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Complementary State and Transition Model for Rangeland Management: A Viewpoint

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ABSTRACT

Vegetation and soil management needs a holistic approach which is already devised into the state and transition model and other ecological, while abolished, models. But these models have some disadvantages and limitations that disable them for managerial purposes. Here in this paper, using a case study to prove the idea, another complementary state and transition model is introduced. This model is more comprehensive and gives managers a more wide view into ecological processes undergoing in a site.

Introduction

In the wild, areas of land and volumes of water contain assemblages of different species, in different proportions and doing different things. These communities of organisms have properties that are the sum of the properties of the individual denizens plus their interactions [1]. Interactions between species can be defined as those mechanisms that affect community structure allowing the community to be viewed as possessing emergent properties greater than the sum of the individual plants [2]. These interactions along with inherent or exotic welcome or unwelcome changes in environmental conditions bring about the tendency in biota and fauna to change position toward better or worse conditions. This process is called ecological succession [3]. The process of succession is usually associated with a single local community: the initiation of a new community at an unoccupied site is referred to as primary succession; recovery following a disturbance is termed secondary succession [4].

In other words, succession is the change in species composition and associated substrate changes over time. It is a dynamic process that is studied with descriptive, experimental, theoretical, and modeling approaches. Formal, descriptive studies of succession began in the late 19th and early 20th centuries and were an extension of observations by natural historians, foresters, and agriculturalists during the previous several centuries [5]. An early classic definition of succession was introduced by Clements [6]. In Clements' point of view, habitat will follow an innate tendency to move forward along a single continuum of 'condition' towards a 'climatic climax' [7].

According to Clementsian viewpoint, the climax was condition of great stability in which the vegetation had reached equilibrium with the present climate. Clementsian succession theory was an equilibrium viewpoint in its assumption that succession change necessarily progressed towards the development of a stable vegetation type in equilibrium with the regional climate. It was deterministic by postulating that the development of the climax was orderly and as predictable as the life history of an individual organism [8].

This monoclimax view was challenged by many ecologists, amongst whom Tansley (1939) was prominent. The polyclimax school of thought recognized that a local climax may be governed by one factor or a combination of factors: climate, soil conditions, topography, fire and so on. Thus, a single climatic area could easily contain a number of specific climax types [1]. In Clements' climatic climax, the trend of progression and retrogression is linear and the Seral stages of succession trend are predetermined while in nature, except in a very general sense (e.g. the expectation that forests will develop in the eastern USA), the plant communities that develop during succession are not predictable [2].

Today, the problems with the climax view of vegetation are well understood and include the observations that vegetation change is not as predictable as expected under the climax theory, that vegetation dynamics are non-equilibrium, and that successional change that might lead to a climax community is non-deterministic [2].

Instead of mono or multi-climax models, Westoby et al [9] proposed a new model named State and Transition. This model is concerned with the recognition of "multiple stable states" and transitions between them [9, 10]. The state-and-transition model was presented as a qualitative model that possessed the capacity and flexibility to accommodate various types of knowledge and information associated with vegetation management on rangelands [11].

This model is a new development to oppose successional theory promoted largely by Clements (1916,). Clementsian successional theory fostered the concept of a "climax"

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vegetation state characterized as the final stage in plant succession. If a system was displaced from the climax plant species composition by disturbance such as grazing, it was said to be dys-climax. Moreover, the theory predicted that when the disturbance pressures were removed, that the system would inevitably return to, or converge on, the climax species composition: a highly linear style of model. Westoby et al. (1989) were able to show that this neat behavior was rarely observed in many rangeland situations [10].

What is followed is a quick review of the structure and terminology used in the state and transition model.

Definition of state

State could be defined as an alternative and stable vegetation community unable to revert to previous community in a linear way [9, 12, 13]. In other words, a state is necessarily an abstraction encompassing a certain amount of variation in space and time [9]. Vegetation communities wouldn't be stabilized before getting to the new state [14, 15]. Alternative states (or regimes) represent major shifts in ecosystem function. The shifts are due to changes in the abundance and composition of dominant species and associated biological and physical processes. Alternative states tend to be recognized when ecosystem changes have societal significance and are persistent with regard to management timeframes [16].

Definition of threshold

Ecological thresholds are of great importance for natural resource managers [17]. Ecological threshold is a concept showing the abrupt or gradual changes in ecosystem's attributes and functions [18]. Threshold could be a specified species richness level which is crosses according to increase or decrease of the intensification of rangeland degradation or improvement [19]. After all, 'Thresholds' are boundaries in space and time among the multiple stable communities that can occupy a site and can be categorized as pattern, process, or degradation thresholds [20].

