*Journal of Arid Environments* (2000) **45:** 289–304
doi:10.1006/jare.2000.0645, available online at http://www.idealibrary.com on IDEAL®

# Indicators of Great Basin rangeland health

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*(Received 6 October 1998, accepted 30 March 2000)*

Early-warning indicators of rangeland health can be used to estimate the functional integrity of a site and may allow sustainable management of desert rangelands. The utility of several vegetation canopy-based indicators of rangeland health at 32 Great Basin rangeland locations was investigated. The indicators were originally developed in rangelands of the Chihuahuan Desert. Soil resources are lost through wind and water-driven erosion mainly from areas unprotected by plant canopies (i.e. bare soil). Study sites in Idaho had the smallest bare patches, followed by sites in Oregon. The more arid Great Basin Sagebrush Zone sites in Utah had the largest bare patches. Several vegetational indicators including percent cover by vegetation, percent cover by life-form, percent cover by sagebrush, and percent cover by resilient species were negatively related to mean bare patch size and are potential indicators of Great Basin rangeland condition. Plant community composition and the range of bare patch sizes were different at sites in the three locations in Idaho, Oregon and Utah. Therefore, expected indicator values are location specific and should not be extrapolated to other locations. The condition of study sites were often ranked differently by different indicators. Therefore, the condition of rangeland sites should be evaluated using several indicators.



**Keywords:** bare patch size; vegetation cover; forb; grass; shrub; resilience; resistance; relative preference index; sagebrush

## Introduction

Effects of human activity on ecosystems worldwide have prompted efforts to better manage natural resources to avoid irreversible damage. Unfortunately, in most cases, by the time landscape deterioration is detected ecosystem function is already acutely compromised (e.g. Pechanec *et al.*, 1937; de Soyza *et al.*, 1998). At an advanced stage of deterioration, merely removing the anthropogenic stressors is usually

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insufficient to halt or even slow the continuing processes of degradation. In order to sustainably manage an ecosystem, early changes in ecosystem function, structure and composition must be detected. Therefore, a rangeland health monitoring system must detect changes in features of the ecosystem, i.e. indicators that are sensitive to environmental stress, that focus on the risk of ecosystem degradation, and that are related to ecosystem function (Herrick & Whitford, 1995; de Soyza *et al.*, 1998; Whitford *et al.*, 1998).

Rangelands of the 11 western states of the U.S.A. occur mainly in four desert ecosystems: Chihuahuan, Sonoran, Mojave and Great Basin. These deserts differ functionally because of differences in the spatial and temporal distribution of soil and water resources within the ecosystems (Schlesinger *et al.*, 1990), and each desert is characterized by a unique suite of climatic, vegetational and soil characteristics.

The vegetation of the Chihuahuan Desert has changed substantially over the past century (e.g. Buffington & Herbel, 1965). Rangeland ecosystem degradation in the Chihuahuan Desert is ascribed to combinations of environmental (e.g. recurrent drought) and anthropogenic factors such as over-grazing. Evidence for the causal impact of grazing stressors on rangeland degradation comes from comparisons between sites not grazed by livestock and adjacent livestock-grazed pastures (e.g. de Soyza *et al.*, 1997). Using information from these comparisons and from grazing gradients on the Jornada Experimental Range in the Chihuahuan Desert, several sensitive early-warning indicators of ecosystem degradation have been developed (de Soyza *et al.*, 1998; Whitford *et al.*, 1998). These indicators included the proportion of spreading 'long-lived' grasses such as *Bouteloua eriopoda* (black gramma), the overall cover by perennial vegetation, and the proportion of vegetation that is composed of invasive shrub species such as *Larrea tridentata* and *Prosopis glandulosa*. The presence of spreading grasses indicates the ability of an area to quickly re-cover recently induced bare patches while overall vegetation cover describes the proportion of land that has some degree of protection from wind- and water-driven erosion. The proportion of invasive shrub species present at a site indicates the potential for shrub cover, and concomitantly for resource-losing bare patches to increase. While the proportion of bare soil (the inverse of vegetation cover) is important, bare patch size is a better indicator of an area's ability to lose soil and water resources.

The Great Basin Desert is a cold desert with winter precipitation mostly as snow and characterized by the almost ubiquitous occurrence of sagebrush, *Artemisia* species. While Great Basin ecosystems are considered to be dominated by shrubs or by a combination of shrubs and grasses, many Chihuahuan Desert ecosystems are considered to be perennial grasslands. With the exception of the somewhat sandier soils of the southern areas, Great Basin soils tend to be heavier and stonier than Chihuahuan Desert soils (MacMahon, 1985). Although there are obvious differences in the structure and functioning of warm deserts and cold deserts, researchers in Great Basin ecosystems have also recognized the importance of environmental and anthropogenic factors, such as drought and overgrazing, in driving ecosystem deterioration (e.g. Pechanec *et al.*, 1937). While the indicators developed in the Chihuahuan Desert worked well in Chihuahuan Desert ecosystems (e.g. de Soyza *et al.*, 1998; Whitford *et al.*, 1998), their sensitivity and applicability in other rangeland ecosystems is untested. In this paper the results of applying several indicators developed in the Chihuahuan Desert to rangelands in the Great Basin are presented.

## Methods

### *Study sites*

Study sites in the Great Basin were selected which met the criteria of having a known recent livestock grazing history and of being adjacent to ungrazed areas with similar topography and soil type. Sixteen grazed and ungrazed pairs of sites (32 sites) in three states, Oregon (five pairs of sites), Idaho (four pairs of sites) and Utah (seven pairs of sites) were identified. All sites in Oregon were on the Northern Great Basin Experimental Range (NGBER), near Burns, Oregon. Sites in Idaho were on the U.S. Sheep Experiment Station (USSES), near Dubois, Idaho, and on the Idaho National Engineering and Environmental Laboratory (INEEL) near Idaho Falls, Idaho. The Utah study sites were on the Desert Experimental Range (DER) near Milford, Utah. The pastures and ungrazed exclosures of the NGBER were established in 1936; the USSES and INEEL exclosures were established between 1935 and 1950; and the DER exclosures in 1934.

