Woolsheds and Catastrophe Theory: The lower Lachlan Experiment

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The landscape of the lower Lachlan area of New South Wales was transformed by the expansion of market pastoralism in the nineteenth century. With the wool boom of the 1870s and 1880s ever larger and more specialised woolsheds were built, but they were used at full capacity for only a short time before the ecological disaster of the drought of the 1890s ended the pastoral pattern of land use in the area. The sudden and severe nature of the ecological breakdown suggested that it may be useful to apply the mathematical tool of catastrophe theory to analyse the situation of several variables changing over time. Using rainfall records, station records and official reports, a qualitative analysis of some of the variables suggested that the model provides useful insights into the relationships and interactions between many ecological conditions.

INTRODUCTION

Scattered across the open plains of the lower Lachlan, beside roads or isolated in paddocks of wheat like dinosaurs in a changed landscape, stand the remains of buildings which recall the era of pastoralism (Fig. 1). While they operated at full capacity for only a short time, about twenty years in most cases, the woolsheds were the focus of a system of land use that utterly transformed the landscape of the area during its brief period of dominance. Large simple structures built of local materials, the woolsheds are an eloquent expression of the demands of an exacting environment.

The history of the building of the woolsheds and their subsequent fate is linked closely with that of the area. They were the central unit of the wool industry, efficient factories for the processing of the fleeces on which the economy depended. Moreover, they were closely woven into the social fabric of an isolated community attempting the experimental utilisation of a harsh and capricious environment. The length of time that they were in use was brief but even now the scale and concentration of the buildings hold an echo of the role they once played.

There is limited interest in simply recording the features of these structures, however beautiful they seem. One wants some insight into the underlying dynamics of change that they reflect. As patterns of settlement are limited by ecological constraints, a model of these processes could illuminate the situation. Ecology is a dynamic process where the relationships among the variables change over time, so a qualitative analysis of the relationships is needed. Much change in an ecosystem is slow. Often a small change in one part of an ecosystem will produce similarly small changes in the system as a whole. However, in some situations, a small change in one part can produce sudden disproportionate changes in the whole system. In the latter case, there is an opportunity to use the modern mathematical tool of catastrophe theory to analyse relationships among the variables. Catastrophe theory is a qualitative analysis. It does not yield numerical solutions or simple predictions, but, in providing a model of several variables changing over time, it gives a framework in which to explore the sequence of recorded events.

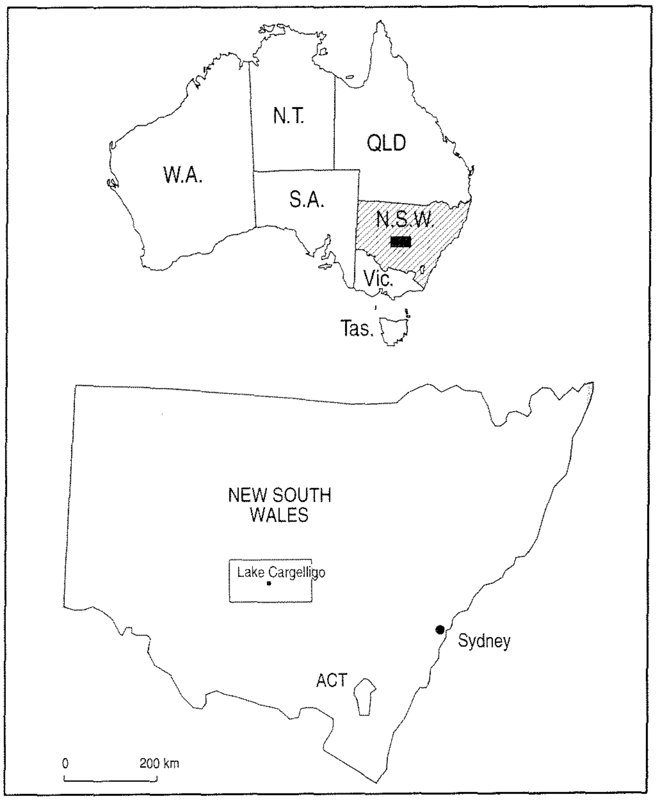

Fig. 1: Map showing location of the lower Lachlan area in New South Wales.

It is not always possible to use a formal model in studying the past as there is a need for an independent description of the conditions. Fortunately, in this case there are some records available. Early archives are few but vital since the records of the early explorers Oxley [1] and Mitchell [2] include descriptions of the area before European settlement. Town rainfall records and station books for the 1890s give details of the onset of the great drought which saw the end of the wool boom while at the end of the drought there is the detailed evidence and Report of the Royal Commission into the Western Division.[3]

SETTLEMENT AND WOOLSHEDS

With the arrival of European settlers during the nineteenth century, pastoralism became the main system of land use in the lower Lachlan area. A few squatters were established by the 1840s and most of the riverfronts were taken up in large blocks running cattle with a few sheep for variety by the 1860s. This study is focused on the large territorial unit which included those early leases and is centred on the Lachlan River between the crossing at Euabalong and the present township of Hillston.

The earliest woolsheds were improvised structures, but the switch from cattle raising to wool growing which followed the end of the early gold rushes, saw the construction of more substantial woolsheds in the area. Those built during the 1850s and 1860s were generally of rectangular plan with capacity for up to twelve shearers. Probably the first purpose-built woolshed in the area was the one on North Whoey. It had the typical early rectangular plan with a central board area and sheep pens at either side. The small woolroom was lower and was located at the end of the board. The woolshed at the adjoining property, Boorithumble, is also of early date with its heavy frame and original roof of wooden shingles beneath the galvanised iron. The plan is similar to that at North Whoey.

By the 1870s and 1880s specialist contractors were building huge T-plan woolsheds with up to 76 shearer's stands. One of the finest was Wooyeo, built by William McFadzean in 1873 with 52 stands and many carefully designed features to facilitate the smooth flow of work. Skylights and ventilators, sliding sheep-pen gates, trapdoors for wool handling and ample sheep shelter were provided. The shell of Wooyeo is now used for shelter and storage on a small mixed farm.

