effects

7. Disturbance: Human activity, noise, collisions with vehicles, lights

8. Design the monitoring project to distinguish among different stressors
a. Border patrol activities and their relationship to resource condition
b. Invasive species spread related to border and non-border impacts
d. Distinction between direct and indirect effects
e. Statistical power (robustness)

9. Impacts of controlling illegal activities

10. Impacts to mobile elements of the ecosystem (i.e., wildlife)

11. Invasive species

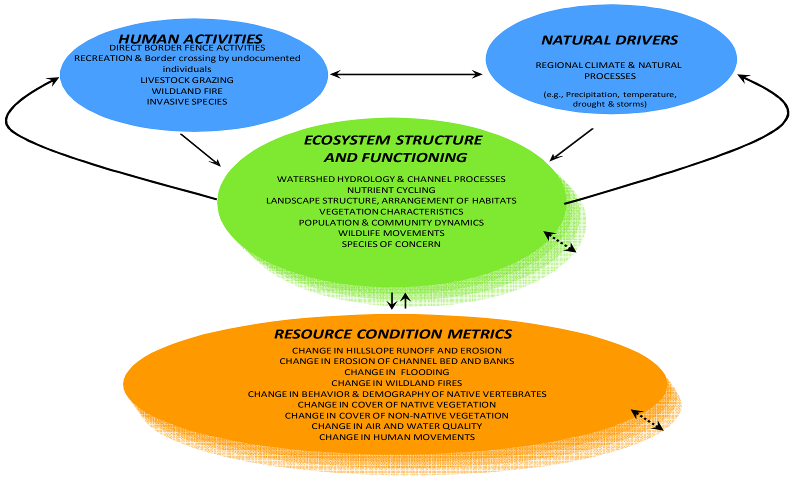
In addition, representatives of the U.S. Department of Homeland Security requested that an ecosystem approach be a focus in the development of the monitoring strategy

In developing a strategy to account for the numerous border and non-border factors identified by managers, it is necessary to take an ecosystem approach where key attributes are identified that relate to management issues, and provide insight into the overall behavior of the study system. This ecosystem approach is holistic and is likely to be more economical than an issue-by-issue approach. Further, it allows for development of integrated criteria that result in a better understanding of ecosystems along the border fence and the so-called "health" of those systems.

The following conceptual model summarizes how natural and human drivers interact with key structural and functional elements of ecosystems that span the U.S.-Mexico border region (Figure 1). The conceptual model focuses on natural resource assets of concern to resource managers and the public, as well as how illegal border activities, border security infrastructure and enforcement interact with natural disturbance processes to influence border ecosystems. The model further links selected structural and functional attributes to specific physical and biological metrics, which can be used to monitor change in resource condition over time.

Within this model an ecosystem is considered a spatially defined unit of the landscape that includes all organisms and all components of the physical environment within its boundaries (Christensen *et al.* 1996). Ecosystem structure includes the types, amounts, and spatial arrangement of physical and biological components of an ecosystem. Ecosystem functioning refers to flows of energy and materials through biological and physical components of an ecosystem. Functional processes include stream flow and related channel change processes, hill-slope runoff and erosion, nutrient cycling, and the production, retention and decomposition of organic material (Díaz and Cabido 2001). A complete list of ecosystem structural and functional elements is provided in Appendix A. A driver within the model is any natural or human-induced factor that directly or indirectly causes a change in an ecosystem (Carpenter *et al.* 2006). Important physical and biological drivers include climate and weather, natural disturbance events such as fires or floods, land-use conversion, diseases, and invasions by nonnative species. Ecosystems and resource conditions change over time, and vary in response to changes in natural drivers such as climate. This natural range of variation is represented in Figure 1 by the shifting edges and dashed arrows associated with ecosystem elements as well as resource-condition metrics. Any long-term ecological monitoring effort should be undertaken with an understanding of the natural range of variation of resources within an ecosystem.