### *Line transects and plant canopy*

During June and July 1995 a 100 × 100 m plot was established at each of the sites, within which parallel, 100 m transect lines were placed, 10 m apart. All lines were oriented down the dominant slope of the landscape. Along each line a 50 m segment (0–50 or 50–100 m) was randomly selected and measurements were taken along that segment. The lengths and species identities of plant canopies and unvegetated (bare) patches intercepted by the line were recorded (see Canfield, 1941). Using the line transect intercepts we calculated the mean size and proportion of unvegetated (bare soil) patches at each site and calculated a bare patch index ($BPI_c$) which was calculated as:

$$BPI_c = B_{\text{mean}} \times \Sigma B / \Sigma L$$

where $B_{\text{mean}}$ = mean size of bare patches at a site, $\Sigma B$ is the total bare soil, and $\Sigma L$ is the total length of the transect (de Soyza *et al.*, 1998).

Percent cover by life-form (grass, forb, shrub and tree), percent cover by species able to reproduce vegetatively (e.g. from root segments), species resistant to grazing (e.g. due to toxicity) and resilient species (able to recover from damage) were calculated. Since Great Basin ecosystems are often dominated by *Artemisia* species (sagebrush), percent canopy cover of sagebrush at each site was calculated, and regression analysis was used to investigate its relationship with grass and forb cover. Species were assigned to categories (Table 1) based on plant structure, chemical composition and phenology (Stubbendieck *et al.*, 1993). A relative preference index (RPI) (de Soyza *et al.*, 1998) was also calculated for all species at a site:

$$\text{RPI} = \Sigma (FV \times T_{pal}) C$$

where $FV$ = forage value of species (Stubbendieck *et al.*, 1991) where good = 1, fair = 0·75, poor = 0·25 and none = 0; $T_{pal}$ = proportion of year when species is preferred; and $C$ = canopy cover of plant species.

## Results

All three indicators of bare patches varied substantially among locations (Idaho, Oregon, and Utah) and the study sites (Table 2). Mean bare patch size varied by up to 397%; percent bare soil by up to 238%; and $BPI_c$ by up to 1200% among all sites (Table 2). In general, $BPI_c$ was largest at sites in Utah, smallest at sites in Idaho, and intermediate at sites in Oregon.

At sites within each location, percent vegetation cover appeared to decrease with increase in bare patch size, and percent vegetative cover was highest at sites in Idaho, intermediate in Oregon, and lowest at sites in Utah (Fig. 1(a)). Grasses, forbs and shrubs were the most common life-forms at the study sites. Trees occurred on only one

**Table 1.** *List of the 104 perennial plant species encountered on Great Basin study sites and the various indicator categories to which they were assigned. Shrubs and subshrubs were merged into a single shrub category for indicator analysis. A blank cell in the Vegetative, Resilient or Resistant categories indicates that the plant species did not fall into that category.* ⋆*indicates species assigned to* Artemisia *(sagebrush) category*

| Species | Life-form | Vegetative | Resilient | Resistant |
|---|---|---|---|---|
| *Achillea millefolium* L. (Asteraceae) | Forb | Yes | | |
| *Agropyron cristatum* (L.) (Poaceae) | Grass | Yes | Yes | |
| *A. smithii* Rydb. (Poaceae) | Grass | Yes | Yes | |
| *Agroseris glauca* (Pursh) D. Dietr (Asteraceae) | Forb | | Yes | |
| *Allium acuminatum* Hook. (Liliaceae) | Forb | | Yes | |
| *Antennaria dimorpha* (Nuttall) (Asteraceae) | Forb | | | |
| *A. rosea* Greene (Asteraceae) | Forb | | | |
| *Arenaria franklinii* Dougl. (Caryophyllaceae) | Forb | | | |
| *Arnica fulgens* Pursh. (Asteraceae) | Forb | | | |
| *Arabis holboellii* Hornem. (Brassicaceae) | Forb | | | |
| *Aristida purpurea* Nutt. (Poaceae) | Grass | | Yes | |
| *Artemisia arbuscula* Nutt. var. arbuscula (Asteraceae) | Shrub⋆ | | Yes | |
| *A. nova* A. Nels. (Asteraceae) | Shrub⋆ | | Yes | |
| *A. spinescens* D.C. Eaton (Asteraceae) | Shrub⋆ | | Yes | |
| *A. tripartita* Rydb. (Asteraceae) | Shrub⋆ | | Yes | |
| *A. tridentata* Nutt. (Asteraceae) | Shrub⋆ | | Yes | |
| *Astragalus calycosus* Torr. (Fabaceae) | Forb | | Yes | Yes |
| *A. convallarius* Greene (Fabaceae) | Forb | | Yes | Yes |
| *A. curvicarpus* (A. Hell.) Macbr. (Fabaceae) | Forb | | Yes | Yes |
| *A. filipes* Torr. (Fabaceae) | Forb | | Yes | Yes |
| *A. lentiginosus* Dougl. ex Hook. (Fabaceae) | Forb | | Yes | Yes |
| *A. mollissimus* Torr. (Fabaceae) | Forb | | Yes | Yes |
| *Atriplex bonnevillensis* C.A. hanson (Chenopodiaceae) | Shrub | | | |
| *A. confertifolia* (Torr. & Frem.) Wats. (Chenopodiaceae) | Shrub | | Yes | |