The 1890s opened with a note of optimism. Despite the problems arising from the shearing dispute, progress continued to be made in the frozen meat industry. An excellent season was reported and the wool trade was flourishing with Europe and the U.S.A. purchasing Australian wool, in addition to the usual British buyers. Infrastructure had developed to a stage where a growing network of railways shortened the time the wool spent in transit to the city where it was awaited by a network of warehouses and woolstores. A number of specialised support trades, such as drovers, carriers and scourers had emerged as had a varied and complex marketing network. Finance was more flexible as specialist firms undertook brokerage activities. Banks also entered the area. During the 1880s the Australian sales network had greatly matured with the establishment of local branches of foreign dealers and manufacturers culminating in the establishment of local sales facilities by the wool and finance houses such as Dalgety's (1887) and Union Mortgage & Agency Co. (1888). The growing sophistication of the industry is also reflected in the emergence of various specialist organisations, especially the formation of the Australian Shearers Union in 1886 and various graziers groups, some in direct response to the shearers union, during the 1890s.

Australian pastoralism was set up as an export industry employing a small labour force and using a battery of exploitative techniques such as clearing, enclosure and water conservation measures. There were no precedents to guide the settlers so they were in effect conducting a huge experiment in land use. This pushed the ecosystem to its limits and many of the events of the 1890s were the result of these practices reaching the limit of their application at the same time as the climatic variation swung to its extreme. Throughout the 1880s a series of

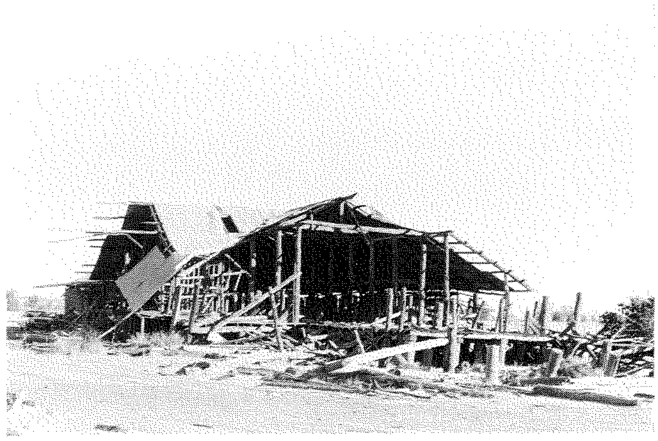

Fig. 2: Wooyeo woolshed. This T-shaped structure was built in 1873 with 52 stands to shear 100,000 sheep each year and includes such details as sliding gates and trapdoors to encourage a smooth work flow as well as ample sheep shelter and wool storage space. I t now serves multiple storage purposes on a small farm as it gradually melts into the surrounding wheat paddocks.

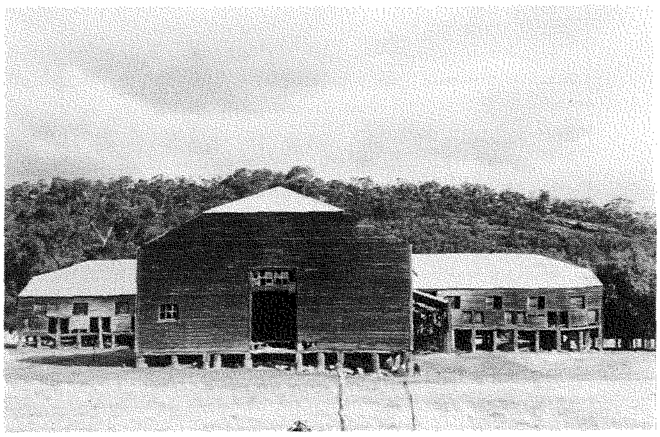

Fig. 3: Naradhan woolshed was built in 1888 on a similar plan to Wooyeo but on a smaller scale with stands for 28 blade shearers. It still functions as a shearing shed with 4 stands in operation.

technological advances had been widely adopted in the grazing industry. Fencing had subdivided the runs and agricultural machinery was of increasing sophistication while the use of steam engines for shearing required a supply of wood to fuel them causing further loss of tree cover near the shearing sheds.

The spread of the pastoral industry had been swift. When the Europeans arrived in 1788 no hoofed animals trod the continent's soil, but by 1890 over a hundred million sheep and nearly eight million cattle were established. In 1890 sixteen million of those sheep grazed on the fragile lands of the Western Division. While the colony as a whole had experienced about one hundred years of grazing, the lower Lachlan had only felt this influence for about fifty years, but that was sufficient to trigger irreversible change to the landscape. In particular, the tall perennial grasses and edible shrubs were under great stress. Graziers did not seem to realise that these resources were not readily renewable but fragile perennials and that their stocking policies were

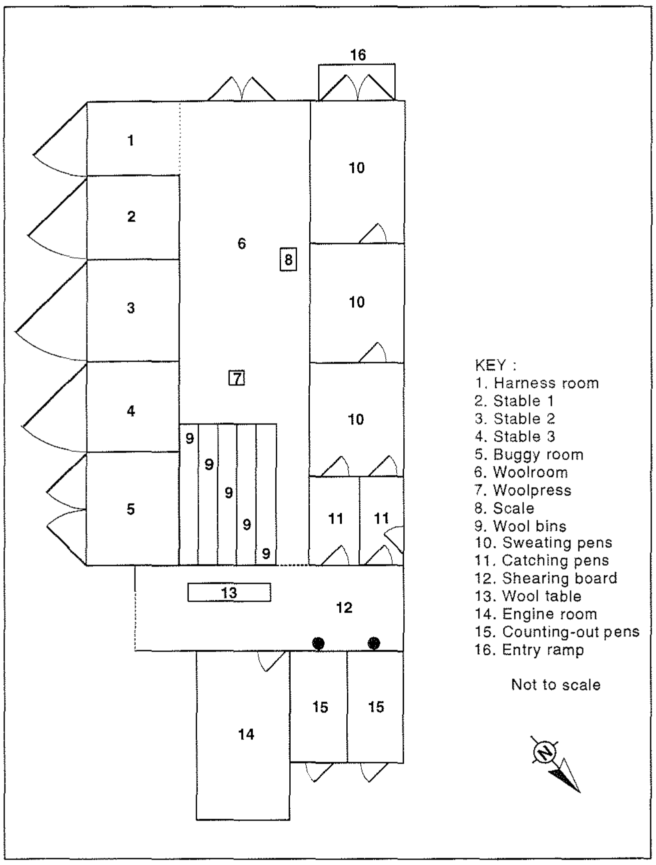

Fig. 4.