Definition of Transition

Transitions between states, i.e. the change from one relatively stable community to another, are triggered by large changes in weather (such as a drought or unusually wet cycles), intense grazing pressure, fire, or combinations of these ecological factors [21]. In any case, if the ecological processes are altered such that a threshold is crossed, the plant community will transition from the original state to a new state with a suite of altered ecological processes that work to reinforce the function of the new state. As a result of the altered processes, the structure of the new state will differ from that of the previous state in species composition, ground cover characteristics, and/or production [22].

Resistance and resilience of vegetation community

Of the various aspects of stability, an initial distinction can be made between the resilience of a community (or any other system) and its resistance. Resilience describes the speed with which a community returns to its former state after it has been perturbed and displaced from that state. Resistance describes the ability of the community to avoid displacement in the first place [1, 14]. Quantification of communities and transitions within long-term vegetation records presents several quantitative metrics such as transition frequency, magnitude of accompanying compositional change, presence of unidirectional trajectories, and lack of reversibility within various timescales, which can clarify resilience concepts and inform the construction and interpretation of STMs [23].

Formulating STM models for range management

Under the state and transition formulation, knowledge about a given rangeland should be organized and expressed in the following forms [9]:

a) A catalogue of possible alternative states of the system
b) A catalogue of possible transition from one state to another

Concepts for STMs address three elements. First, they specify plant community properties, including composition, cover, and production of reference states that are chosen to best reflect the soil and climate-determined potential of the site. Second, reference states are contrasted with alternative states and should specify distinct structure-function (or pattern process) feedbacks. Third, STMs describe the triggers, drivers and mechanisms of transition among states (see [24]). STMs should include i. reference values for quantitative indicators ii. list of key indicators (expressing rangeland ecosystem's resistance and resilience [24]) and descriptions of changes in them that suggest an approach to a transition iii. a rigorous documentation of the theory and assumptions (and their alternatives) underlying the structure of each model [20]. Westoby et al. (1989) diagram of state and transition model for semiarid grassland in eastern Australia is as follow.

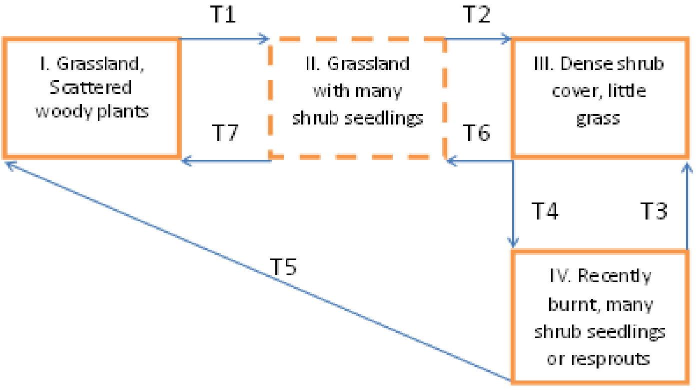

Fig. 1 State and transition diagram developed by Westoby et al. (1989) for semiarid grassland in eastern Australia

In this diagram, 4 alternative states are provided along with 7 transitions. Different opportunities and hazards were elicited by Westoby and colleagues. Different managerial scenarios were discussed using the information provided by this diagram.

A case study extended for the evaluation of state and transition model

As a case study to evaluate state and transition model, an evaluation carried out by Aghakhani *et al.* [25] is being reevaluated to delineate 2 rangeland vegetation state according to the methodology proposed by Westoby *et al.* [26].

Sisab rangeland as a representative of semi-arid rangeland is located in the north-eastern part of Iran. Annual precipitation is about 270 mm mainly snow which is distributed unevenly during the year and the major part falls in the winter. The soil of this area is dominated by loamy and clayey textures. Sheep is the key grazing animal of the region.

The exclosure's been applied since 1986 and the vegetation composition has changed from forb dominated to grass dominated because of the absence of sheep grazing pressures. This vegetation alteration is summarized in table 1.

Carbon, organic matter, phosphorous and nitrogen percentages, pH and electro conductivity (EC) of these two states were calculated. Results show the existence of significant differences among these states regarding the abovementioned parameters. Carbon, organic matter, nitrogen percentages show incretion in the exclosure rangeland compared to the grazed one.