**Table 1.** *Continued.*

| Species | Life-form | Vegetative | Resilient | Resistant |
|---|---|---|---|---|
| *A. falcata* (M.E. Jones) Standl. (Chenopodiaceae) | Subshrub | | Yes | |
| *Balsamorhiza sagittata* (Pursh) Nutt. (Asteraceae) | Forb | | | |
| *Castilleja angustifolia* (Nutt.) G. Don (Scrophulariaceae) | Forb | | Yes | |
| *Calochortus macrocarpus* Dougl. (Liliaceae) | Forb | | | |
| *Chenopodium* sp. (Chenopodiaceae) | Forb | | | |
| *Chrysothamnus greenei* (Gray) Greene (Asteraceae) | Shrub | | | |
| *C. nauseosus* (Pall.) Britt. (Asteraceae) | Shrub | Yes | | |
| *C. viscidiflorus* (Hook.) Nutt. (Asteraceae) | Shrub | | | |
| *Collinsia parviflora* Lindl. (Scrophulariaceae) | Forb | | | |
| *Comandra umbellata* (L.) Nutt. (Santalaceae) | Forb | | | |
| *Crepis acuminata* Nutt. (Asteraceae) | Forb | | | |
| *Cryptantha interrupta* (Greene) Pays. (Boraginaceae) | Forb | | | |
| *Crepis occidentalis Nutt.* (Asteraceae) | Forb | | | |
| *Delphinium menziesii* (Ranunculaceae) | Forb | | | Yes |
| *Elymus elymoides* (Raf.) Sweezy (Poaceae) | Grass | Yes | Yes | |
| *E. lanceolatus* (Scribn. & Smith) Gould (Poaceae) | Grass | | Yes | |
| *Erigeron caudatus* (Asteraceae) | Forb | | | |
| *Erigeron filifolius* Nutt. (Asteraceae) | Forb | | | |
| *E. linearis* (Asteraceae) | Forb | | | |
| *Eriogonum caespitosum* Nutt. (Polygonaceae) | Subshrub | | | |
| *E. heracleoides* Nutt. (Polygonaceae) | Subshrub | | | |
| *E. microthecum* Nutt. (Polygonaceae) | Subshrub | | | |
| *E. ovalifolium* Nutt. (Polygonaceae) | Forb | | | |
| *E. sphaerocephalum* (Polygonaceae) | Forb | | | |
| *E. umbellatum* Torr. (Polygonaceae) | Subshrub | | | |
| *Eriogonum* sp. (Polygonaceae) | Forb | | | |

**Table 1.** *Continued.*

| Species | Life-form | Vegetative | Resilient | Resistant |
|---|---|---|---|---|
| *Erioneuron pilosum* (Buckl.) Nash (Poaceae) | Grass | | Yes | |
| *Erigeron pumilus* Nutt. (Asteraceae) | Forb | | | |
| *Grayia spinosa* (Hook.) Moq. (Chenopodiaceae) | Shrub | | Yes | |
| *Gutierrezia sarothrae* (Pursh) Britt. and Rusby (Asteraceae) | Subshrub | | Yes | |
| *Hedysarum boreale* Nutt. (Fabaceae) | Forb | | | |
| *Hilaria jamesii* (Torr.) Benth. (Poaceae) | Grass | Yes | Yes | |
| *Ipomopsis congesta* (Hook.) V. Grant (Polemoniaceae) | Forb | | | |
| *Iva axillaris* Pursh (Asteraceae) | Forb | | | |
| *Juniperus occidentalis* Engelm. (Cupressaceae) | Tree | | | Yes |
| *Kochia americana* Wats. (Chenopodiaceae) | Subshrub | | | |
| *Koeleria macrantha* (Ledeb.) J.A. Schult. (Poaceae) | Grass | Yes | Yes | |
| *Krascheninnikovia lanata* (Pursh) Guldenstaedt (Chenopod.) | Shrub | | | |
| *Leymus cinereus* (Scribn. & Merr.) A. Love (Poaceae) | Grass | Yes | | |
| *L. flavescens* (Scribn. & Smith) Pilger (Poaceae) | Grass | Yes | | |
| *Leptodactylon pungens* (Torr.) Nutt. (Polemoniaceae) | Subshrub | | | |
| *Lomatium dissectum* (Nutt.) Math. and Const. (Apiaceae) | Forb | | | |
| *L. macrocarpum* (Hook. & Arnott) Coulter and Rose (Apiaceae) | Forb | | | |
| *L. nevadense* (Wats.) Coult. & Rose (Apiaceae) | Forb | | | |
| *L. triternatum* (Pursh) Coult. & Rose (Apiaceae) | Forb | | | |
| *Lupinus argenteus* Pursh (Fabaceae) | Forb | | | |
| *L. burkei* S. Wats. (Fabaceae) | Forb | | | |
| *L. lepidus* Dougl. (Fabaceae) | Forb | | | |
| *Lygodesmia grandiflora* (Nutt.) T. & G. (Asteraceae) | Forb | | | |

**Table 1.** *Continued.*

| Species | Life-form | Vegetative | Resilient | Resistant |
|---|---|---|---|---|
| *Machaeranthera canescens* (Pursh) Gray (Asteraceae) | Forb | | | |
| *Oenothera pallida* Lindl. (Onagraceae) | Forb | | | |
| *Opuntia polyacantha* Haw. (Cactaceae) | Succulent | Yes | Yes | Yes |
| *O. pulchella* Engelm. (Cactaceae) | Succulent | Yes | Yes | Yes |
| *Oryzopsis hymenoides* (R. & S.) Ricker in Piper (Poaceae) | Grass | Yes | Yes | |
| *Pascopyrum smithii* (Rydb.) A. Love (Poaceae) | Grass | Yes | Yes | |
| *Penstemon cyananthus* Hook. (Scrophulariaceae) | Forb | | | |
| *P. speciosus* (Scrophulariaceae) | Forb | | | |
| *Phlox hoodii* Rich. (Polemoniaceae) | Forb | | | |
| *P. longifolia* Nutt. (Polemoniaceae) | Forb | | | |
| *Poa nevadensis* Vasey (Poaceae) | Grass | Yes | Yes | |
| *P. secunda* Presl. (Poaceae) | Grass | Yes | Yes | |
| *Prunus* sp. (Rosaceae) | Shrub | | | |
| *Psoralidium lanceolatum* (Pursh.) Rydb. (Fabaceae) | Forb | | | |
| *Pseudoroegneria spicata* (Pursh) A. Love (Poaceae) | Grass | Yes | Yes | |
| *Purshia tridentata* (Pursh) D.C. (Rosaceae) | Shrub | | | |
| *Ribes cereum* Dougl. (Saxifragaceae) | Shrub | | | |
| *Schoenocrambe linifolia* (Nutt.) Greene (Brassicaceae) | Forb | | | |
| *Senecio integerrimus* Nutt. (Asteraceae) | Forb | | | |
| *Sporobolus contractus* A.S. Hitchc. (Poaceae) | Grass | Yes | Yes | |
| *S. cryptandrus* (Torr.) Gray (Poaceae) | Grass | Yes | Yes | |
| *Sphaeralcea grossulariifolia* (H. & A.) Rydb. (Malvaceae) | Forb | Yes | | |
| *S. munroana* (Dougl.) Spach (Malvaceae) | Forb | Yes | | |
| *Stipa comata* Trin. & Rupr. (Poaceae) | Grass | Yes | Yes | |
| *S. thurberiana* Piper (Poaceae) | Grass | Yes | Yes | |
| *Stellaria longipes Muhlenberg* (Caryophyllaceae) | Forb | | | |