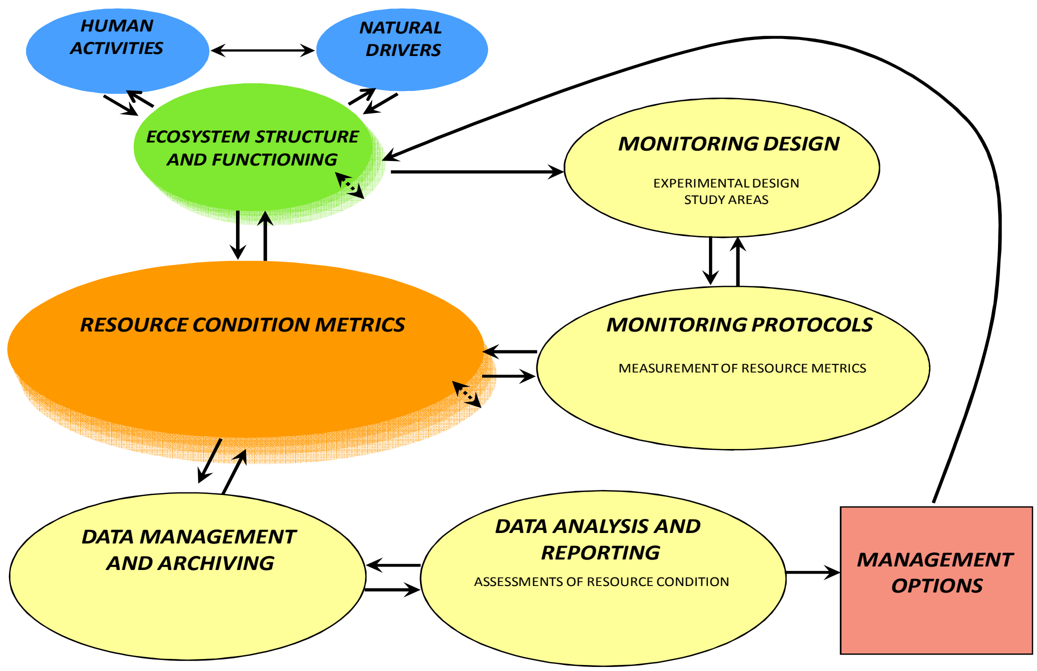
Figure 1. A conceptual ecological model representing U.S.- Mexico border ecosystems, along with related physical and biological metrics (orange ellipse).



This conceptual model depicts the parameters and variables that could be monitored to document and explain change in resource condition within the border-fence region over time. Ecosystem structural and functional elements (green ellipse) interact dynamically with natural and human drivers (blue ellipses) of ecosystem change. Ecosystem elements and condition metrics vary over time in response to natural drivers (dashed arrows).

Any ecosystem-monitoring program draws upon key ecosystems and ecosystem elements to identify study areas and to define an explicit sampling design. Figure 2 depicts the conceptual ecological model in the context of project design and implementation. Specific monitoring protocols, to be developed in consort with manager recommendations, will be developed to measure changes in specific resources efficiently. Implementation produces quantitative data on resource condition and other metrics, and will address the entire border ecosystem as well as differences among the three main border-fence structures (pedestrian barriers, vehicle barriers, remote towers). This sampling design will be most robust if it includes appropriate reference and/or control conditions. It is important that data accrued during the monitoring phase are managed and archived so that they can be analyzed and used to report on the direction and magnitude of change in resource condition over time. Assessments of resource condition could be used to trigger management actions intended to reverse undesirable trends in ecosystem structure and functioning. Thus, the monitoring-program design process is consistent with an adaptive management framework whereby monitoring is used to evaluate and refine the effectiveness of management actions on resource condition.

Figure 2. A Model showing the relationship of monitoring-program design, implementation, and data management, analysis and reporting with border ecosystems and selected resource metrics that could be monitored along the U.S.-Mexico border.



