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Arid and semiarid rangeland monitoring in North America

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Abstract

Canada, the United States and Mexico all have a long history of rangeland monitoring. However none have developed a nationwide database or even a standardized set of protocols. The lack of standardization, inadequately developed relationships between management objectives and monitoring protocols, and an emphasis on data collection rather than analysis and interpretation have limited the value of past monitoring efforts. The future of monitoring is bright in all three countries. New policies reward ranchers who can document positive changes on their land. Non-equilibrium theory developed in Europe, Africa, Australia and North America increases the value of monitoring data. New protocols increasingly focus monitoring on ecological processes.

Key words: rangelands, data base, arid zone.

Résumé

Surveillance continue des pâturages arides et semi-arides d'Amérique du Nord

Le Canada, les États-Unis et le Mexique ont une longue pratique de la surveillance continue des terrains de parcours arides et semi-arides. Cependant aucun n'a pu développer une base de données dans l'ensemble du pays ou même un ensemble normalisé de protocoles. Le manque d'étalonnage, les rapports insuffisamment développés entre les objectifs de gestion et les protocoles de surveillance continue, et la priorité placée sur la collecte plutôt que sur l'analyse et l'interprétation de données ont limité dans le passé la valeur des efforts effectués. L'avenir de la surveillance continue est prometteur dans chacun des trois pays. Les nouvelles politiques avantagent les propriétaires de ranches qui peuvent documenter les changements positifs intervenus sur leur terre. La théorie de non-équilibre développée en Europe, Afrique, Australie et en Amérique du Nord augmente la valeur des données continues. Les nouveaux protocoles mettent de plus en plus l'accent sur la surveillance continue des processus écologiques.

Mots clés : parcours, base de données, zone aride.

History

The Society for Range Management defines monitoring as "The orderly and quantitative collection, analysis, and interpretation of resource data to evaluate progress toward meeting management objectives. The process must be conducted over time in order to determine whether or not management objectives are being met" [1]. Based on this definition, rangeland monitoring in North America is largely limited to the past 50 years. Most monitoring that meets this relatively narrow definition has been driven by legislative mandates and has had data collected by government employees [2, 3].

Based on the broader dictionary definition of monitoring – to watch, observe or check, especially for a specific purpose" [4]–rangeland monitoring has been practiced for at least several millennia. There is evidence that Native Americans intentionally modified fire regimes [5]. The repeated inventories required for this type of landscape management likely resulted in the development of knowledge bases that served the same function as today's more formal databases.

The longest rangeland monitoring records in North America are based on revisiting the written inventories of the earliest explorers and surveyors. Revisiting Lewis and Clark expedition (1803-1806) campsites allowed Laliberte *et al.* [6] to conclude that while significant changes had occurred along some parts of the route, other areas had retained much of the previously existing wildlife. In the more arid southwest, repeat photographs and journals of the Stanton expedition reflect long-term landscape dynamics [7].

While the records of the early explorers were necessarily anecdotal, the surveyors who followed often provided more systematic vegetation descriptions across the landscape. By comparing a vegetation map based on one-square mile grid cell observations from an 1858 survey near the current US-Mexican border with contemporary maps, Buffington and Herbel [8] were able to document the dramatic conversion of grasslands to shrublands. This transition has occurred throughout the arid and semiarid southwestern United States and Northern Mexico [9]. These *ad hoc* monitoring records, in turn, have been used together with experimental studies to develop our current understanding of vegetation dynamics and the importance of ecological thresholds [10] and soil-vegetation feedbacks [11].

Documentation of rangeland conditions during the first half of the 20th century consisted primarily of inventories that were used to generate assessments supporting new legislation or to establish research stations in the southwestern United States, such as the Santa Rita Experimental Range (established 1903) and the Jornada Experimental Range (established 1912). They were not intended to serve as the basis for long-term monitoring.