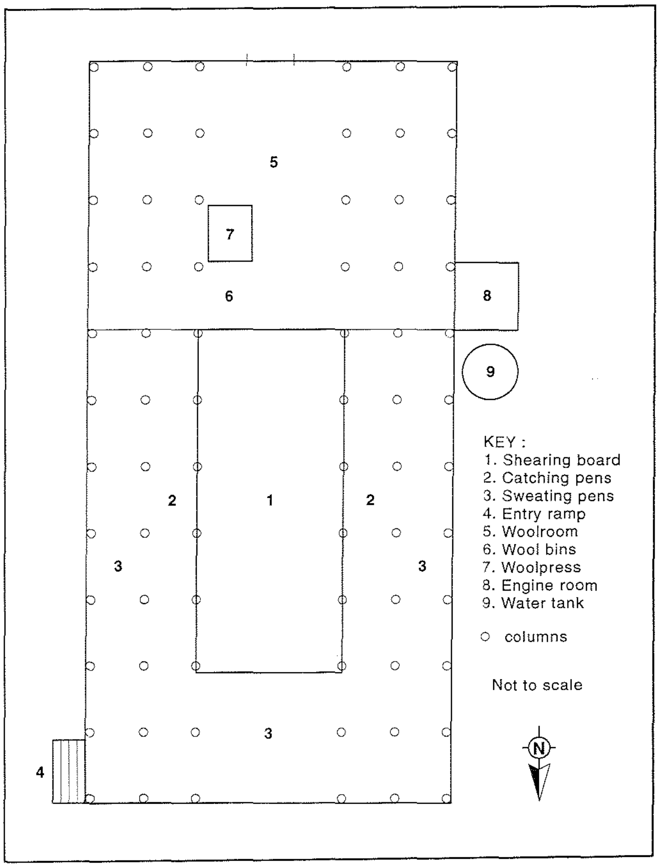

Fig. 5.

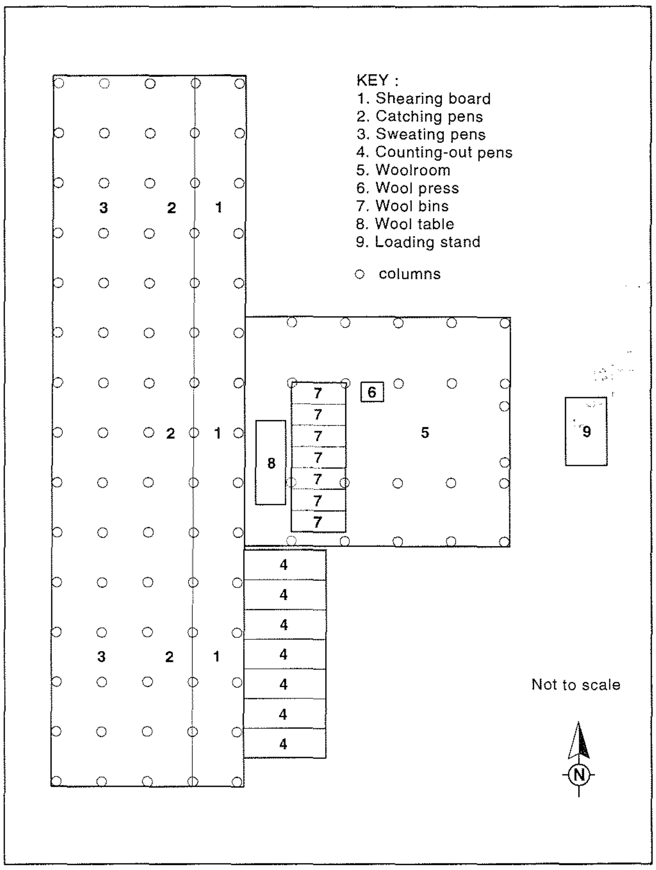

Fig. 6.

Schematic plans of:
Fig. 4: Hyandra stable. This was an early improvised shearing space in part of a stable with a small extension for the board area (12-15), which was used until the 1960s
Fig. 5: North Whoey woolshed. The earliest purpose-built woolshed in the area, it had a low rectangular plan providing little sheep shelter and crowded work space for 12 shearers.
Fig. 6: Uabba woolshed. Built in the early 1880s by the same specialist contractor as Wooyeo and Naradhan, Uabba had a similar T-plan with careful provision for the efficient flow of sheep and wool. It remained in use on a medium-sized property until it was burnt in 1988.

consuming the very capital on which the industry was based.