**Table 1.** *Continued.*

| Species | Life-form | Vegetative | Resilient | Resistant |
|---|---|---|---|---|
| *Stephanomeria spinosa* (Nutt.) S. Tomb (Asteraceae) | Forb | | | |
| *Tetradymia canescens* DC. (Asteraceae) | Shrub | | | |
| *T. spinosa* H. & A. (Asteraceae) | Shrub | | | |
| *Townsendia florifer* (Hook.) Gray (Asteraceae) | Forb | | | |
| *Viola nuttallii* Pursh. (Violaceae) | Forb | | | |

site (> 1% cover) and cover by succulent life-forms was always less than 1% and were therefore excluded from further analyses. Grasses accounted for less than 20% of total cover at all sites. No consistent differences were found in the percent grass cover among sites in Idaho, Oregon, or Utah, and percent grass cover did not change substantially with increase in bare patch size (Fig. 1(b)). Forbs accounted for over 30% of total cover at one site in Idaho, but accounted for less than 20% at all other sites. Forbs were a larger component of the vegetation at the Idaho and Oregon sites than at the Utah sites (Fig. 1(c)). With the exception of one site in Idaho where forbs dominated, shrubs were the largest component of vegetation cover at the Idaho and Oregon sites (Fig. 1(d)). At the Utah location grasses were the dominant life-form at six sites while shrubs dominated at the other eight sites, and percent shrub cover appeared to decrease with increase in bare patch size. There were few species of long-lived grass (see de Soyza *et al.*, 1998) at the sites studied, percent cover was low (> 1%), and no patterns with mean bare patch size were found.

There were different relationships between sagebrush canopy cover and grass and forb canopy cover at the three locations (Fig. 2). Simple linear regression models indicated that there were no relationships between grass ($p = 0{\cdot}334$) or forb cover ($p = 0{\cdot}582$) and sagebrush cover at the Oregon sites (Fig. 3(a)), but at the Idaho sites increase in sagebrush cover was related to a decrease in grass ($p = 0{\cdot}019$) and forb ($p = 0{\cdot}037$) cover (Fig. 3(b)). At the Utah sites, increase in sagebrush cover was related to increased forb cover ($p = 0{\cdot}005$), but there was no relationship with grass cover ($p = 0{\cdot}629$) (Fig. 3(c)). There appears to be an overall pattern of declining percent sagebrush cover with increasing mean bare patch size (Fig. 2).

The secondary indicators for each site gave mixed results. Percent cover of vegetative reproducers was highest at sites in Oregon and lower at sites in Idaho and Utah, yielding a modal pattern when all three locations were plotted against mean bare patch size (Fig. 4(a)). Percent cover of resilient species was highest at sites in Idaho, and lowest at sites in Utah, yielding a pattern of declining percent cover of resilient species as bare patch size increased (Fig. 4(b)). Percent cover of resistant species was very variable within and among locations and showed no patterns with changing mean bare patch size (Fig. 4(c)). The relative preference index indicator was highest at sites in Idaho, followed by Oregon, and Utah, resulting in a pattern of decreasing RPI with increasing bare patch size (Fig. 5).

Finally, in order to compare the differences among indicators we ranked sites by the values calculated for each indicator (Table 3). The mean bare patch size and percent vegetation indicators (life-form categories) were somewhat similar, as were percent shrub and percent cover of sagebrush, but there were often large differences among these and all other indicators (Table 3).

**Table 2.** *Study sites arranged in sequence of increasing mean bare patch size. Also shown is the corresponding bare ground percentage of the site and the bare patch index for each site. The rank of each site on the basis of $BPI_c$ is shown within parentheses in the $BPI_c$ column*

| Site | Mean bare (cm) | Percent bare (%) | $BPI_c$ (rank) |
|---|---|---|---|
| ID1B | 16·55 | 36·98 | 6·12 (1) |
| ID2B | 22·04 | 46·55 | 10·26 (2) |
| ID1A | 25·03 | 50·81 | 12·72 (3) |
| ID4B | 26·43 | 52·04 | 13·75 (4) |
| ID4A | 27·65 | 55·2 | 15·26 (6) |
| ID2A | 28·06 | 55·77 | 15·65 (7) |
| ID3B | 28·47 | 51·04 | 14·53 (5) |
| ID3A | 30·54 | 59·65 | 18·22 (9) |
| OR5A | 30·57 | 70·03 | 21·41 (10) |
| OR6B | 31·49 | 54·07 | 17·03 (8) |
| OR1A | 33·97 | 63·53 | 21·58 (11) |
| OR3A | 34·71 | 70·94 | 24·62 (14) |
| OR4B | 36·25 | 61·97 | 22·46 (12) |
| OR4A | 36·61 | 71·27 | 26·09 (16) |
| OR3B | 38·59 | 68·96 | 26·61 (17) |
| OR6A | 39 | 72·62 | 28·32 (18) |
| OR5B | 39·08 | 65·57 | 25·62 (15) |
| OR1B | 40·51 | 57·61 | 23·34 (13) |
| UT6A | 41·28 | 80·41 | 33·19 (19) |
| UT1B | 46·23 | 72·64 | 33·58 (20) |
| UT5B | 50·46 | 84·11 | 42·44 (21) |
| UT7B | 52·7 | 82·42 | 43·53 (22) |
| UT3A | 53·33 | 87·97 | 46·91 (26) |
| UT7A | 54·69 | 83·28 | 45·55 (23) |
| UT1A | 56·62 | 82·75 | 46·85 (24) |
| UT4B | 56·77 | 82·56 | 46·87 (25) |
| UT3B | 60·08 | 85·81 | 51·55 (28) |
| UT2A | 62·78 | 80·94 | 50·81 (27) |
| UT5A | 66·21 | 87·83 | 58·15 (29) |
| UT6B | 69·3 | 85·03 | 58·93 (30) |
| UT4A | 74·26 | 88·27 | 65·55 (31) |
| UT2B | 88·52 | 84·93 | 75·18 (32) |