Human activities

Human activities influence ecosystem structure and function in a positive and negative manner (Figure 1). Human activities that influence ecosystem monitoring elements include border security, construction and maintenance of the border fence, traffic by undocumented people, livestock grazing, human-caused wildfire, recreation, and invasions by nonnative species. Vehicle-based activities in particular can directly impact soils, vegetation and local hydrology (Brooks and Lair 2009). Repeated use of established or informal campsites by recreationists and illegal visitors can create impacts in the vicinity, such as soil compaction, waste disposal and firewood depletion. Heavy foot and vehicular traffic can impact forbs and grasses (dune species may be especially vulnerable), and can disturb desert pavements and cryptogamic crusts, producing negative aesthetic and biological effects (Kuss and Morgan 1986). Rangeland value is related frequently to its ability to support livestock; hence appraisal of rangeland condition is important in evaluating border effects. Grazing potential (determined by net primary productivity of palatable plant species) has been negatively impacted by undocumented immigration and border interdiction activities. In contrast, rangeland conditions may improve in areas where border fencing restricts foot traffic and trespass cattle from Mexico.

Ecosystems along the U.S.-Mexico border have become increasingly fragmented during past decades by development of new roads and trails that disrupt the continuity of fuels that historically carried natural wildfires. Although habitat fragmentation from border activities and human development can reduce fuel connectivity, human-caused ignitions are believed to have increased thus affecting influencing fire frequency, distribution, and behavior. Invasive, non-native herbaceous species, if left unmanaged, could fundamentally alter grassland and Sonoran desert ecosystem structure through competition with native species for resources, thereby reducing species diversity and enhancing the spread of wildfires. Non-native riparian trees and grasses can alter stream hydrology and geomorphology and compete with native plants for valuable resources. Invasive species are typically spread along human-migration corridors.

The goal of the U.S.-Mexico border environmental monitoring program described in this chapter would be to variously measure and assess changes in ecosystem structure and function over time, both positive and negative, as a result of natural drivers and human activities (including drought, temperature, livestock grazing, wildfire, air quality, and water quality) along the border. Issues of concern focus on changing patterns in climate and land use, including grazing pressure, rates of fire ignition, vegetation fragmentation, and road and trail development and use. When possible, we suggest that monitoring protocols emphasize non-intrusive remote sensing methods coupled with ground verification. Metrics will vary depending on the monitoring element, but may include change in net primary productivity, change in spatial and temporal distribution of wildfires, and spatial distribution of invasive plants. Methods will vary according to the monitoring element but ideally are quantitative and spatially explicit.

It is important that border monitoring efforts include development of protocols that accurately monitor changes in rangeland condition, wildfire, spread of invasive species, and air and water quality. Similarly, it is important that data collected during the monitoring efforts are subject to Quality Assurance and Quality

Control (QA/QC) procedures and that the data are archived, analyzed and reported. Products are most useful if they are quantitative in nature and include appropriate input for synthesis with modeling efforts related to human movement, vegetation dynamics and soil dispersal and displacement. In addition, it is important that these products are suitable for peer-reviewed outlets and useful for adaptive management of the U.S.-Mexico border ecosystem.

Other goals of this monitoring effort will address how to measure, assess, characterize and model the diffuse and changing movement patterns and the associated landscape impacts of human traffic and interdiction efforts along the border. Understanding the factors that influence levels of human use along the U.S.-Mexico border might also include an evaluation of what effect the perceptions of local and visiting publics have on recreation experiences and opportunities in the face of border enforcement activities. It is important that metrics of vegetation change, and changes that reflect multiple trailing, trail widening, erosion as well as numbers and types of dispersed use, overall movement patterns and recreation experience and opportunity constraints are emphasized. Protocols might also emphasize non-intrusive remote sensing methods such as trail counters, remote cameras, or other mechanical counting devices that are calibrated with ground measurements on the U.S. side of the border and that can be augmented with field-impact assessment and evaluation techniques.