Reports such as "The Range Problem in New Mexico" [12] described the devastation caused by a combination of overgrazing and drought in the late 19th century. The first comprehensive report describing the state of rangelands in the Western United States was finally published in 1936 as a Senate report [2], but even this was based primarily on ocular assessments of current condition relative to some idealized historic reference.

Formal rangeland monitoring in Canada began on rangeland benchmark sites as early as the 1930s in the western part of the country. These were established to help understand the effects of grazing and subsequently to develop range condition guides. The use of benchmark sites has increased within the last few decades in an effort to better understand the effects of herbivory on the plant community in a greater number of habitat types. Presently, there are about 377 sites in British Columbia, 185 in Alberta, 3 in Saskatchewan, and none in Manitoba. New benchmark sites are in the process of being developed in forested rangeland in Saskatchewan (Jeff Thorpe, personal communication) and Manitoba (Gil Lahaie, personal communication). Benchmark sites normally consist of a livestock exclosure (of about one hectare in area). In addition to benchmark sites, reference areas have been established on grazed rangeland that consist of photo-points, permanent transects, or GPS-defined fixed locations that enable monitoring.

Rangeland monitoring of the benchmark sites is commonly based on species composition determined either by point sampling or ground cover. These estimates are used to derive the climax or potential community, which is then used to develop a guide to establish range condition and stocking rates.

Species composition may be monitored every five to ten years but standing crop can be sampled every year. In Alberta standing crop is also measured on the surrounding grazed areas both within and outside temporary enclosures to provide estimates of utilization. British Columbia also monitors rangeland sites using photo-points and permanent transects.

Widespread monitoring of fixed plots and transects on United States public lands finally began in the 1950s and 1960s with the adoption of the Parker 3-step method by the Forest Service [13]. Data were collected and interpreted at the scale of individual allotments (an area that is typically thousands of hectares in size that is leased to an individual rancher for livestock grazing). While the Parker method suffers from a number of limitations, the data represent virtually the only quantitative long-term record of change in many parts of the western US. Several pieces of federal legislation enacted during the late 1970s required inventories of nearly all of the nation's rangelands. As in Canada, the standard for most of these inventory and monitoring efforts was based on species composition and comparison to a historic climax plant community.

In Mexico, the establishment of the *Comisión Técnica Consultiva de Coeficientes de Agostadero* (COTECOCA) in 1966 marked the first attempt to implement the principles established in Article 27 of the Mexican Constitution, which pertains to the size of land holdings for ranching. The methodology for evaluating range condition was based on Canfield [14], Dyksterhuis [15], Renner and Alfred [16], González and Johnson [17], and reports of COTECOCA at the state and paddock level published from 1972-1986. Monitoring methods have also benefited from the development of an *ad hoc* methodology [18]. An attempt to inventory and monitor the natural resources of the state of Jalisco, Mexico, is reported by Martinez Moreno *et al.* [19].

Drivers of change in rangeland monitoring systems

During the past 25 years, three changes have occurred that have significant implications for rangeland monitoring in North America. The first is the increasing acceptance that successional dynamics are insufficient to explain the dramatic and persistent changes that have occurred in arid rangelands throughout the world. The existence of relatively irreversible soil and vegetation transitions, or "thresholds" [20, 21], and multiple pathways among different plant communities and states (*figure 1*) complicate the interpretation of monitoring data. An understanding of these dynamics, however, can help focus limited monitoring resources on areas that have the greatest degradation risk or opportunities for recovery.