Table 1. Vegetation composition and soil characteristics alteration during a 26-year exclosure in Sisab rangelands. ***(F, S, G stand for forb, shrub, grass and A and P stand for annual and perennial respectively)***

Species	Family	Growth form	Life cycle	State 1 (Grazing)	State 2 (Exclosure)
Bunium Cylendericum (Boiss&Hohen.)	Apiaceae	F	A	-	0.63
Scandix pectin-veneris L.	Apiaceae	F	A	-	0.05
ratula husskenchtii Boiss	Asteraceae	F	A	0.22	3.3
Centaura virgata Lam.	Asteraceae	F	P	-	0.14
Centaura depressa M. B.	Asteraceae	F	P	0.15	7.74
Cousinia assyriaca Jaub&Spach	Asteraceae	F	P	3.4	2.1
Artemisia sieberiBesser subsp. sieberi.	Asteraceae	S	P	-	0.43
Artemisia aucheriBoiss.	Asteraceae	S	P	2.85	0.87
Lappula microcarpa(Ledep.) Gurke.	Boraginaceae	F	A	0.15	-
Dianthus orientalisAdams.	Caryophillaceae	F	P	0.3	0.39
Convolvulus commutatus Boiss.	Convolvulaceae	F	P	0.25	0.3
Convolvulus pseudocantabrica Schrenk	Convolvulaceae	F	P	1.62	1
Isatis raphanifolia Boiss.	Cruciferae	F	A	-	0.03
Eruca sativa Lam.	Cruciferae	F	A	0.02	-
Alyssum bracteatum Boiss. &Buhse	Cruciferae	F	P	0.39	0.06
Alyssum daycarupm Steph. Ex Willd.	Cruciferae	F	P	0.03	0.015
Scabiosa rotataM.B.	Dipsaceae	F	A	-	0.03
Ephedra sp	Ephedraceae	S	P	-	0.75
Euphobia bungei Boiss.	Euphorbiaceae	F	P	-	0.015
Onobrychis radiata	Fabaceae	F	P	-	0.81
Astragalus raddei	Fabaceae	F	P	0.18	0.6
Glycyrrhiza glabra L.	Fabaceae	F	P	0.05	0.1
Asteragalus(Poterion) glucacanthus Fischer	Fabaceae	S	P	-	0.7
Astragalus sp	Fabaceae	S	P	0.7	1.95
Iris persica	Iridaceae	S	P	0.1	-
Lagochilus cabulicus Benth.	Labiatae	F	P	-	0.45
Eremostachys pulvinari Jaub&Spach s	Labiatae	F	P	-	0.1
Proveskia abrotanoides	Labiatae	F	P	-	0.84
Stachys lavandulifolia Vahi.	Labiatae	F	P	-	0.075
Salvia limbata C.A.Mey.	Labiatae	F	P	0.12	-
Phlomis cancellataBunge	Labiatae	F	P	3.33	3.69
Stachys turcomanica Trautv.P.	Labiatae	F	P	2.35	3.51
Allium stamineum Boiss.	Liliaceae	F	A	-	0.07
Tulipa montana Lindl. var. chrysantha (Boiss.)	Liliaceae	F	P	-	0.06
Linium marshallianum	Linaceae	F	A	0.04	0.15
Acantholimon sorchenes Rech.f.& Schiman	Plumbaginaceae	S	P	0.49	-
Avena sativaL.	Poaceae	G	A	-	0.015
Taeinatherum crinitum(Schreb.) Nevski	Poaceae	G	A	-	0.66
Aegilops cylindrica Host	Poaceae	G	A	0.4	0.006
Boisseria squarrosa Hochst. ex Steud.	Poaceae	G	A	0.06	0.015
Bromus danthonia Trin.	Poaceae	G	A	0.07	0.05
Bromus tectorum L.	Poaceae	G	A	0.15	0.05
Eremopyrum confusum Melderis	Poaceae	G	A	0.13	0.015
Bromus tomentellus Boiss.	Poaceae	G	P	-	0.05
Poa bulbosa L.	Poaceae	G	P	-	0.39
Festuca ovina L.	Poaceae	G	P	7.12	16.35
Stipa barbata Desf.	Poaceae	G	P	9.3	2.11
Rosa persica Michx.	Rosaceae	S	P	-	0.045
Galium verum L.	Rubiaceae	F	P	-	0.001
Asperula gilanica Trin.	Rubiaceae	F	P	2	0.45
Linaria lineolata Boiss	Scrophulariaceae	F	A	-	0.057
Hyoscyamus pusillus L.	Solanaceae	F	P	0.04	0.36
Ferula ovina L.	Umbeliferae	F	P	-	0.09

There was no difference for phosphorous level between two states. EC and pH expressed increasing and decreasing trend between the states respectively. The reason why this happen goes back to the implications of grazing on the organic matter added to the top soil. So, once the livestock was jettisoned, the fertility of soil started improving and the vegetation characteristics started reverting to the older state which is unknown. Soil and vegetation together are responsible for this change gradient and the intensity of this trend alteration. In other words, soil and vegetation characteristics fluctuate in concert whether good or bad.