The standing structures of the area suggest that life on the properties along the Lachlan had become more comfortable. The early shelters had been exchanged for more spacious and diverse buildings. Homesteads were larger, of more substantial materials and of growing complexity.[4] The surrounding service structures were also more numerous and more specialised with a proliferation of smithies, dairies, offices, barns, stables and storage sheds on all the leases. Most noticeable of all were the woolsheds. Large simple structures of local materials, they were the activity centre of the sheep runs during the crucial shearing season when the produce of the year's work entered the system of wool classification and distribution. Because of their bulk and also the bustle surrounding their annual operation, they were a prominent feature of the landscape. By the 1890s, steam engines were used to power the shearing so a new layer of technology surrounded their operation and brought a range of extensions to the sheds and a new group of experts to run them [5]

THE DROUGHT OF THE NINETIES

Stable as it seemed on the surface, however, the pastoral system was in a very vulnerable state. In the fragile region of the Lachlan, this was soon to be demonstrated. The mode of resource utilisation evolved by the graziers was based neither on a tradition resulting from long term trial and error, nor on a management plan based on scientific observation of the resources and climate. Instead, it was simply an experiment in stretching the parameters of tolerance in the ecological system. The response to the buoyant conditions of the late 1880s was to increase stocking rates to the maximum. This strategy carried grave risks. Moreover, the rabbits had arrived. The year 1888 was very dry but it was followed by three good years, which encouraged graziers to maintain high stocking rates in response to the falling price of wool.

Difficulties arose on many fronts including a series of labour disputes and strikes as well as a succession of bank failures. Many properties run by families and individuals were taken over by banks and companies during this crisis. From the viewpoint of later research, this had the positive aspect that detailed book-keeping was implemented. In the study area several properties kept detailed station records. An overview of the region and its context is provided by the Report of the Royal Commission into the Western Division. The Western Division covers that section of the State of New South Wales to the west of the Lachlan River. The properties in this survey which are located along that divide enjoy some of the more benign conditions in the Western Division. Some of the evidence given to the Commission is cited below.[6]

The Commission heard evidence that 'The country is a howling wilderness... the abomination of desolation. It is something fearful. There is nothing to be seen but dry, black tussocks ... The soil is as loose and friable as an ash bed.' Many witnesses reported that terrible dust storms added to the problems faced by the graziers as 'The destruction of bush and low scrub by the rabbits has deprived the country of nearly all surface protection, so that the prevailing winds sweep the face of the country, raising dust storms, silting up tanks and natural waters, covering fences, yards, &c., and destroying feed'. That the speed and severity of these storms was intense can be appreciated from a submission describing one such experience in the area; 'I went out in the morning, and there was a tank of mine of 400 or 500 yards; a lot of weak sheep were watering at it. A fearful storm occurred that day, and when I came home that night there were fifteen to sixteen sheep buried alive there, and no remnant of that tank left.'

Among the main themes to emerge from the mass of evidence were the drought, overstocking and the arrival of the rabbits. The experimental nature of the occupation was also noted by some of those giving evidence. Some understanding of the processes of environmental change had been gained. For many of the witnesses, however, this was seen as a very direct relationship between one or more factors, for example, 'The country has altered very much ... Since 1891 it has gone off considerably every year owing to droughts and rabbits.'

In the Report, a more sophisticated analysis was given as the Commissioners found that the problems in the Western Division resulted from a combination of causes which they then examined.[7] While the recent drought was accepted as an obvious precipitator of the calamity it was recognised that 'the meteorological history of our Western Division shows it to be essentially a country of almost invariably low rainfall and inevitably recurring drought ... that the story of our western country makes such a gloomy page... is probably mainly due to the general failure... to recognise that drought is the predominant characteristic of the west'. This failure to face the reality of climate was in spite of the fact that 'There have been not more than eight good seasons in forty-six years'. With such a huge gap between the resource perception of the pastoralists and the system they were trying to manipulate, it is not surprising that the collapse was so swift and so severe.

CATASTROPHE THEORY AND THE ECOLOGICAL SYSTEM

The swiftness of the collapse suggested that it may be useful to develop a model of the ecological processes involved in the breakdown of the pastoral system. However, the important characteristic of stability, used in the sense of resistance to change, is not quantifiable within the scope of most ecological models. This is a barrier to exploring the environmental thresholds and landscape sensitivity of the system. However, an approach to situations where sudden changes occur in the pattern of relationships among the elements of a system has emerged through the mathematical theory of singularities, often referred to as catastrophe theory, which received great impetus in the 1960s from work by the French mathematician Rene Thom.[8] During the nineteenth century the radically new discipline of

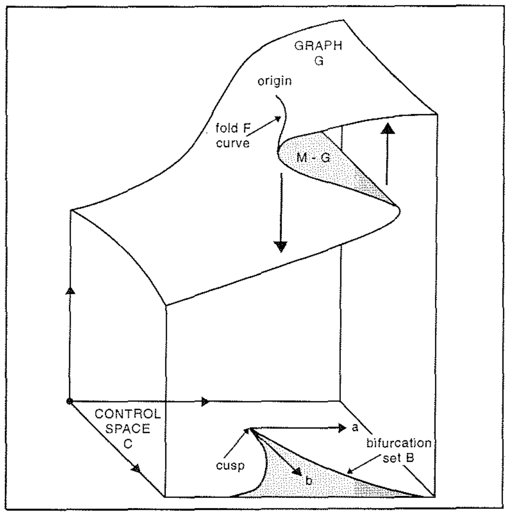

Fig. 7: The cusp catastrophe (after Zeeman).