This led, in part, to the second change, which is a demand for more comprehensive information about the status of agricultural land in Canada [22] and the United States [23, 24]. The term "health" is increasingly used to refer to the capacity of the land to support multiple land use objectives and to resist and recover from

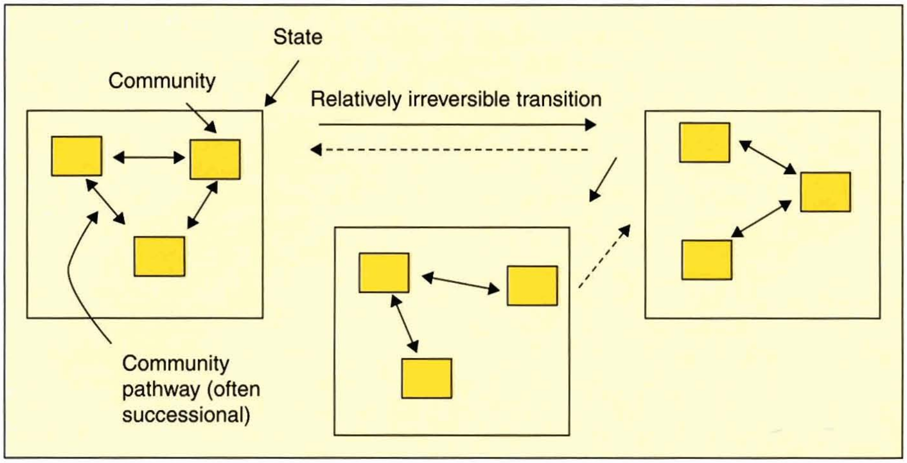

Figure 1. Schematic of the organizational structure of a State and transition model (from [37]; modified from [41]).

Large boxes are States connected by relatively irreversible threshold transitions. Small boxes (plant communities) within States are connected by relative pathways. Single-State systems are possible where no thresholds have been identified.

degradation. In the United States, protocols were subsequently developed to qualitatively assess [25-27] and quantitatively monitor [28] three attributes of rangeland health: soil and site stability, hydrologic function, and biotic integrity. A hybrid system is increasingly applied in the province of Alberta [29-31]. New guides have also been implemented in British Columbia (Rick Tucker, personal communication) and similar initiatives are under development in progress in Saskatchewan and Manitoba.

The third change is increasing monitoring requirements associated with government financial support. In Mexico, a federal government program – Reglas de Operación del Programa de Estímulos a la Productividad Ganadera [32] – was established to improve range condition. In order to receive payments of up to 3,600 pesos over a four-year period, ranchers, ejidatarios, and communal land managers must document increases in basal plant cover: 1% per year in arid zones, 2% per year in semiarid zones, 3% per year in temperate zones, 5% per year in dry tropics, and 8% per year in the wet tropics, while increasing forage production by up to 12% by the end of the program in 2006. If successful, it is likely that the program will be extended.

In the United States, the Conservation Security Program (CSP) rewards landowners who demonstrate that they have practiced good management in the past and requires them to commit to continued improvement in their management. Monitoring is one of the options landowners may accept in order to meet this requirement. This program emphasizes rangeland health over the traditional species-based standards.

Current status

Based on the broad dictionary definition of monitoring as "watching, tracking or checking on for a specific purpose", it could be argued that most arid rangeland in North America is monitored at some level by those who manage it, particularly if it is being used for livestock forage production [33]. However, there is currently no comprehensive monitoring system covering arid lands in Canada, the United States, or Mexico that meets the more formal Society for Range Management definition listed above.

In addition to the long-term efforts discussed above, Canada initiated an Environmental Assessment and Monitoring Network in 1994 [34]. At present, this national-level effort has only a limited number of sites in the semiarid region, and they are monitored primarily by volunteers. The Canadian Conservation Areas Database documents the features of existing conservation areas – which include the region of semiarid rangeland – and can potentially be used to monitor those sites [35].

In the United States, where tens of millions of dollars have been spent on rangeland inventory and the monitoring of hundreds of thousands of plots and transects during the past 25 years, the reasons for the lack of a unified protocol include a patchwork of land ownership and jurisdictions (*figure 2*), a diversity of management and monitoring objectives, and the lack of a single legislative mandate. While the lack of national coordination makes reporting difficult, plot-level data continue to be used to make grazing management decisions, and a number of recent initiatives are increasing the use of monitoring data in National Parks and on military bases.

