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STATES AND TRANSITIONS: THE TRAJECTORY OF AN IDEA, 1970–2010

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ABSTRACT

State-and-transition language for ecosystem dynamics was articulated in a 1989 paper written by Imanuel Noy-Meir in collaboration with Westoby and Walker. That paper has been surprisingly influential considering that the publication it appeared in, *Journal of Range Management*, serves a relatively small community of researchers. Here we trace the wider history within which the paper sits, both the context that led up to its being written and its influence subsequently. Our aim is to explain Noy-Meir's distinctive and constructive role, at several points in the history.

PREHISTORY

Israeli ecology has a long and distinguished history in the study of arid zones, which was further enriched by the experience gained by Imanuel Noy-Meir in Australia during the 1960s. In 1972, as a young faculty member of The Hebrew University, Noy-Meir came to Utah State University to write reviews of arid zone ecology for the then-new *Annual Review of Ecology and Systematics*. There he met Mark Westoby, who was a graduate student within the modelling group of the US/IBP Desert Biome. Noy-Meir organized his reviews (Noy-Meir, 1973, 1974) around a pulse-reserve paradigm that had been developed by Westoby for the modelling group's purposes. The reviews drove a shift away from equilibrium towards event-driven thinking for arid ecosystems.

During the 1970s, Noy-Meir clarified how grazer–plant interactions could generate alternative persistent states in rangelands. In 1978, Brian Walker spent a sabbatical leave with Noy-Meir in Israel, and they developed a model of semiarid savanna dynamics that captured the non-linear dynamics of these systems that Noy-Meir had described in his simple models of grazing dynamics (Walker and Noy-Meir, 1982). The work behind this paper fed into Walker's subsequent work with C.S.Holling about resilience concepts. By inviting a contribution to a special issue of the *Israel Journal of Botany*, Noy-Meir also induced Westoby (1980) to develop ideas about plant strategies to deal with a staccato flow of rainfall episodes.

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Westoby had moved to Australia in the mid-70s, and Walker in the mid-80s. They met with Noy-Meir in Adelaide in 1986 at the International Rangelands Congress. By that time there was a wide variety of theory about arid zones and rangelands that did not depend on equilibrium concepts, but it was not being adopted into management at all. Range management continued to be based around the equilibrium range succession worldview that traced back to Clements and the "founding school" of American plant ecology (Tobey, 1981).

So the discussion among Noy-Meir, Walker, and Westoby turned away from purely scientific questions to the question of how managers should best conceptualize a rangeland to accommodate non-equilibrium and nonlinear dynamical processes. Their 1989 paper arose from these discussions about how concepts about dynamics might be translated into management. In that paper, the dynamics are seen from a manager's perspective. The manager sits outside the ecological system, and tries to "avoid the threats and seize the opportunities" (Westoby et al., 1989).

DEVELOPMENTS SINCE 1989

The States and Transitions (S&T) framework became widely used amongst rangelands researchers. The US-based *Journal of Range Management* has published some 72 papers that deal in one way or another with state-and-transition models. In Australia, the journal *Tropical Grasslands* published a special section in 1994 (Vol. 28) on "State and Transition Models for Rangelands" that included 13 papers. Several of these provided detailed quantitative models for particular situations. Others sought to refine methods for making the conceptual S&T framework modelling more useful for application to management. As an example, the paper by Scanlan (1994) used the S&T framework to develop a Markov model for estimating probabilities of transitions between states.

The most far-reaching development from S&T thinking has been to incorporate human decision-making propensities directly into the representation of the system. The manager no longer sits outside the system. Rather, the human social and economic systems become a source of feedback and feedforward mechanisms within the overall linked system of humans and nature.

In these applications, the S&T language is used to focus on alternate stability domains and on unwanted surprises in linked systems of humans and nature. The framework has been used as a means of helping to identify potential threshold effects in the *Resilience Alliance* workbooks (http://www.resalliance.org/3871.php). These workbooks aim to assist people undertaking resilience assessments at the scale of farming regions and catchments, focused strongly on including humans within the dynamics of the system, now called a social–ecological system. Cumming et al. (2006) provide examples of thresholds and unanticipated transitions in marine and terrestrial systems, and they focus on the mismatch in the scales at which the two domains function as one of the main causes of unexpected effects caused by the feedbacks.

As an example of a S&T conceptual model of a linked social-ecological system, Mathevet et al. (http://sag.sagepub.com/cgi/content/abstract/38/2/233), working with four resource user groups in the Camargue (Rhone delta), developed a S&T model involving eight states of the system that represent different combinations of vegetation and human use. They identify the associated conditions for transitions between these eight states to guide development of agreed management amongst the user groups. The process involved incorporating the S&T model into a role-playing game that enabled the user groups to investigate the outcomes of proposed management strategies. The model is depicted in Fig 1.