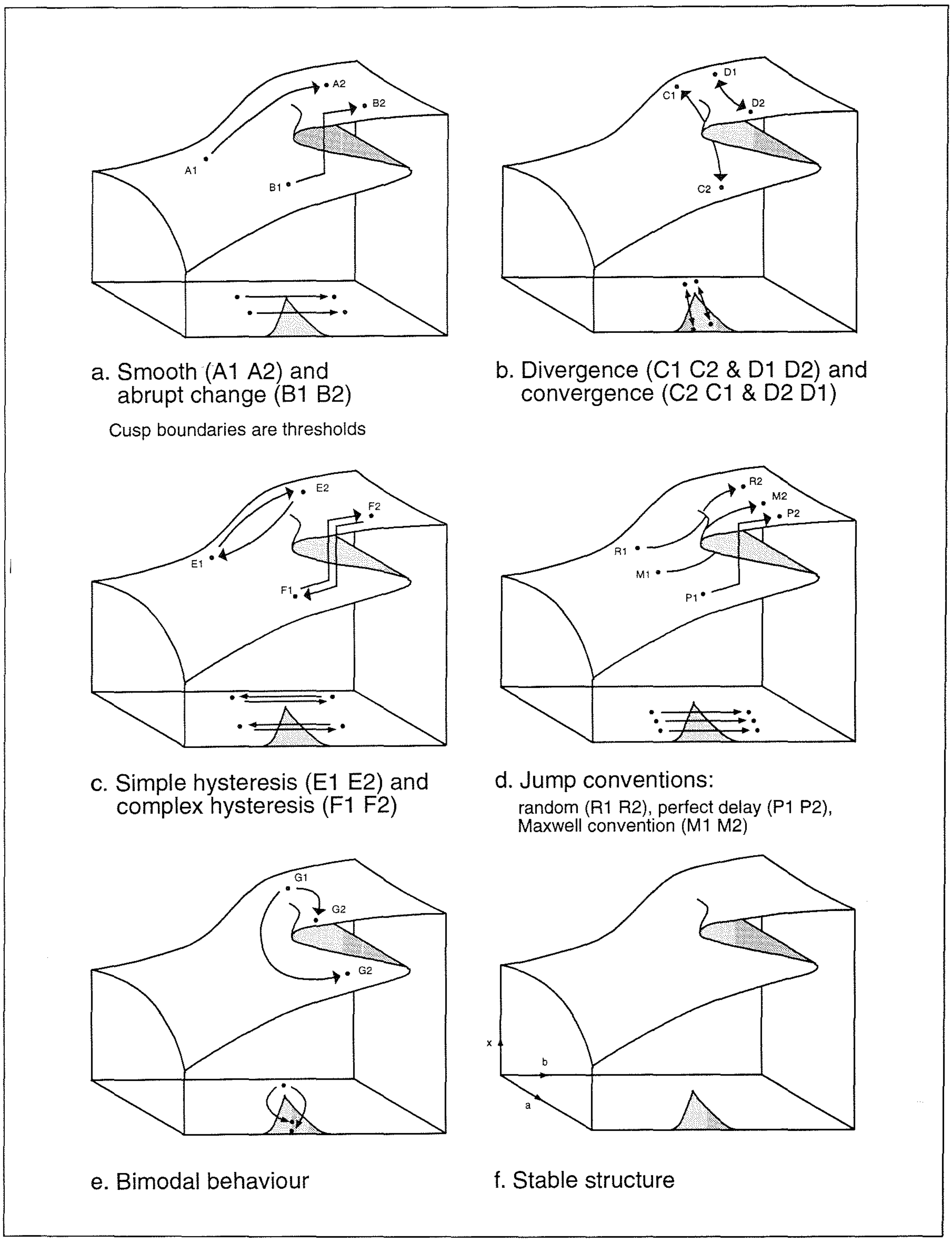

Fig. 8: Characteristics of the cusp catastrophe (after Burrin and Scaife).

topology had emerged from the classical field of geometry to study those properties of figures that persist under severe distortion. Thom's innovation was to use this theory to model discontinuous changes in natural systems. His own major early work emphasised the importance of structural stability and the concept of insensitivity to change.[9]

Catastrophe theory provides a formal means of approaching situations where slowly changing variables produce sudden changes or jumps. Many examples of this type of behavior have been observed to occur in nature. For example, a constant amount of heat applied to a vessel of water can result in the water suddenly boiling. Volcanos erupt without warning. Lemming populations fluctuate dramatically. The potential of the theory was soon recognised and applications were made to a wide range of theoretical and physical problems. These applications include the social sciences and archaeology. A full exposition of the mathematical basis of catastrophe theory is beyond the scope of this paper, but several accessible works are available.

The deep mathematical results in the geometry of many dimensions which were proved by Thom provide a classification theorem of the seven elementary catastrophes which can occur in up to four dimensions. The word elementary is used in the sense of fundamental, not of simplicity or triviality. While other catastrophes occur in higher dimensions, they are of such abstraction that they are not relevant to likely applications and will not be considered here. Each of the elementary catastrophes describe a pattern of change which is the product of the number of control factors in the equation. The nature of the variables and the type of relationship among them is irrelevant.

The seven elementary catastrophes may each be formally described by an mathematical equation which may be used to illustrate the phenomena of continuous forces producing discontinuous results in particular cases. The most direct application is to systems which either maximise or minimise some function. As this function is often energy, systems can be described in terms of equilibrium or entropy. Such an approach is quite easy to appreciate in areas like geology or ecology and provides a convenient vocabulary for the study of landscape stability.

The first of the elementary catastrophes is the *fold catastrophe* but as it has only one control factor and one response variable it produces a two dimensional graph of very limited application because few systems can be described in such simple terms. More useful is the next catastrophe which has two control factors and one response variable and is called the *cusp catastrophe.* It is realised in a three dimensional graph, (shown in Fig. 7). The figure shows how two control variable *a* and *b,* (for example, heat and stress) produce a series of values for the control variable ~, (for example, structural cracking). These points form the surface M. In general, each combination of *a* and *b* produce one point on the surface, but some values can produce multiple points. The cusp is usually considered the most appropriate model for use in the social sciences.[10] It is the highest dimensional catastrophe which can be graphically represented in two dimensions. The higher dimensional catastrophes require abstract algebraic or topological description and are of no relevance here.

The cusp catastrophe, see Fig. 7, is formally described as the cubic surface M in three dimensions defined by the equation:

$$x^3 = a + bx$$

where *a* and *b* are the horizontal control axes and x is the vertical response axis. To represent this three dimensional figure in two dimensions, the control space C appears as a plane below the origin on Fig. 7. The curve on the surface where the upper and lower sheets fold over is called the fold curve. While the fold curve F is itself a smooth and continuous curve, the *bifurcation* set B, which is obtained by projecting F on to the control space, has a cusp or fold at the origin and this is the source of the name cusp catastrophe.