In the case of Mexico, it may be argued that a lack of resources has also limited the establishment of a national-level program. Monitoring is further complicated by ongoing changes in land tenure policy, including the most recent amendments to Article 27 of the National Constitution in 1992. Nevertheless, Mexico has a good legislation pertaining to the use and

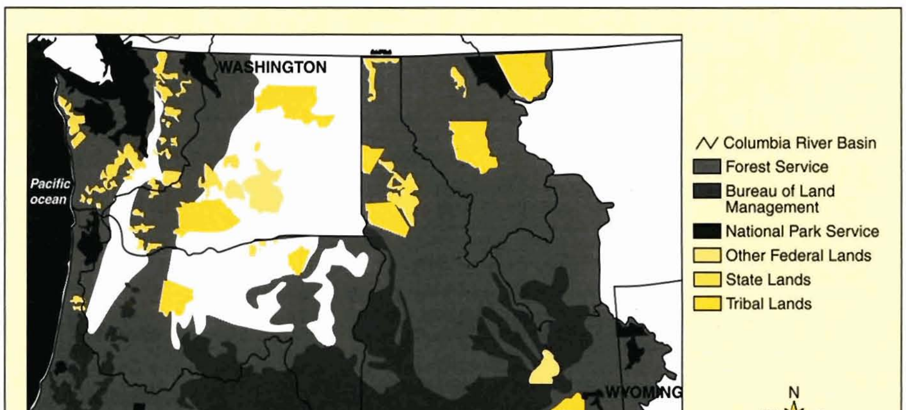

Figure 2. Land ownership map for the northwestern United States.

Disclaimer: Map is to be used for general display purposes only and is not intended to represent any legal boundaries or information. The best available data were used. Source: Interior Columbia Ecosystem Management Project (ICBEMP); Montana State Library Natural Resource Information System; BPA Regional GIS Database, 2002.

management of natural resources. Also, as a member of the United Nations, Mexico has agreed to several international protocols including Climate Change, Biodiversity, and Desertification [36]. Many of these national and international documents could be used to support monitoring should resource availability increase. Furthermore, with a strong central government, Mexico possesses many of the bureaucratic structures that support data integration across multiple scales.

In each country, at least some monitoring is currently completed that addresses one or more of three basic objectives (*table 1*). The first is to assess changes in the status of an individual management unit such as a ranch or national park. The second is to ensure compliance with a particular mandate. Compliance monitoring often includes a combination of use (e.g. utilization) and response (e.g. basal cover) indicators. The third is to provide information for national reporting on the status of rangelands.

Sampling strategies

Sampling strategies currently applied in North America include subjective, random, stratified random, and systematic [28]. The key area concept is widely applied at the management unit scale throughout North America. In the United States, it has been used by both the Bureau of Land Management (BLM) and Forest Service (USFS) to establish and modify stocking rates during the past 50 years. It is also commonly used by extension agents to design ranch-specific programs. Based on their location within disturbance gradients (e.g. biospheres), key areas are assumed to reflect changes occurring across larger areas. While this approach is often more sensitive to local patterns and land use than random sampling schemes, it has a high potential for bias and is difficult to quantitatively extrapolate.

Random and systematic sampling strategies are more commonly applied for national-level inventories. Both the National Resource Inventory (NRI) for non-federal lands and the Forest Inventory and Analysis system (FIA), which includes non-forested lands managed by the USFS, use national sampling grids for site selection. Because they have a stronger statistical foundation, random and systematic strategies are also commonly applied to address the effects of specific management actions, including restoration treatments. These programs often include control areas to account for random temporal variability due to weather.