Methods that are employed in the monitoring effort would be most effective if they are quantitative in nature, incorporating spatial-temporal models that document and predict patterns of use and associated impacts as affected by illegal border crossing activities, border barriers and interdiction efforts, and interactions with land use and climate changes. These models would also incorporate the ability to examine changing recreation experiences and opportunities through perceptual response and derived behavioral rules from legal users. Human-activities drivers of concern may be the changing patterns in human use and associated impacts (loss of vegetation cover, trampling, soil disturbance and compaction) across the landscape, and perceptions and response to changing recreation experiences and opportunities.

Natural drivers

Climate and other natural processes play a central role in southwestern natural systems (Figure 1), and therefore monitoring these processes is fundamental to understanding short- and long-term changes in ecosystem parameters and variables. Sustained drought, in particular, is a major driver within ecosystems along the U.S.-Mexico border, and floods can alter the structure and composition of riparian ecosystems. Although regional climate is not directly influenced by border activities, collection of climate and weather data would be necessary at all locations to understand those changes as related to other parameters that are being monitored. Broad categories of ecosystem structure and function are summarized here as the major, integrative elements of ecosystems that are most likely to respond to border activities (Figure 1).

Ecosystem structure and function

Soils

Soils are the foundations for arid and semiarid ecosystems and control surface and subsurface hydrology (Brooks and Lair 2009). Therefore, factors that cause changes in soil resources can also impact hydrology, soil fertility, and ultimately ecosystem health. Trail erosion can be linked to a number of variables, including climate (seasonality and intensity of precipitation), vegetation type, substrate, and slope. Users of DOI lands are encouraged and expected to use established trails and rights-of-way such that they can be 'managed' and even guided to use alternative routes. Without utilizing designated routes, utilizing an alternative route often results in damage to the environment and require maintenance or closure. In contrast, border-related enforcement-activities have resulted in networks of undesignated trails and roads that have formed throughout the U.S.-Mexico border region. Effective management of soil resources requires that managers have reliable quantitative information about the effects of trails on various soil types and land surfaces. The goal of this section is to create a monitoring protocol that will be able to detect small net changes in soil resources of upland and desert riparian areas.

Drivers of soil conditions include disturbances at a range of scales, including trampling by humans and cattle, the formation of trails and roads related to border infrastructure construction and maintenance, and interdiction activities such as off-road pursuit. The effects of these drivers can be monitored in the context of ongoing recreational and agricultural activities and other land uses requiring human access in the study areas. Potential metrics include soil compaction, dilation resulting in loss of surface-horizon structure, increased erosion and gullying by wind and water, and possible loss of the native seed bank.

It is important that monitoring protocols are developed for identifying, quantifying, and evaluating soil conditions relative to key drivers over time and in response to any management activities aimed at protecting soil resources. Methods can be quantitative, ranging from remotely-sensed to site-specific measurements of extent of trailing in disturbed and undisturbed areas, xeroriparian as well as upland locations and with respect to soil surface type. Effects of roads and trails on soil properties would be measured including bulk density and soil strength to assess compaction, surface roughness, and trail physiognomy to assess surface damage, hill slope, and stream sediment erosion, transport, and depositional processes. Monitoring will benefit from methods that adequately quantify baseline trail and road networks as well as trends in the distributions and densities of trails and roads. Soil compaction and erosion would be measured and used to inform models for predicting those parameters at a watershed scale. Methods developed in this monitoring protocol can be useful for modeling changes to vegetation, hydrology, and plant invasions. Deliverables can also include protocols for data collection, QA/QC, and data analysis, archiving, and synthesis.