## Discussion

Several indicators of rangeland ecosystem health which were developed in northern Chihuahuan Desert ecosystems worked to different degrees at three locations in the Great Basin. In some cases the values of indicators changed in the predicted manner when plotted against mean size of bare patch, which we used as a surrogate measure for ecosystem condition. However, predictivity was not extremely high, perhaps because the three locations (Idaho, Oregon and Utah) had different plant community compositions. In the absence of evidence to suggest that the three locations had similar vegetational, soil and climatic characteristics when ecosystem deterioration began, we cannot justify the assumption that the vegetation of sites at one location (e.g. Idaho) will respond similarly to vegetation at sites of another location (e.g. Oregon or Utah) when bare patch size increases. Therefore, while plots of sites from all locations suggest

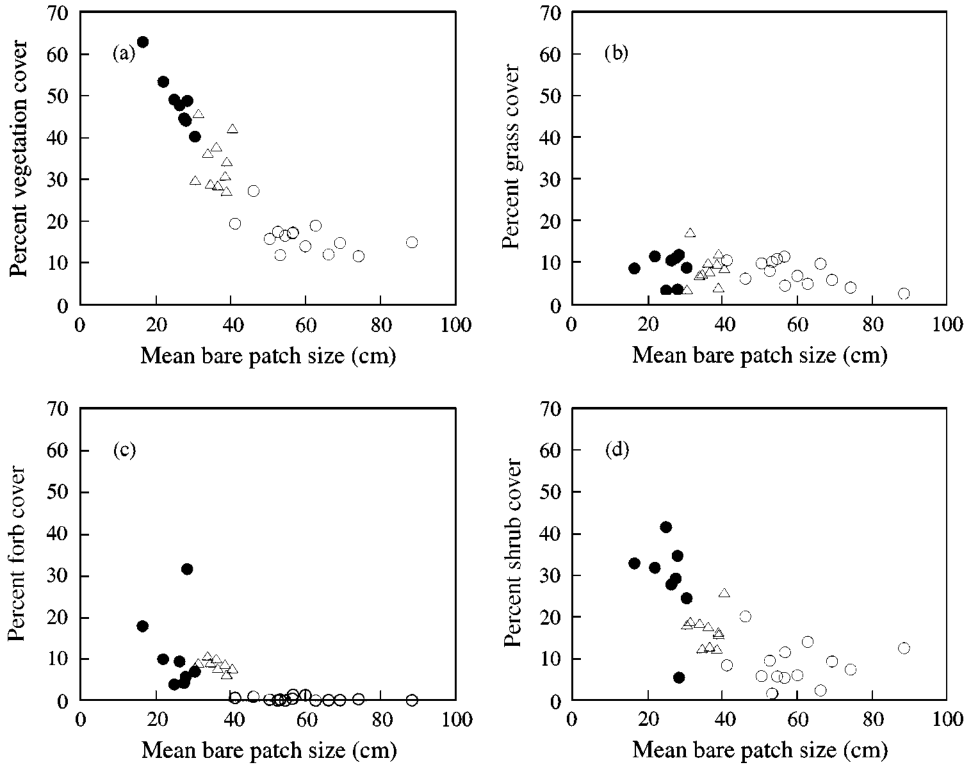


**Figure 1.** Effects of increasing mean bare patch size on four vegetation-based indicators at each study site. (a) Percent cover of all vegetation; (b) percent grass cover; (c) percent forb cover; and (d) percent shrub cover. Sub-shrubs were included in the shrub category: ● Idaho; △ Oregon; ○ Utah.

a general pattern of change, further study is needed before we can predict indicator responses beyond the bare patch size limits measured for each location.

We consider rangeland ecosystem health to be primarily related to the ability of an ecosystem to conserve its soil resources and to retain and store water resources (Herrick & Whitford, 1995). Resource loss is likely to be higher in areas of bare soil because the erosional effects of wind and water are greatest where the soil surface is not protected by a plant canopy. Therefore, bare patch size, by virtue of its direct relationship with the potential for resource loss, is probably one of the best indicators of rangeland ecosystem health. The indicators for the warm-desert ecosystems of the Chihuahuan Desert were developed specifically for ecosystems where both wind and water play a major role in resource loss. In many ecosystems of the Great Basin, where much of the precipitation occurs as snow, water-driven resource loss may be somewhat less important than in the Chihuahuan Desert. However, bare patches are also important in wind-driven erosion of resources. Wind erosion can be described by the Wind Erosion Prediction System model (Skidmore, 1986) in which wind fetch or unvegetated (bare) patch size is the most important variable determining the magnitude of erosion.

Indicators of ecosystem health that are based on vegetational characteristics depend on the responses of plants to changes in the temporal and spatial availability of soil and water resources, and these changes are often related to the size and frequency of bare soil patches. It was found that the general pattern was that an increase in bare patch size

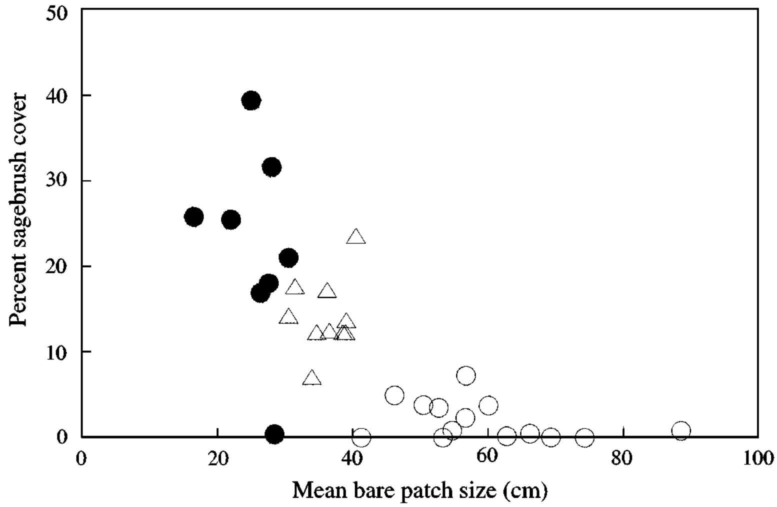


**Figure 2.** Effects of increasing mean bare patch size on percent cover by sagebrush species (see Table 3) at each study site: ● Idaho; △ Oregon; ○ Utah.

corresponded to a decrease in vegetation cover. This suggests that as the condition of a site deteriorates vegetation loss occurs mainly along the periphery of bare patches, resulting in larger bare patches.