Stratified random sampling is becoming increasingly popular as individuals attempt to increase monitoring program cost-effectiveness. Stratification allows monitoring intensity to be increased in areas that are of greater interest, have higher internal variability, or where change is anticipated. Soil- and climate-based "ecological sites" were recently adopted as a common stratification system by the three agencies responsible for inventorying most US rangelands. By stratifying the landscape based on its ecological potential rather than existing vegetation, this system is expected to be relatively stable over time [37].

Future trends

Future trends that are likely to dramatically modify the way North American arid rangelands are monitored include changes in ecological theory, technology, land use, and the increasing demand for protocol standardization.

Ecological theory

The paradigm shift from succession-retrogression to multiple ecological states, which include both successional and threshold-like processes, is changing both where and what is monitored. Because remediation of post-threshold systems is often not economical, monitoring is increasingly designed to anticipate and avoid irreversible transitions. This is particularly true for invasive species monitoring, where the costs of control increase exponentially through time. Stratified monitoring systems are used to focus attention on areas with a high potential for invasive plant establishment or expansion, and indicator selection emphasizes both the plants themselves and site conditions (e.g. bare soil) that increase susceptibility to invasive species establishment. This approach is consistent with advances in our understanding of erosion processes, which increasingly emphasize focusing attention on relatively small parts of the watershed that contribute a disproportionate amount of sediment.

A growing awareness of the importance of changes in resource redistribution processes presents new challenges for monitoring. These processes are difficult to monitor because they extend across multiple scales, can include interactions between wind and water, are often associated with relatively rare, extreme events, and are frequently obscured from view by plant canopies. Tongway [38] addresses some of these limitations, particularly for water-driven systems with a unidirectional gradient, but has not been widely applied in the United States. The NRI [39] now includes measurements of gap size distributions [28] that are often correlated with susceptibility to resource redistribution by wind and water. We predict that future monitoring systems will become increasingly spatially explicit and dynamic, allowing managers to rapidly shift focus across multiple scales and processes as landscapes evolve in response to different threats and opportunities.

Technological advances

These changes will be facilitated by new technology for acquisition, storage, and analysis of monitoring data. Data acquisition opportunities are increasing yearly with the deployment of new sensors on satellites for broad-scale measurements and the development of UAV systems for on-demand low-cost acquisition of high-resolution imagery [40]. Ground-based measurements will continue to be necessary to calibrate and interpret remotely-sensed data, but even these will benefit from technological advances through the deployment of *in situ* environmental sensors connected to virtual wireless networks. These wireless networks will dramatically increase the number of processes that can be monitored directly rather than relying on inferences from snapshot patterns. We predict that integration of diverse remote sensing systems with ground-based measurements will lead to the creation of multi-scale, nested monitoring designs with the ability to address changes in both fine- and broad-scale patterns and processes.

Land use

Land use patterns are changing rapidly in many parts of North America. In Canada and the United States, recreation and watershed protection increasingly trump livestock production as the most economically valuable product of many rangelands. In Mexico, migration and privatization of communal lands is creating new challenges. Agricultural land abandonment in semiarid regions of central Mexico is leading to an increase in rangeland area. In all three countries, the dynamic nature of land use and the unpredictability of future land uses are contributing to a shift away from a focus on specific values. Instead, governments and individual land managers are increasingly interested in monitoring changes in the overall health of the land and its capacity to resist and recover from degradation. We predict that this trend will continue, and that the first attempts to assess and monitor ecosystem health [25, 28, 29] will be enhanced or replaced in order to more effectively address the advances in ecological theory addressed above.