Water

Managers responsible for sustainable use of all lands are concerned that the combined influences of legal visitor use, fence and road construction, undocumented immigrants, drug smugglers, and enforcement interdiction effects are affecting landscapes at the watershed scale. With respect to hydrology at border areas, the net result of watershed-scale impacts is the concern that erosion and sediment yield, as well as the magnitude of floods, have increased, while water quality has decreased. As a result, the combined impacts may accelerate resource degradation. To assess changes in the hydrology, the study would characterize and quantify impacts to stream flow and water quality attributable to disturbances such as human migration, foot traffic, vehicular traffic, patrolling, fence construction, and locating barriers across stream channels. Scales of interest range from the channel to the watershed scale, and would include impacts resulting from diffuse disturbances. Metrics of watershed change include changes in erosion rates, sediment-transport rates, transport rates of flow debris, surface-water discharge, flood rates (frequency and especially magnitude), hydrologic characteristics that result from border fence design, and surface- and groundwater quality. Monitoring and analysis methods should identify, quantify and document alteration of surface flow, including run-off, flooding patterns, erosion, sediment transport, and organic-debris transport. Standard models and field methods should be used if possible, but development of novel techniques may be required to meet the project goals.

Information may include data collected directly, such as flow measurements and water quality, data collected indirectly, such as regional-scale soil data sets, and also may include data collected remotely. Indirect and remotely-sensed data can be calibrated/ground-truthed with directly-collected data. Drivers of concern to characterize changes to hydrologic systems of the border areas may include, but are not limited to, soil disturbance, soil compaction, road construction, barrier construction, patrolling efforts, grazing patterns, invasive plant introduction and human-caused contamination and fires. We recognize that precipitation events are a strong natural driver and, therefore, it would be informative to consider interactions between natural and human-activities drivers. Products would be quantitative in nature, and include data appropriate for synthesis with modeling efforts related to wildlife, hydrology, vegetation, and soils, from the hill-slope to the watershed scale. It is important that data and models developed as part of the project are appropriately archived. It is also important that products are useful for adaptive management of border areas and of sufficient quality for peer-reviewed scientific publications.

Vegetation

Monitoring of vegetation communities along the targeted border areas would include establishing baseline conditions and documenting historical and future changes. Metrics of vegetation change would include fragmentation, cover, productivity, and species demography, composition, and richness. To allow monitoring of large areas, sampling protocols would emphasize non-intrusive remote-sensing methods verified with ground measurements on both sides of the border. By using quantitative data-collection methods, the data can be used to document vegetation patterns as affected by legal recreation and illegal border crossing activities, interdiction efforts, border barriers and maintenance of barriers, and interactions with land-use and climate changes. Drivers of concern to vegetation include: trampling, road construction, soil disturbance and compaction, grazing patterns, plant invasions, air quality and fire. A vegetation monitoring program would include protocols for data collecting and monitoring, QA/QC and archiving, analysis, modeling, and reporting results. Products would be quantitative, and include appropriate input for synthesis with modeling efforts related to wildlife, hydrology, watershed, and soils. It is important that vegetation metrics are suitable for change detection studies that can inform resource management agencies, that products are useful for adaptive management of border areas, and that they are of sufficient quality for peer-reviewed scientific publications.

Wildlife

Monitoring of wildlife would serve as a barometer of the influences of border activities and associated infrastructure on wildlife populations, communities, and responses to habitat change. It is important to provide a quantitative framework for assessing changes in these wildlife-related responses over both the short- and long-term, and to provide information to inform management decisions. Metrics of the effects of border activities on wildlife would reflect the scales at which species use the landscape. Metrics for specific groups (e.g., birds, mammals, reptiles) would include relevant aspects of demography and behavior, including movements and gene flow, and community structure and composition. To minimize cost and avoid adverse impacts on wildlife, sampling protocols would need to be logistically feasible, sensitive to species status, and minimally invasive to individuals that are being monitored.

Methodologies and results that provide quantitative assessments of the impact of border barriers and human activities on wildlife in the short term also provide the foundation for long-term monitoring of wildlife responses to border transformations. Drivers especially relevant to wildlife responses are fence permeability, transportation-corridor influences, habitat degradation, and human activities related to legal use and illegal immigration and associated border enforcement. A wildlife monitoring program would include short- and long-term monitoring protocols for data collection, QA/QC and archiving, analysis, modeling, and reporting results. Products would be quantitative and include rigorous justification for sampling designs, including sample sizes, have the potential for integration with other monitoring programs, and be relevant to resource managers for establishing mitigation measures.