While bare patch size may determine erosion rates, vegetational changes may provide an even earlier indicator of the potential for ecosystem deterioration. For example, in the Chihuahuan Desert, a high percentage of cover by long-lived perenial grasses indicates a high potential for a site to recover from periods of stress, i.e. the ability to re-establish a vegetative cover over bare patches generated during a period of environmental stress. However, a decrease in long-lived grass cover together with an increase in, for example, short-lived grass cover may result in bare patch size and percent vegetation cover remaining approximately the same but with the site having a reduced ability to recover from periods of stress (reduced resilience). Unfortunately, long-lived grasses were rare at the sites we studied and we were unable to identify indicators with similar responses at the Great Basin study sites.

The percent cover due to vegetative reproducers is a measure of site resilience to degradation and it is also a component of a more general indicator of resilience. Resilient species included vegetative reproducers and species with protected meristems which enables quick recovery of canopy cover. While cover by vegetative reproducers was greatest at sites with intermediate-sized bare patches (Oregon) overall site resilience was greatest at the sites with small bare patches (Idaho). Thus, the relative contributions of protected meristems and vegetative reproducers to the resilience of a site appears to be different at the different locations, emphasizing the inappropriateness of assuming a continuum of indicator responses over all Great Basin plant communities.

There were differences in plant community composition among the study sites, and the relationships between the three community types (locations) and mean bare patch size were different. Sagebrushes are the definitive species of Great Basin ecosystems but they are naturally less common in salt-desert scrub ecosystems. Therefore, care is needed when interpreting life-form or species cover responses to changes in bare patch size. This was illustrated in the relationships between sagebrush and grass or forb cover at the three locations. The expected pattern of higher sagebrush cover corresponding to a lower grass or forb cover (e.g. Baxter, 1998) was found only at sites

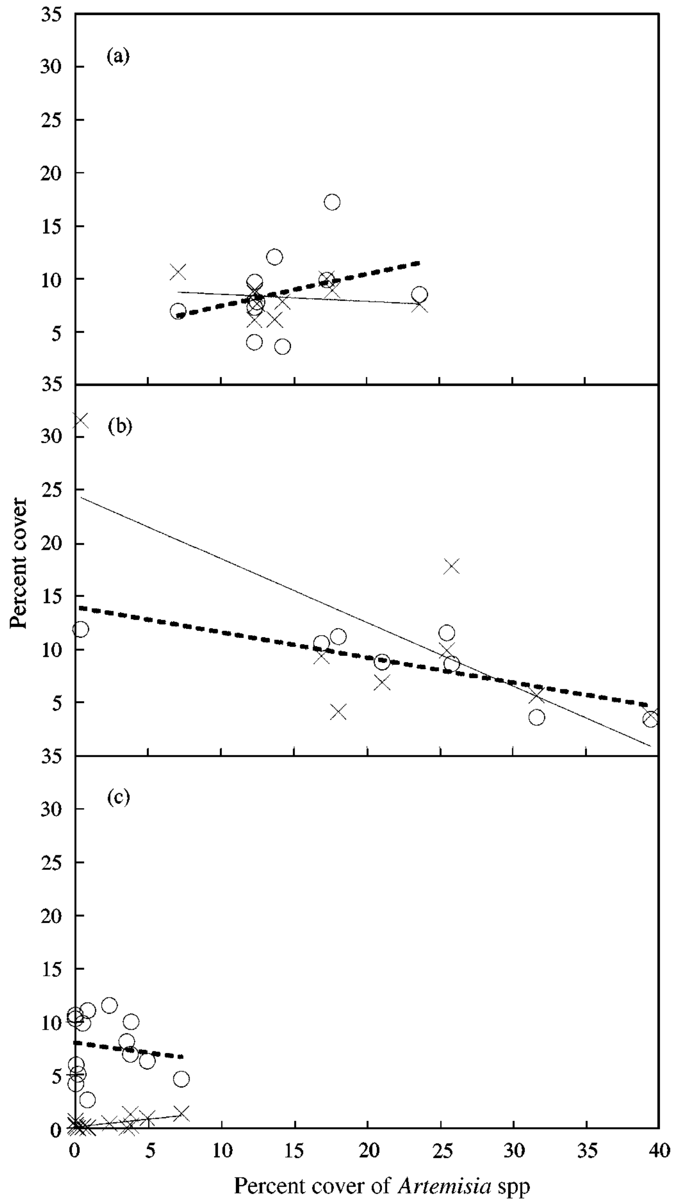


**Figure 3.** Percent cover by three vegetational functional groups at each study site. (a) Plants with the ability to reproduce vegetatively; (b) species resilient to physical damage; (c) species resistant to grazing (see Table 3). Study sites are arranged in order of increasing mean bare patch size: (a) Grass: $r^2 = 0{\cdot}12$, $p = 0{\cdot}334$; Forb: $r^2 = 0{\cdot}04$, $p = 0{\cdot}582$; (b) Grass: $r^2 = 0{\cdot}63$, $p = 0{\cdot}019$; Forb: $r^2 = 0{\cdot}54$, $p = 0{\cdot}037$; (c) Grass: $r^2 = 0{\cdot}02$, $p = 0{\cdot}629$; Forb: $r^2 = 0{\cdot}49$, $p = 0{\cdot}005$.

in Idaho where sagebrush cover was highest. The effect of increasing sagebrush cover and decreasing grass cover has been attributed to heavy spring grazing by livestock (Mueggler, 1950; Laycock, 1967).