With respect to the idea given above, in state and transition model, vegetation and soil characteristics should be considered together and as complementary components. The idea is given in diagram 2 below.

Vegetation community establishment owes its existence to many factors including climate, soil, topography, geology and biological interactions [28, 29]. So considering only vegetation composition to determine vegetation state would result in misinterpretation of statuesque, in other words, soil and vegetation should be regarded with equal importance in order to get to a more sophisticated state and transition model [30, 31].

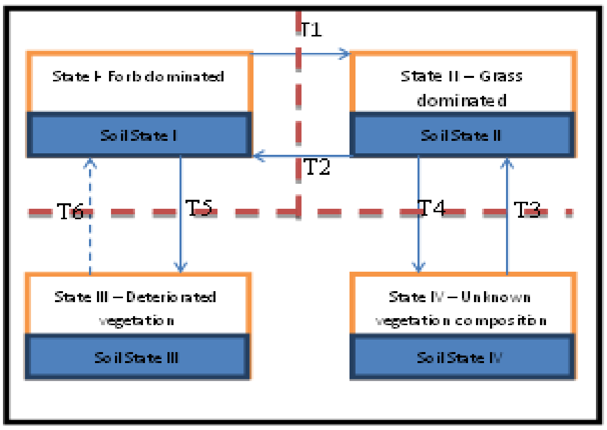

Diagram 2. Developed state and transition model for Sisan rangelands. The state and transition model complemented by soil states.[27]

Moreover, soil and vegetation factors should be quantified in order to reach at an objective state and transition model, because one of the main shortcomings of classical model is the lack of quantifiable information to understand transition process [32]. In the proposed diagram, four vegetation and soil states are introduced. The principle states are the one under grazing and the other one which is exclosed to local livestock. If the exclosed state is kept intact, the current state will succeed toward *unknown* vegetation and soil states which is likely to be grass dominated and have more fertile soil [33-35]. To go back to the other state, if the grazing pressure which acts as the driving force of transition, continue its implications, this state will transit toward a deteriorated state in which soil and vegetation will likely to loose the capacity to revert to the first state. Soil and vegetation change together, yet soil restoration is in need of longer time. This condition might be irreversible because the restoration of soil will take time and vegetation degradation would continue and soil and vegetation will stock in a vicious circle [36-38]. Here, additional help might be needed like fertilizers and other range improvement techniques [15]. Moreover, state and transition model is developed for arid and semi-arid rangelands [9, 13, 39]. While vegetation recovery and soil maturity in arid and semi-arid rangelands is so gradual that degraded rangelands won't restore its previous condition in a normal way, additional help would be needed [40, 41]. The recovery of vegetation in response to disturbance, rely on the intensity and nature of the stress and the heterogeneity of soil and vegetation [42-44].

Another problem that arises from vegetation composition is the inherent resistance of stressed rangelands against outer tensions in such a way that low-resistant species have been jettisoned from vegetation community through time [27]. So, looking only for vegetation composition changes for managerial purposes will result in last-minute decisions.

Soil seed bank plays a key role for vegetation community to recover after a perturbation, if soil seed bank is well-managed, the vegetation recovery process will accelerate [45]. On the other hand, if soil seed bank is damaged, the vegetation recovery will be hampered and there will be the need for additional managerial measures [46-48]. So soil plays two justified role in ecosystem recovery, as the basis of plant growth and as the basis of plant recovery through its seed bank.

Conclusion

State and transition model is a well-developed range management model for arid and semi-arid environments. Though look comprehensive, state and transition model includes some disadvantages and limitation discussed above. The main limitation of this model is not counting the soil as the basis of the ecosystem. So in this paper, we sought a solution to include soil into this model to reach at a more sophisticated ecological model for range management. Here instead of vegetation composition in order to define states, soil is regarded in tandem. So, each site could have multiple soil and vegetation states with the same or different transition status. But, the boundary of these states may have overlap or gap which requires a lot of in-situ researches. The case study brought, showed that soil and vegetation responded to exclusion in a positive way, while the level of alterations might not be matched. Finally, state and transition model for soil and vegetation states should be quantified till the managers are able to manage the site with a wide look toward the future.

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