Socio-Cultural Resources

Monitoring of socio-cultural resources would include measuring, assessing and characterizing how activities along the border have changed perceptions of the social-cultural experience and recreation opportunities for local and visiting publics. Metrics would include attitudes towards ecological impacts and illegal use, negative social-cultural experiences, and opportunity constraints. Sampling protocols would focus on social experience, attitudes towards opportunity constraints, and the effects of changing ecological and social conditions on experience opportunities. Monitoring methods would be most useful if they are quantitative, incorporating spatial information and survey methods and focus group sessions with local stakeholders to gather information on current use patterns, and spatial-temporal information on perceived changes of ecological and social conditions. Additional focus group sessions could be included to identify possible solutions. Drivers of concern are the changing patterns of legal human use, associated impacts (loss of vegetation cover, trampling, soil disturbance and compaction) from illegal use, displacement from areas commonly used for recreation due to actions along the border, and changing attitudes towards availability of resources for recreation activities.

A socio-cultural resources monitoring program would include information that outlines perceived impacts and how those affect local users and visitors to the border areas and influence recreation opportunity constraints. It would also include a range of potential user-driven solutions that can inform land managers, law enforcement, and border security on how to provide and maintain high-quality recreation experiences along the border. These potential solutions would be linked to both social and ecological drivers of change. As with other portions of the monitoring protocol described in this chapter, products would be spatial and quantitative in nature, and include appropriate input for synthesis with modeling efforts related to human movement, vegetation dynamics, and soil dispersal and displacement. It is important that products be suitable for peer reviewed outlets and able to be used by DHS for adaptive border management. The Department of Homeland Security (DHS) has conducted inventories of cultural resources along the border fence at locations that would complement the suggested monitoring protocols in this chapter. Much of information collected by DHS on cultural resource type and location is sensitive but, when possible, it could be integrated into the overall monitoring design.

Data products

Data Management and Archiving

All data can be collected in a fashion that complies with federal metadata standards (FGDC-STD-001-1998). Data analysis techniques would vary depending on the specific measurements and collection methods for each protocol. The data archive system would be modeled on the U.S.-Mexico Border GIS system, as developed by the Border Environmental Health Initiative (BEHI; Norman *et al.* 2011). To facilitate binational analysis of environmental issues that involve human health, major efforts have been made to seamlessly integrate U.S. and Mexico geospatial datasets along common themes (USGS 2010).

Analysis and Modeling

Once products of all monitoring elements are available, they can be leveraged to create meta-models in support of management actions. For this portion of the integrated project, researchers can propose ways to synthesize these elements into products useful for effective natural resource management along the U.S.-Mexico border. It is important for modeling to be guided by and responsive to the "Important factors managers identified to consider monitoring" as summarized in Table 1. One goal is to distinguish between effects caused by natural drivers and those caused by human-activities drivers. Models may inform, for example, a better way to control invasive species, optimize mitigation corridors for wildlife, restore habitat and connectivity, and develop decision support systems. Protocols for model development would benefit from feedback provided by stakeholder focus groups, depending on the application.

Conclusions

Previous attempts to evaluate the effects of human activities along the U.S.-Mexico Border have focused on one or few elements, instead of the many aspects of the ecosystem. For example, wildlife has often been the main target of concern and wildlife studies have often ignored other physical and biological elements of the ecosystem, including the influences of human activities. A more integrative approach, as outlined in this chapter, would provide a detailed and scientifically sound evaluation of the consequences of all activities within the U.S.-Mexico Border ecosystem. Integrating all spatial-temporal monitoring data outlined in this chapter would provide the building blocks to better predict future habitat changes in the U.S.-Mexico border region.