The fold curve F divides the surface M into two sections. The small section M - G (which is shaded on Fig. 7) is, for practical purposes, of no interest here. The larger part, the graph G, is the surface where the values of the response variable are set out in graphic form. The *splitting factor* which causes the fold curve to appear is a function of the value of the axis at the cusp point *ab* of the bifurcation set B.

To apply this formal model to the impact of pastoralism on the landscape of the lower Lachlan during the nineteenth century, it is necessary to explore some of the implications of catastrophe theory. This does not involve simple numerical calculations, but a consideration of the way the cusp catastrophe reflects the interactions of the processes involved. As a first step towards fitting the

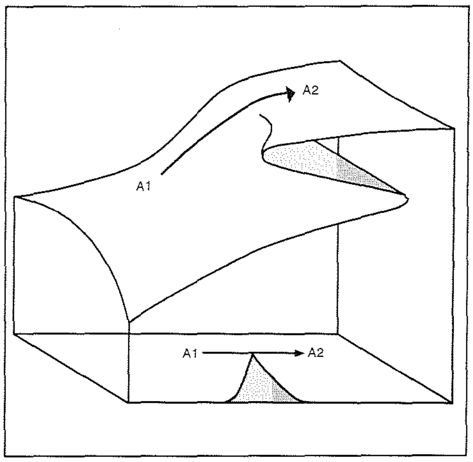

Fig. 9: Smooth change, where A1 is the system at the start of European occupation and A2 is the system in 1860.

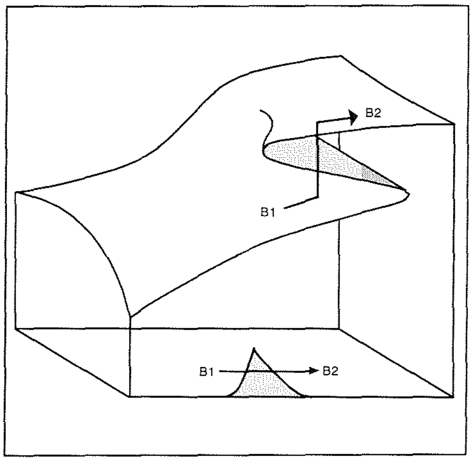

Fig. 10: Abrupt change, where B1 is the system in 1880 and B2 is the system in 1900.

model, two factors must be identified as the control variables whose values produce the response variable. In this context, therefore, let:

a be the annual rainfall

b be the pastoral load on the land, expressed as the number of sheep plus the number of rabbits per unit area.

x be the condition of the landscape, measured by the amount of edible vegetation available per unit area. The values of x form the surface of the graph G.

There are six important characteristics of the surface of the graph and these provide a vocabulary with which to describe the behavior of the system. They are:

(1) Smooth and abrupt change. (See Fig. 8a). Changes may be either smooth or sudden depending on where the point representing the value of the response is located on the surface of the graph. If the point is near the fold, then small changes in the values of a or b may result in a sudden jump in x as it encounters the cusp and crosses a threshold. Similarly, large variations in the value of the control variables may produce only smooth change if the point is located at some distance from the fold.

(2) Divergence and convergence. (See Fig. 8b). Even if the variables start and end at similar points, the system

response to a particular change can move along different paths. The conditions in the system before the change are important here.

(3) Hysteresis (see Fig. 8c). This involves lags in the system. There are three possible delay conventions:

(a) Perfect delay: The point moves into the fold and jumps to the farthest edge.

(b) Maxwell delay: The system jumps as soon as possible.

(c) Random delay: The system jumps at any time in the fold.

(4) Bimodal Behavior (see Fig. 8e). A formal geometric property of the model. It refers to the possible values which may be taken by the response variable x (for example, fast versus slow or inflation versus deflation) when it is projected onto the surface of G.

(5) Instability. A geometrical property of the cusp catastrophe. The unstable area inside the fold curve is a part of the model by definition, but may be ignored in applications of the model.

(6) Stable Structure (see Fig. 8f). The formal definition that the surface and fold curve must be a cusp catastrophe should two variables control a single response variable.

AN APPLICATION OF CATASTROPHE THEORY ON THE LACHLAN

The six characteristics of the cusp catastrophe listed above suggest that it may be a particularly appropriate way to approach the study of landscape stability. It provides a conceptual framework and a vocabulary which can be used to model the possible responses of the ecosystem to changes such as the impact of market pastoralism.

If it is possible to specify the two control variables and the response variable of a system, then it should be possible to predict some of the responses of the system. Not, of course, in a simple numerical or statistical paradigm. Catastrophe theory allows a much more interesting analysis by revealing the trends in the dynamic system. Following this, the model can be used to identify details which might be of critical importance to the operation of the system. It also greatly enhances the power of statistical tools by clearly identifying important variables for further numerical analysis.

While it is a new theory only recently moved from abstract mathematics to the application area, the only formal requirement which it is necessary to fulfil in order to apply the cusp catastrophe model to situations such as the pastoral system under consideration is that the rate (values) of the process of landscape formation is expressed as a bimodal scale which is controlled by the two variables of (a) climate, as measured by annual rainfall and (b) the stocking rate, as measured by sheep numbers plus estimates of the rabbit numbers.

One of the particularly useful aspects of the model is the way that it includes both the initial and ongoing states of the landscape, so that different combinations of values can be studied as changes occur.

As a consequence of its definition, the cusp catastrophe is the formal description of a system with two control variables. In the historical context of the grazing industry, one could suggest other possible control variables, for example, number of bales of wool produced per year or the total financial return for a district. These, however, can readily be reduced to terms of stock carried per acre, so stocking rate seems to provide a realistic measure of the strain imposed by pastoralism on the environmental system.

The process of landscape formation has been observed in some places and at some times as being a slow response to gradual changes in the control variables. The current state of the European landscape has long been recognised by historical geographers to be the product of many centuries of human manipulation. In the lower Lachlan the early phase of pastoral settlement seemed to follow a smooth pattern of this sort. Quite soon after Mitchell's journey in 1836, the first leases were taken up and hoofed animals introduced. Their numbers grew rapidly, but few immediate changes were reported in the landscape.

