Rangeland Monitoring and Adaptive Management

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Introduction Rangeland monitoring data are expressed as three subscripts data, $D_{i,j,k}$, where $i=1, 2, \ldots m$, indicates species, $j=1, 2, \ldots n$, indicates samples, and $k=1, 2, \ldots o$, indicates times (Legendre & Legendre, 1998). Multi-Dimensional Sphere Model, MDSM (Bai, *et al*., 1997) is designed to discover the changing trends in these data. Model uses *m*-vectors, instead of matrix, to express rangeland: uses magnitude of the vector to express the total biomass, and uses direction of the vectors to express the composition of rangelands. In vector space, it is direction, instead of distances, that makes differences, but in rangeland science, it is the composition, instead of production, that makes differences. For example, three position vectors in shrub-grass 2-space, $\boldsymbol{A}=(1, 0)$, $\boldsymbol{B}=(0, 1)$, and $\boldsymbol{C}=(3, 0)$. $\boldsymbol{A}$ is closer to $\boldsymbol{B}$ than to $\boldsymbol{C}$, but $\boldsymbol{A}$ has same direction with $\boldsymbol{C}$, but orthogonal to $\boldsymbol{B}$. Model clusters $\boldsymbol{A}$ and $\boldsymbol{C}$ as shrubland, but $\boldsymbol{B}$ as grassland. In other words, vector space is a projective space, where $n\boldsymbol{A}=\mathbf{A}$ (*Bai*, et al., 2001).

Methods As collinear vectors have the same composition, rangeland vectors have to be standardized (normalized):

$$\boldsymbol{Y}'=\boldsymbol{Y}/|\boldsymbol{Y}|, \quad (1)$$

Where $\boldsymbol{Y}'$ are the state vectors of the rangelands, or the projection of the rangelands on the unit hyper-sphere, $\boldsymbol{Y}$ are the rangeland vectors, or a point in *m*-space, and $|\boldsymbol{Y}|$ is the vector length, the square root of the sum of the squares. Then, model uses time series to express the rangeland dynamics. It defines changing trends as present state over previous,

$$\boldsymbol{T}_k=\mathbf{Y}'_k/\mathbf{Y}'_{k-1}=(\mathbf{Y}_k/|\mathbf{Y}_k|)/(\mathbf{Y}_{k-1}/|\mathbf{Y}_{k-1}|), \quad (2)$$

Where, $\boldsymbol{T}_k$ are trends, $\boldsymbol{Y}_k$ are state vectors of rangelands, subscript k indicate times. The rangeland growth based on cell duplication is expressed as exponential growth, and trends can be used to project the next year' state (Zhao, et al., 1982),

$$\boldsymbol{P}_{k+1}=\boldsymbol{Y}_k * \boldsymbol{T}_k. \quad (3)$$

Where $\boldsymbol{P}_{k+1}$ are the projection of the next year based on given year' information, $\boldsymbol{Y}_k$ are the state of given year, $\boldsymbol{T}_k$ are the trends of given year. The projection can be modified by next year' actual samples to generate expectation of the next year, and this is so called Kalman filter (Jameson*, 1989):

$$\boldsymbol{E}_{k+1}=\alpha * \boldsymbol{P}_{k+1}+(\mathbf{1}-\alpha) * \boldsymbol{D}_{k+1}, \quad (4)$$

where $\boldsymbol{E}_{k+1}$ are expectation, $\boldsymbol{P}_{k+1}$ are projection based on previous year, $\boldsymbol{D}_{k+1}$ are new samples, and $0 \leqslant \alpha \leqslant \mathbf{1}$ is the weighing factor given to $\boldsymbol{P}_{k+1}$. Thus, E have two resources: projection based on history and new actual samples.

Conclusions and discussions vector space and rangeland are (one-one) related: vector magnitude vs. rangeland production, direction vs. composition, addition vs. combination, minus vs. differences, division vs. trends, multiply vs. projection. It has been proven that $\boldsymbol{E}$ are closer to the true values than either $\boldsymbol{P}$ or $\boldsymbol{D}$, and projection error,

$$\boldsymbol{R}=(\mathbf{1}-\alpha) * (\boldsymbol{D}-\boldsymbol{P}) \quad (5)$$

are smaller than either using $\boldsymbol{P}$ or $\boldsymbol{D}$ alone. Furthermore, if we use $\boldsymbol{P}+\boldsymbol{D}$ to replace $\boldsymbol{E}$, and use $\boldsymbol{T}\times\boldsymbol{E}$ to replace $\boldsymbol{P}$, then,

$$\begin{aligned}\boldsymbol{E}_k &= \mathbf{D}_k+\mathbf{P}_k, \\ &= \mathbf{D}_k+\mathbf{T}_{k-1} * \mathbf{E}_{k-1}=\mathbf{D}_k+\mathbf{T}_{k-1} * (\mathbf{D}_{k-1}+\mathbf{P}_{k-1}) \ldots \\ &= \mathbf{D}_k+\mathbf{T}_{k-1} * (\mathbf{D}_{k-1}+\mathbf{T}_{k-2} * (\mathbf{D}_{k-2}+\mathbf{T}_{k-3} * (\mathbf{D}_{k-3}+\ldots+\mathbf{T}_0 * \mathbf{D}_0))) \quad (6)\end{aligned}$$

Rangeland expectation are linked to whole monitoring time series, and the trends calculated from expectations have used all information from the monitoring history, even looks like only two points be used (Bai, *et al*., 2007).

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