Protocol standardization

The public is becoming increasingly less tolerant of the inability to combine or even compare monitoring data collected by different organizations and, in many cases, even by the same organization. In some cases, data incompatibility is due to the need to address different monitoring objectives in different ecosystems. For the most part, however, it is due to a lack of communication and coordination. For example "cover" is one of the most commonly reported monitoring indicators, but different methods for measuring cover results in different estimates. The NRI and most Department of Defence installations use a point-intercept method to generate foliar cover, while the FIA program uses subjective ocular estimates of canopy cover, which includes gaps within the plant canopy. Plant litter and standing dead biomass may or may not be included in cover estimates reported by the same organization. Fortunately, a number of bottom-up and top-down efforts are resulting in significant increases in data compatibility. In the United States, both the Sustainable Rangelands Round table and the Heinz Centre have developed standardized lists of biophysical and socioeconomic indicators. The USFS, BLM, and Natural Resource Conservation Service (NRCS) have joined together to develop an Ecological Site Description manual. Because these documents will include reference data that can be used for monitoring, they will create an incentive for individuals to adopt the standardized methods used to generate these data. We predict that the trend towards increasing protocol standardization within countries will continue, and that the growing number of workshops, scientific exchanges, and collaborative projects will eventually result in an ability to compare data across international borders.

Summary and Conclusions

Despite a long history of formal and informal monitoring in North America, none of the three countries discussed in this paper have developed a nationwide database or even standardized set of protocols. The lack of standardization, inadequately developed relationships between management objectives and monitoring protocols, and an emphasis on data collection rather than analysis and interpretation have limited the value of past monitoring efforts. Nevertheless, we are optimistic that new theory, protocols, and collaborative initiatives will increasingly allow individuals and organizations to develop high quality monitoring programs that are relevant to policy and management. These programs must use standardized methods so that the data can be integrated and compared across jurisdictional boundaries and at appropriate scales, while allowing for the flexibility necessary to address new threats and opportunities.

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Pastizales y producción animal en las zonas áridas de Argentina

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Resumen

Las tierras áridas de Argentina abarcan alrededor de 108 millones de hectáreas, es decir, el 39% del área continental del país. La diversidad de características ambientales deriva de la vasta extensión latitudinal del país. La provisión de agua para bebida del ganado es generalmente inadecuada. La vegetación muestra cierto grado de degradación por sobrepastoreo, extracción de leña e incendios. Aproximadamente el 59% de las ovejas, el 52% de las cabras y el 96% de llamas (*Lama glama*), vicuñas (*Vicugna vicugna*) y alpacas (*Lama pacos*) existentes en el país se encuentran en la zona arida. La densidad de ganado domistico y fauna es de 2,4 UA km^2. Los sistemas de producción dominantes son cría de terneros, carne de caprinos y lana de ovejas. La cantidad de crías logradas al destete es de 47% (terneros), 80-160% (cabritos) y 40-80% (corderos). Las especies de la fauna compiten por el forraje y el agua con las del ganado doméstico y algunas enfermedades son comunes a ambas.

Palabras llaves : zona árida, Argentina, ganado, producción animal, pastoreo, pastoralismo, enfermedades animales.

Résumé

Productions pastorale et animale dans les zones arides d'Argentine

Les terres arides d'Argentine couvrent environ 108 millions d'hectares, c'est-à-dire 39 % du secteur continental du pays. La diversité caractéristique de cet environnement est liée à son étendue en latitude. L'approvisionnement en eau du bétail est généralement insuffisant. La végétation témoigne d'une certaine dégradation due au surpâturage et à l'exploitation du bois. Environ 59 % des moutons, 52 % des chèvres et 96 % des llamas (*Lama glama*), vigognes (*Vicugna vicugna*) et alpagas (*Lama pacos*) du pays se trouvent en zone aride. La densité du bétail domestique et de la faune est de 2,4 UA/km^2. L'élevage de veaux et de chevreaux pour la production de viande et de moutons pour la production de laine constitue le système de production dominant. Quarante-sept pour cent des veaux atteignent le sevrage alors que le taux est de 80 à 160 % pour les chevreaux et de 40 à 80 % pour les agneaux. La faune est en concurrence avec le bétail domestique pour la nourriture et l'eau ; ils sont confrontés aux mêmes types de problèmes sanitaires.

Mots clés : zone aride, Argentine, élevage, production animale, bétail, maladie animale, pastoralisme.