However, even on a local scale, some changes to the stability of the landscape do appear to be very sudden. Examples abound throughout the state during the early phase of occupance and include the disappearance of the edible scrubs from the Western Division in a period of about twenty years. This suggests that environmental thresholds are involved in the response patterns. The curve of the fold on the cusp catastrophe is a modern mathematical expression of such a threshold and so provides a powerful model of the process.

The proximity of the system to the fold curve on the graph also determines the sensitivity of the system. Should it be located at some distance from the fold and if its relaxation path avoids the cusp, then the adjustment of the system will be smooth and no sudden jumps will occur.

As elsewhere in Australia, the first European settlers found a landscape that had a rich accumulation of the perennial grasses and scrubs on which they could establish an industry. The graziers in the first wave who arrived at the Lachlan between 1840 to 1860 increased the stock load on the environment very substantially and very rapidly but this did not produce a jump in the values of the landscape variable as the system was not then located near an environmental threshold. There was a large reserve of perennial grasses which provided capital to sustain the increase in stock numbers. Moreover, it seems that the rainfall did not vary much for several decades. This situation is set out in Fig. 9.

However, if the initial state of the system is located near to the fold, it is very sensitive to change. Such a situation can be seen in the response pattern of the landscape variable in later years. When rabbits arrived in the area in about 1880, they produced a sudden and unexpected increase in the stocking rate variable.[11] Their numbers have been estimated by various experts and can be expressed in terms of 'sheep equivalents', as shown in Fig. 11. The number of sheep in the Western Division increased from 6.5 million head in 1879 to 15.3 million head in 1887. At the same time, the number of rabbits grew from zero to 16 million sheep equivalents. Few land holders could have been aware of the true magnitude of the rabbit population during the early years of this process and so both variables continued to grow and the total grazing load on the landscape increased fourfold. This is a large increase but comparable rates of growth had occurred throughout the 1870's without a sudden deterioration in the environment.

The crucial difference at the later time, was that the system was closer to a threshold because of the changes that had been occurring, especially:

(a) Eating out of the saltbush and other perennial shrubs;

(b) Clearing of the tree cover for grazing and specialist usage such as construction of woolsheds, sheepyards, dips and farm buildings and the powering of steam engines;

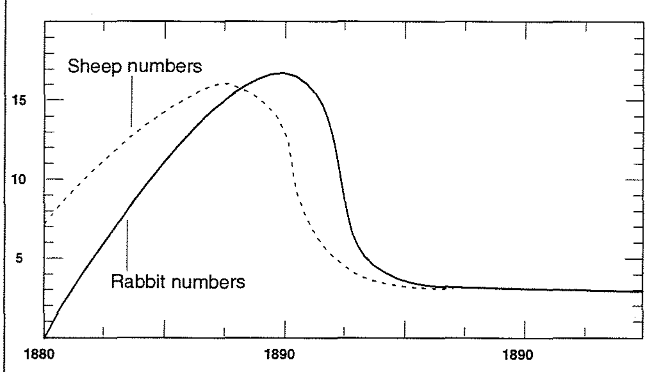

Fig. 11: The number of stock carried by the Western Division. Sheep numbers from statistical returns; Rabbit numbers expressed as sheep equivalents, where ten rabbits are taken as equivalent to one sheep.

(c) Drought had already affected the quantity and quality of annual grasses;

(d) Qualitative changes to the herbage as the rabbits ate out the choicest growth at the roots thereby killing the plant.

Any additional load at such a time, when the system was located near the fold, would cause the relaxation path to cross the fold and rapid landscape instability could occur. The records show that large and rapid changes did in fact occur at this time and these are described in the Report of the Royal Commission on Western Lands.

The Jump Conventions of the cusp catastrophe specify that the precise rate of the relaxation path will depend on how the threshold is crossed. As was explained above the possible conventions are perfect delay, Maxwell delay or random delay (Fig. 12). This flexibility of response makes it clear that it cannot be assumed that all landscape change occurred in the same way. Just as in cases when an outcome of a smooth or abrupt relaxation path is involved, the sensitivity of the system is important here. Consider, for example, the situation where a very large build up in the stocking rate occurs following a flood so that the ground water level is high even though all the herbage is quickly denuded and the surface of the ground shows cracking. In the absence of other problems, the relaxation path should be through the narrow part of the fold as the system will recover to its stable threshold more readily than in very dry conditions.

At the time, however, the landscape may appear similar to that on an adjoining block which missed the flood but was subjected to several years drought with constantly high stocking levels. As its originally lush vegetation was eaten out at the roots by rabbits and the seeds blew away with the topsoil it will enter the fold on a steeper path than its neighbour and may emerge at a very distant point, that is, it may be much more severely eroded before it regains its stability. The characteristic of Bimodality which is entailed by the model suggests that a system undergoing change can respond in one of two ways should the point representing the system be located in the area of the fold. Fig. 13 sets out such a case. For a given set of values of the control variables, say 10 sheep to the acre and 10 inches of annual rainfall, the response variable x will be projected onto both the upper and the lower surfaces of the graph. The antecedent conditions are important in determining which relaxation path will be taken. In a year when this stocking rate represents a reduction of fifty per cent from the previous year when the rainfall was 8 inches, the point would be located on the lower part of the graph at G^2. In this sensitive location near to a threshold, such a change would push the response over the fold curve and a sudden improvement in grass cover, and therefore surface stability, would occur.

In a season following several good years when there was ample grass already, the point would be located towards the top of the graph in a region away from the fold. No threshold would be encountered and no sudden jump would result.

The initial position of a system on the surface is also important when considering Hysteresis. In a case of simple hysteresis, an initial increase in the stocking rate of sheep may lead to improved management of the land and to deposits of animal manure which enrich the soil and encourage the growth of good quality grasses rather than the initial cover a weedy mix which is early eaten out. The capital generated by the sale of the wool may be invested in fencing which is used to prevent stock concentrations at vulnerable points near waterholes and to exclude rabbits. In theory at least an increased stocking rate may thus lead to a regaining of the stability lost under a less well managed but numerically lighter load.