Appendix A

This Appendix provides a table of information with structural and functional elements that can possibly be included in a border environmental monitoring plan. The elements are physical and biological influences that presently exist within the U.S.-Mexico border ecosystem. We have identified Department of the Interior (DOI) lands as possible study locations that may be suitable for monitoring units, but in this Appendix they are used only as examples. Descriptors define whether the structural and functional element has a high, medium or low amount of influence in the identified DOI study location, while "x" indicates that information as available. This evaluation is only a general index, determined by consensus among the authors.

Critical Physical & Biotic Factors Matrix				
Structural and Functional Elements	**San Pedro Riparian National Conservation Area/ San Bernardino National Wildlife Refuge**	**Buenos Aires National Wildlife Refuge**	**Organ Pipe Cactus National Monument/ Cabeza Prieta National Wildlife Refuge**	**Lower Colorado River**
Human Activities Drivers				
Border Security Infrastructure	x	x	x	x
Pedestrian fence	x	x	x	x
Vehicle barrier	x	x	x	
Wire fence	x	x	x	x
Mobile surveillance	x	x	x	x
Access road network	x	x	x	
Tower construction/use	unknown	unknown	unknown	unknown
Impact of lights	unknown	unknown	unknown	unknown
Enforcement Activities				
Border Patrol interdiction effects	moderate	high	high	high
DOI agency use	moderate	moderate	high	high
Impact on soundscape				
Recreational Impacts	high	high	high	high
Human Impacts				
Trailing	high	high	high	high

Encampments	high	high	high	high
Water quality	high	high	high	high
Vandalism	unknown	unknown	unknown	unknown
Impact on soundscape				
Livestock Grazing				
Trespass from Mexico	high	high	low	low
U.S. grazing effects	high	high	low	not present
Wild land Fire				
Human-caused wildfires	high	high	low	high
Fire suppression effects	high	high	low	low
Invasive Species	high	high	moderate	high
Invasive species vectors	high	high	high	low
Natural Drivers				
Climate & Natural				
Albedo changes	high	high	moderate	low
Disturbances				
Diurnal temperature changes	moderate	moderate	high	high
Seasonal temperatures	moderate	high	high	high
Precipitation	moderate	high	high	high
Drought frequency	moderate	high	high	high
Storm intensity	high	high	high	moderate
Ecosystem Structure and Functioning				
Catchment				
Runoff generation/infiltration	high	high	moderate	low
Characteristics				
Soil erosion/sediment yield	high	high	high	moderate
Perturbation	low	moderate	high	moderate
Ephemeral/perennial flow	high	high	low	low
Flood frequency	high	high	moderate	low
Sediment transport	high	high	high	moderate
Elevation ranges	3,500-6,000 ft	1,000-4,000 ft	600-4,800 ft	150-500 ft
Topographic diversity	moderate	high	high	low
Substrate variability	high	high	moderate	low
Land uses/cover changes	high	high	moderate	high
Hydrologic				
Barrier effects on surface flow	high	moderate	high	high
Channel erosion/deposition effects	high	high	high	high
Tinaja water quality	low	high	high	low
Ephemeral streams	high	high	high	moderate
Perennial streams	high	moderate	not present	high

Drainage direction	north at border	south at border	south at border	south at border
Geomorphic				
Soil and substrate	low	low to high	high	high
Dust production	high	high	low	high
Biogeochemical Habitat Structure, Arrangement & Connectivity				
Population connectivity	high	high	high	low
Migration corridors	high	high	low	high
Vegetation Characteristics				
Cover	moderate to high	low to high	low	low in desert, high in riparian
Structure	high	low to high	moderate	low in desert, high in riparian
Diversity	high	low to high	high	low in desert, high in riparian
Community classification	Chihuahuan desert grassland	grassland - Sonoran Desert	Sonoran Desert	lower Sonoran Desert
Primary production	high	moderate	low	high in riparian area
Evapotranspiration	high	moderate	high	high in riparian area
Phenological shifts	not applicable	not applicable	not applicable	not applicable
Recovery from historic grazing	high	high	high	low
Recovery from border fence construction	moderate	moderate	moderate	high
Rest-rotation related to changing trail formation by undocumented people	high	high	high	moderate
Seed dispersal	unknown	unknown	unknown	unknown
Population Dynamics				
Vertebrate assemblages	high	high	high	high
Temperature effects	not applicable	not applicable	not applicable	not applicable
behavioral change (avoidance of human presence & structures)	high	high	high	moderate
Physiological stresses	moderate	high	high	moderate
Effect on reproductive	low	high	moderate	high