As a further step in the process from conceptual S&T models to models of alternate stability regimes, the model in Fig. 2 was derived by a group of social scientists and ecologists in a Dahlem conference on “Do humans cause deserts?”

Fernandez et al. (2002) paper showed how this conceptual model was applied to grazing systems in the Sahel, South Africa, Namibia, and Australia. In each of these situations, which have very different political economies as well as some differences in ecology, the conceptual model helped to understand how degradation takes place, with the emphasis on the feedbacks between the social and ecological systems in each case.

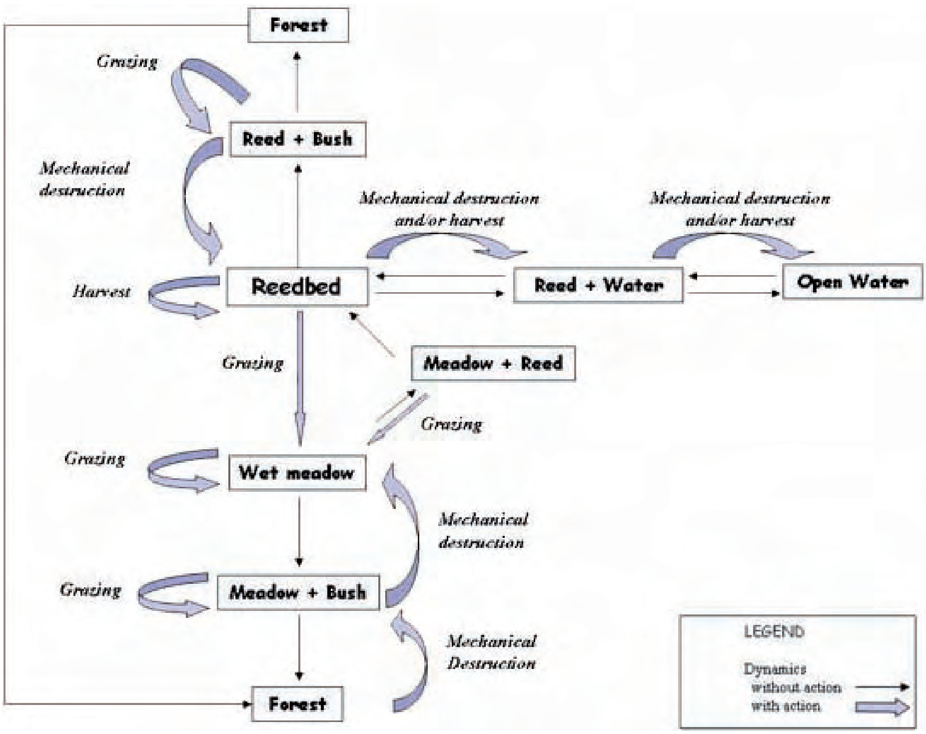

Fig. 1. State-and-Transition model of the Camargue wetland system in the Rhone delta. Boxes = alternate states (or transitional states). Arrows define how interventions mediate the transitions.