The absence of a general pattern within locations or over all sites for the resistant cover indicator suggests that this indicator, in its current form, is not very useful for

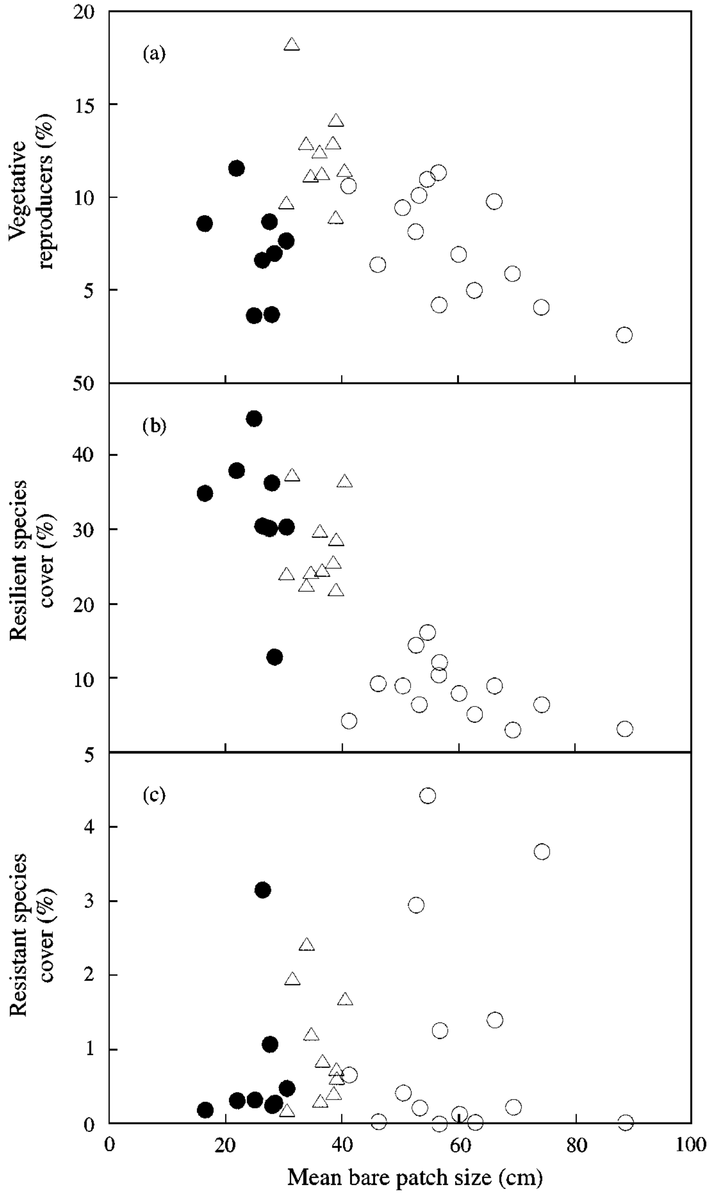


**Figure 4.** Relationships between sagebrush cover and grass or forb cover at sites in (a) Oregon, (b) Idaho, and (c) Utah. Regression lines are based on a simple linear model and coefficients of determination ($r^2$) are shown: ● Idaho; △ Oregon; ○ Utah.

Great Basin sites. However, the relative preference index indicator, which worked well in Chihuahuan Desert sites (de Soyza *et al.*, 1998), showed a general decreasing pattern with increasing bare patch size. In rangelands, plant material palatable to livestock is essential. A low relative preference index indicates that a site has low potential for grazing by livestock. This may be because of natural species composition or it may be an indicator that a site has been over-grazed and be susceptible to further degradation. At

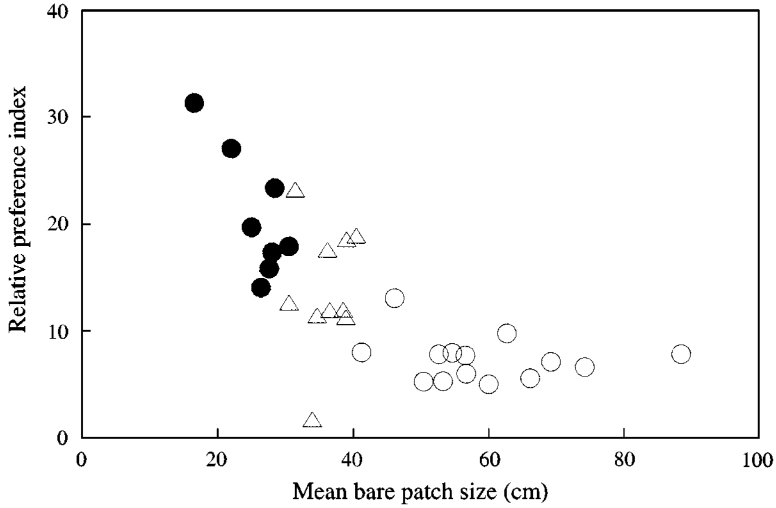


**Figure 5.** Effects of increasing mean bare patch size on the relative preference indices of the study sites: ● Idaho; △ Oregon; ○ Utah.

the Great Basin sites studied grazing did not consistently cause larger bare patches, less vegetation, or a lower RPI. This may be because Great Basin soils are somewhat resistant to physical disturbance associated with grazing, due to the presence of microphytic crust communities, or the continuing long-term effects of grazing prior to the establishment of the experimental exclosures. The current grazing system (season, intensity, stocking density and duration) may also affect the vegetation at a site (e.g. Kitchen & Hall, 1996) as may the species of livestock (cattle or sheep).

The general trends for indicator values were interspersed with values that were obvious outliers to the trend and different indicators ranked sites differently. Sites classified as 'degraded' by one indicator may be classified as 'not degraded' by another indicator. These outliers and differences in indicator values highlight the importance of not making decisions on ecosystem condition based on a single indicator.