However, should complex hysteresis result from the position of a system near the threshold the path will be different. For example, the proportion of rabbits in the total stocking rate may increase over several dry seasons despite a reduction in sheep numbers. The greater damage which rabbits inflict on the pasture, trees and soil will push the system near to the fold and the path will vary accordingly, as in Fig. 14. Divergence describes the situation where two initial points are similar, but an increase in either a or b produces very different results. Again, should one relaxation path pass through the threshold curve, it can take a very different path to the other which just skirts the fold without entering (Fig. 15).

Consider, for example, two systems with similar stocking rates and adjacent positions near the threshold. A very slight increase in rainfall could come at a critical time (e.g. in spring) in one but not the other. Such a slight differential could allow this system to move down a relaxation path beside the threshold while the other one is pushed over the fold. Very small differences in rainfall can been seen to have disproportionably large effects in the study region. The records for the town of Lake Cargelligo show that this part of the area enjoys a consistent advantage over Hunthawang Station of about one inch per year.[12] This threshold, however, is enough to permit dry land wheat growing on the south side of the river. There is also a wealth of anecdotal material recording how one crop was saved by a shower at the last minute while a nearby one was lost for its lack.

The final characteristic, Convergence, models the situation where two widely separated points can converge toward the same end values. The swift reduction of the initially lush saltbush areas with river frontages to a condition resembling the arid mallee plains at some distance from the river, suggests that the system moved closer and closer to the fold under the influence of constant changes in the rainfall and stocking rate variables.

CONCLUSION

This brief exploration of an application of catastrophe theory to the ecological system encountered by the early European pastoralists on the Lachlan has led to the identification of a range of responses. Not only the

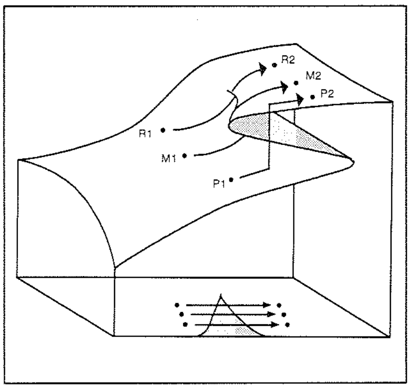

Fig. 12:

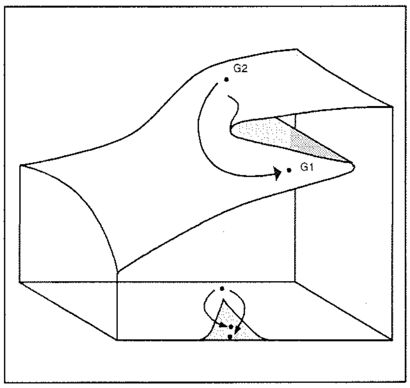

Fig. 13:

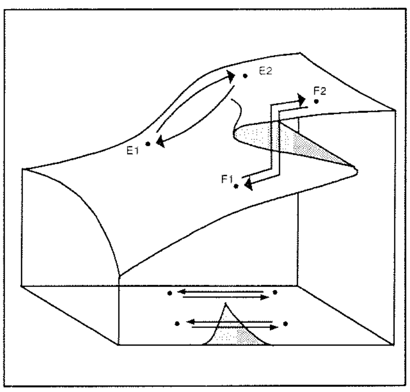

Fig. 14:

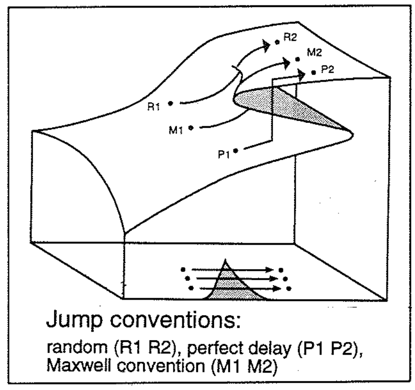

Fig. 15:

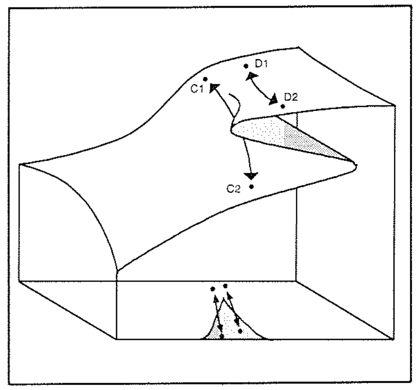

Fig. 16:

12: Jump conventions across the fold.
13: Bimodality. Point G_1 represents the system near the threshold. Point G_2 shows the system in a stable region of graph G.
14: E: More sheep on good well-watered land. F: More rabbits and less sheep during drought.
15: C: No spring rainfall. D: Small spring rainfall
16: C: Saltbush area near river under heavy stocking and drought. D: Arid mallee plain under light stocking and drought.

obvious relationships of amount of rainfall, number of sheep etc, but also combinations such as increasing rabbit numbers with condition of perennial grasses, proximity to water with duration of drought, emerge as important determinants of system response. Relationships between variables which seemed unimportant at the commencement of the study were seen to have played a role in the catastrophic transformation of the ecosystem. The study confirmed the view that the utility of the model rests on its ability to suggest interactions and behaviors among the variables that are not intuitively obvious.

NOTES

1. Oxley 1820: 125-132.
2. Mitchell 1839: 33-38.
3. Report of the Royal Commission 1901.
4. Cantlon 1981: 139.
5. Freeman 1980: 22.
6. Royal Commission 1901, Part I, Summary of Evidence: 11-25.
7. Royal Commission 1901, Report:v-vi.
8. Thom 1972.
9. Thom 1976.
10. Poston and Stewart 1978.
11. Condon 1976b.
12. Cannon 1992: A20.

Photographs by John Cannon.

Map produced by Cartography, University of Sydney.

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