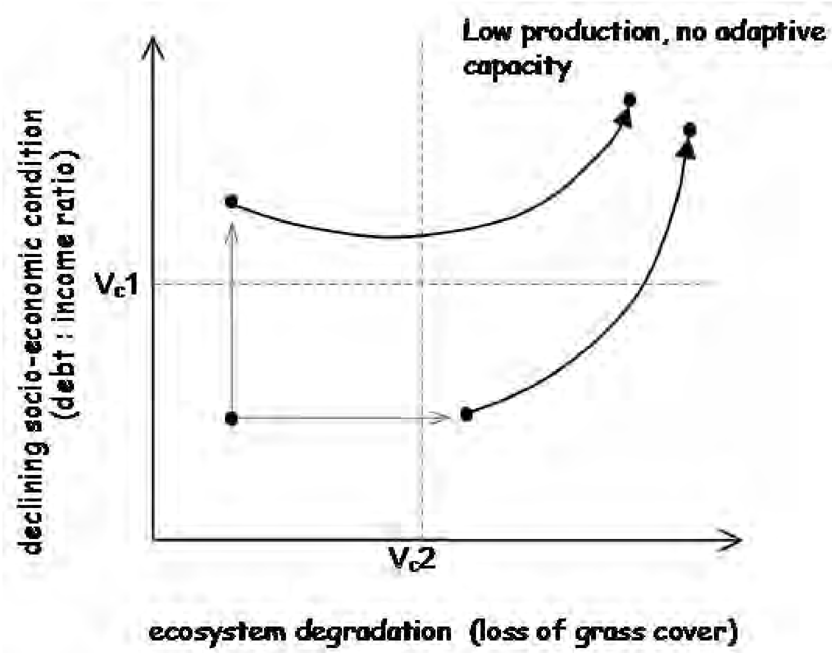

Fig. 2. Conceptual model of possible states of a semi-arid grazing system. The dotted lines represent critical thresholds between alternate stability domains of the ecological and social systems. Crossing the ecological threshold causes changes in the social (debt : income) system which can lead to crossing that threshold, and vice-versa, resulting in a "doubly defined" poverty trap. (After Fernandez et al., 2002).

As a final example of alternate stability domains in a linked social-ecological system, Fig. 3 is the outcome of a study of the resilience of a farming region in SE Australia, the Goulburn–Broken Catchment, used mainly for irrigated dairy and horticulture. Each of the boxes in Fig. 3 represents a threshold that, if crossed, leads to an alternate stability domain at the scale and in the domain indicated. Crossing one threshold can either increase or decrease the likelihood of another being crossed. The kind of "shock" the system is subjected to determines which of the thresholds is most likely to be challenged.

The shift from providing humans with decision tools to incorporating their decisions as part of what is to be understood has been associated with elevating state-and-transition thinking to the global scale. A recent exercise led by the Stockholm Resilience Centre (Rockstrom et al., 2009) identifies nine planetary boundaries, i.e., nine potential transitions to alternative states of global ecology. The catalogue of conditions for each transition is not fully understood. Some are clearly irreversible, but others may not be. The S&T framework has now extended to the biggest possible questions: big in the sense of planetary scale, and big in the sense of the search for global sustainability.

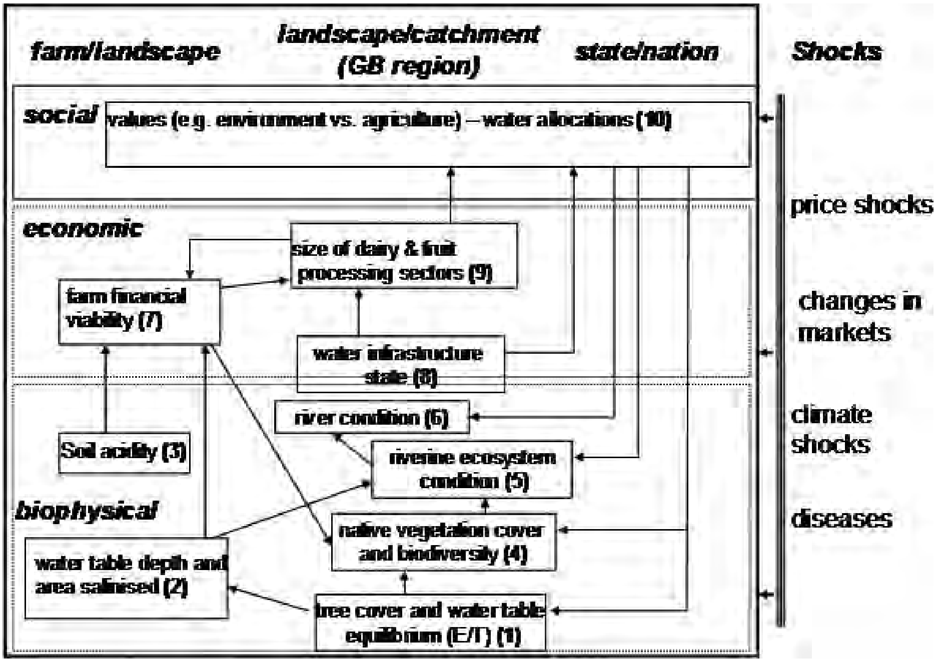

Fig 3. Ten thresholds between alternate stability domains in the ecological, economic, and social domains, at three scales, in the Goulburn–Broken Catchment, SE Australia. Arrows indicate the likely cascading effects of crossing any one threshold. (From Walker et al., 2009).

CONCLUSION

Noy-Meir had an excellent feel for quantitative processes, but at the same time he was more interested in understanding the real world than in constructing a mathematical apparatus. He understood the crucial role of concepts for applied ecology. His simple grazing models led first to alternate stable state ideas in rangelands, and subsequently to the development of the S&T language for describing alternative pathways of change and threshold effects. His ability to reduce seemingly intractable complexity to essential dynamics will be very much missed.

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