We only measured cover by perennial plant species because the occurrence of annual plants in North American deserts is generally very variable seasonally and annually. Annual plant densities are low in the Chihuahuan Desert but in the Great Basin annual species are more common. The exotic annual cheatgrass (*Bromus tectorum*) may flourish on disturbed sites (e.g. Kitchen & Hall, 1996). In some cases the density of cheatgrass may be sufficient to carry a fire on rangelands where fire was not a part of the evolutionary history of the vegetation. Fire may further reduce perennial vegetation cover and result in increased wind and water erosion. Therefore, the cover of this exotic grass should probably be incorporated into the suite of early warning indicators for the Great Basin.

Each indicator focused on only a portion of the factors that determine the overall condition of a site. Different indicators may assess different aspects of ecosystem condition. Therefore, the overall condition of a site is best determined by considering several indicators. The cold desert ecosystems of the Great Basin may be less susceptible to water-driven erosion of soil resources but, overall, some indicators of ecosystem health developed in the northern Chihuahuan Desert also showed potential for use in the Great Basin. However, further studies must include assessments of the microphytic components of the soil and take into account the different physical and biological criteria affecting resource loss in cold desert ecosystems.

**Table 3.** *Great Basin study sites ranked on the basis of indicators. Mean bare (patch size) is ranked in ascending order while all other indicators are ranked in descending order, as appropriate for these indicators. % Sage = percent cover by sagebrush and % VR = percent cover by vegetative reproducers*

| Site | Indicators | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean bare | % Veg. | % Forb | % Grass | % Shrub | % Sage. | % VR | % Resil. | % Resist. | $RPI_c$ |
| ID1B | 1 | 1 | 2 | 16 | 3 | 3 | 19 | 6 | 27 | 1 |
| ID2B | 2 | 2 | 5 | 4 | 4 | 4 | 6 | 2 | 21 | 2 |
| ID1A | 3 | 3 | 18 | 31 | 1 | 1 | 31 | 1 | 19 | 5 |
| ID4B | 4 | 5 | 6 | 8 | 6 | 10 | 24 | 7 | 3 | 12 |
| ID4A | 5 | 7 | 17 | 6 | 5 | 7 | 18 | 9 | 11 | 11 |
| ID2A | 6 | 8 | 16 | 30 | 2 | 2 | 30 | 5 | 23 | 10 |
| ID3B | 7 | 4 | 1 | 3 | 29 | 27 | 22 | 20 | 22 | 3 |
| ID3A | 8 | 10 | 13 | 15 | 8 | 6 | 21 | 8 | 16 | 8 |
| OR5A | 9 | 15 | 10 | 29 | 12 | 11 | 15 | 15 | 26 | 14 |
| OR6B | 10 | 6 | 8 | 1 | 10 | 8 | 1 | 3 | 6 | 4 |
| OR1A | 11 | 12 | 3 | 21 | 11 | 18 | 4 | 16 | 5 | 32 |
| OR3A | 12 | 16 | 7 | 20 | 18 | 15 | 10 | 14 | 10 | 17 |
| OR4B | 13 | 11 | 4 | 11 | 13 | 9 | 5 | 10 | 20 | 9 |
| OR4A | 14 | 17 | 11 | 19 | 17 | 13 | 9 | 13 | 12 | 16 |
| OR3B | 15 | 14 | 9 | 13 | 20 | 14 | 3 | 12 | 17 | 15 |
| OR6A | 16 | 18 | 15 | 27 | 14 | 16 | 17 | 17 | 13 | 18 |
| OR5B | 17 | 13 | 14 | 2 | 15 | 12 | 2 | 11 | 15 | 7 |
| OR1B | 18 | 9 | 12 | 17 | 7 | 5 | 7 | 4 | 7 | 6 |
| UT6A | 19 | 20 | 22 | 9 | 24 | 32 | 12 | 30 | 14 | 20 |
| UT1B | 20 | 19 | 21 | 23 | 9 | 19 | 25 | 23 | 29 | 13 |
| UT5B | 21 | 26 | 26 | 12 | 27 | 20 | 16 | 25 | 18 | 30 |
| UT7B | 22 | 22 | 29 | 18 | 22 | 22 | 20 | 19 | 4 | 23 |
| UT3A | 23 | 31 | 25 | 10 | 32 | 31 | 13 | 27 | 25 | 29 |
| UT7A | 24 | 25 | 30 | 7 | 28 | 24 | 11 | 18 | 1 | 21 |
| UT1A | 25 | 24 | 23 | 5 | 30 | 23 | 8 | 22 | 32 | 24 |
| UT4B | 26 | 23 | 19 | 26 | 21 | 17 | 28 | 21 | 9 | 27 |
| UT3B | 27 | 29 | 20 | 22 | 26 | 21 | 23 | 26 | 28 | 31 |
| UT2A | 28 | 21 | 32 | 25 | 16 | 28 | 27 | 29 | 30 | 19 |
| UT5A | 29 | 30 | 28 | 14 | 31 | 26 | 14 | 24 | 8 | 28 |
| UT6B | 30 | 28 | 27 | 24 | 23 | 29 | 26 | 32 | 24 | 25 |
| UT4A | 31 | 32 | 24 | 28 | 25 | 30 | 29 | 28 | 2 | 26 |
| UT2B | 32 | 27 | 31 | 32 | 19 | 25 | 32 | 31 | 31 | 22 |

We would like to thank Laura Vogel, Hermi Hiatt, and Arthur Basher for their assistance in field data collection and without whom this study would not have been possible. Jim Glendon provided valuable field assistance at the Idaho study sites, and Kara Paintner assisted with plant identifications in Oregon. Quinn Jacobson assisted with determining species palatability and Dan Heggem assisted with project logistics. Thanks also to John Walker and Scott McCoy of the U.S. Sheep Experiment Station, Bob Breckenridge of the Idaho National Engineering and Environmental Laboratory, Tony Svejcar of the Northern Great Basin Experimental Range, Stan Kitchen of the Desert Experimental Range, and Mike Pellant of the Bureau of Land Management for their assistance with site logistics. Notice: The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, partially funded and collaborated in the research described here. It has been subjected to the Agency's peer review and has been approved as an EPA publication.

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