success				
Human health	high	high	high	high
Aerial animal migration	low	moderate	low	low
Ground animal migration	high	high	high	moderate
Gene flow	unknown	unknown	unknown	unknown
Species of Concern				
Community dominants				
Mesquite	high	high	high	high
Creosote bush	low	moderate	high	high
Black gramma	high	high	low	not present
Columnar cactus	low	moderate	high	moderate
Cottonwood	high	moderate	low	high
Ironwood	high	high	high	high
Native Species, Major Taxa				
Invertebrates	high	high	high	high
Lizards and snakes	high	high	high	high
Rodents	high	high	high	high
Resident birds	high	high	high	high
Migratory birds	high	high	high	high
Whitetail deer	high	high	high	high
Mule deer	high	high	high	high
Carnivores	high	high	high	moderate
Fish	high	low	low	high
Amphibians	high	high	moderate	high
Beaver	high	low	not present	moderate
Burrowing owl	high	high	low	high
Threatened & Endangered Species				
Agave palmeri, A. parryi	high	low	not present	not present
Night-blooming cereus	not present	low	high	unknown
Canelo Hills ladies tresses	high	low	not present	not present
Huachuca water umbrel	high	low	not present	not present
Acuna cactus	not present	not present	high	not present
Nichol's Turk's head cactus	not present	high	not present	not present
Pima pineapple cactus	not present	high	not present	not present
Northern Mexican gartersnake	high	not present	not present	not present
Sonoran tiger salamander	high	not present	not present	not present
Chiricahua leopard frog	high	low	not present	not present
Sonoyta mud turtle	not present	not present	high	not present
Desert tortoise	not present	moderate	high	high
Gila monster	not present	moderate	high	high
Flat tail horned lizard	not present	low	low	high
Masked bobwhite quail	not present	high	not present	not present
Yellow-billed cuckoo	high	low	not present	high
Southwestern willow	high	low	low	high

flycatcher				
Ferruginous pygmy owl	moderate	high	high	not present
Mexican spotted owl	high	don't know	not present	not present
Yuma clapper rail	not present	not present	not present	high
Lesser long-nosed bats	high	moderate	high	high
Sonoran pronghorn	not present	not present	high	not present
Prairie dog	high	not present	not present	not present
Desert bighorn	low	moderate	moderate	not present
Jaguar	moderate	not present	not present	not present
Invasive Species				
Buffelgrass	moderate	high	moderate	low
Lehmann's lovegrass	high	high	not present	not present
Saharan shouldard	not present	moderate	moderate	high
Russian thistle	low	moderate	high	high
Cheatgrass	moderate	high	not present	not present
Giant salvinia	not present	not present	not present	high
Giant reed	not present	not present	not present	high
Tamarisk	moderate	not present	low	high
Bullfrogs	high	high	not present	high
Cultural				
Sites of Cultural Importance				
Archaeological	x	x	x	x
Historical	x	x	x	x
Infrastructure				
Costs/damage	high	high	high	high
DOI Agency Mission				
Diversion of hours from normal job requirements	high	low	high	low
Ecosystem Services				
Recreation	high	high	high	high
Iconic Species	low	moderate	high	high
Biodiversity	moderate	low	low	moderate
Aesthetics	high	moderate	high	moderate
Domestic water availability supporting services	low	low	moderate	low

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