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PIOSPHERES AND THE STATE-AND-TRANSITION MODEL OF VEGETATION CHANGE IN CHENOPOD SHRUBLANDS

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ABSTRACT

New approaches to rangeland management which are directed at overcoming the problems caused by spatial and temporal heterogeneity in paddocks, must be applied in an integrated way. This will maximise their usefulness in improving management. Thus concepts such as the state-and-transition model, which is essentially a temporal model of vegetation change, must be applied at the scale of full-size commercial paddocks and must take account of spatial heterogeneity within paddocks. Ultimately however, computer-based spatial models of both animal distribution in paddocks and erosion must be integrated with temporal models of vegetation change.

This paper demonstrates one simple example of how spatial aspects of grazing impact around a water point (ie. the piosphere) can be integrated with the state-and-transition model. It shows how different vegetation states occur as distance from water increases and how changes in state are reflected as changes in piosphere size. It describes these states and the transitions between states for saltbush (*Atriplex vesicaria*) in the chenopod shrublands of SA. The implications of this for rangeland management and research are briefly discussed.

INTRODUCTION

Recent years have seen a recognition of the important influence spatial and temporal heterogeneity has on the key ecological relationships in Australia's arid lands (Stafford Smith and Morton 1990). In the past, spatial heterogeneity has often confounded attempts to detect biological change but now new methods based on spatial processes have been developed to provide better indices of landscape change (Stafford Smith and Pickup 1990). Similarly, temporal heterogeneity has often resulted in an inability to predict the changes in vegetation resulting from the application or removal of extrinsic factors such as grazing (Griffin and Friedel 1985). In part this has been due to the inadequacies of the range succession or 'climax' model of vegetation change upon which our ideas were based, so to improve our predictive powers, Westoby *et al* (1989) proposed an alternative model of rangeland dynamics, the state-and-transition model. This model suggests that rangeland vegetation can be described by a catalogue of alternative discrete states with a range of possible transitions between states, depending on the combination of climatic events and management factors which are imposed. The focus is on management of the vegetation based on the ecology of the plant species involved. It is potentially a very useful model since it is a temporal model dealing in a time-frame which is appropriate to management. It is also compatible with other important concepts such as thresholds of change in range condition (Friedel 1991, Laycock 1991).

Despite these changes in approach it is often the case that these sources of heterogeneity and their effects on the vegetation and livestock are treated in isolation of the other. Frequently the emphasis is on temporal changes in vegetation only, but recently Coughenour (1991) has stressed the need to relate plant responses to herbivory to spatial grazing distributions. To improve range management Pickup and Stafford Smith (1987) suggested we need to integrate models of soil dynamics, animal distribution and vegetation response - that is, our understanding of spatial and temporal variability needs to be applied in an integrated way. As a start they have shown how spatial models of erosion processes can be integrated with models of the patterns of animal use, to help land managers locate the critical areas within their paddocks where management needs to be focussed. Less progress has been made with the integration of vegetation responses into these models, especially for pastures dominated by long-lived perennial chenopod shrubs.

This paper demonstrates one simple example of how spatial aspects of grazing impact, where water is the dominant factor affecting livestock distribution, can be integrated with temporal aspects of vegetation change in the form of the state-and-transition model. This example is taken from the chenopod shrublands of South Australia where I have been studying the dynamics of saltbush (*Atriplex vesicaria*), a desirable perennial shrub, under sheep grazing in an established piosphere (>50 years old). It includes different states and transitions for saltbush shrublands than those suggested by Westoby *et al* (1989).

THE SOURCES AND NATURE OF HETEROGENEITY

Spatial Heterogeneity

The diversity of soils in Australia's arid lands together with the effects of contemporary processes such as erosion and deposition are the main sources of the high degree of spatial heterogeneity apparent in the zone (Stafford Smith and Pickup 1990). The result is that most of Australia's arid lands consist of a mosaic of 'fertile patches' scattered through large expanses of poorer landscape. These patches are important in determining the location and nature of vegetation communities.

However, introduced domestic livestock are themselves another source of spatial heterogeneity. The need of livestock for water, feed and shade as well as the effect of wind, topography and feed preferences on their behaviour result in uneven use of the landscape by them (Stafford Smith 1988). This not only enhances the natural pattern of landscape processes such as erosion (Stafford Smith and Pickup 1990), it also imposes an additional pattern on the vegetation (ie. the piosphere) which is focussed around watering points (Lange 1969). This is particularly pronounced in the chenopod shrublands.

In the piosphere stocking pressure attenuates linearly with distance away from the water point, creating an almost radial pattern of impact on the vegetation (Lange 1969, Barker 1979). The major changes to the vegetation involve a reduction in the density of the long-lived palatable perennial plants as proximity to water increases with a concomitant increase in less palatable or shorter-lived plants. Over the long term, the cumulative effects of grazing result in a sigmoidal pattern of impact as the palatable perennial plants are completely removed by grazing close to the watering point (Graetz and Ludwig 1978). Under the range succession model these changes have been interpreted as retrogression along the successional pathway. Hence, removal of grazing is expected to result in a reversal of these changes in the vegetation.

Temporal Heterogeneity

The main source of temporal heterogeneity in Australia's arid zone is the unpredictable climate. Short-term fluctuations and episodic events such as occasional periods of heavy rainfall and long droughts are characteristic of the arid zone. These episodic events can play an important part in bringing about major changes to the vegetation, particularly in the long-lived perennial component (Griffin and Friedel 1985, Friedel *et al* 1990), and are thus considered important in inducing transitions between states under the state-and-transition model.

Short-term climatic fluctuations naturally will cause temporal variability in factors such as plant growth rates, phenology and physiological states, and will affect the amount of feed available for livestock. This will ultimately affect the grazing pressure exerted on the perennial components. As well, the relative importance of various 'spatial' factors will change with these fluctuations (eg. wind direction, livestock's need for water and shade etc.), affecting the distribution of livestock within paddocks (Lange 1985, Stafford Smith 1988). Thus there is an interaction between the components of spatial and temporal heterogeneity.

THE DYNAMICS OF PIOSPHERES

The result of all this variability combined is that even under the normal practice of set-stocking, there is considerable spatial and temporal variation in the defoliation of perennial shrubs by livestock. Graetz and Wilson (1984) have suggested that seasonal variation in the availability of ephemeral fodder provides an inbuilt 'rotational grazing system' where under set-stocking the perennial plants are rested from grazing during winter when abundant ephemeral fodder is available. They imply that this rest period is sufficient for preferred perennial plants such as saltbush to recover from grazing experienced during the previous dry summer period.

Spatial heterogeneity can often increase the stability of plant-herbivore interactions (Coughenour 1991). Herbivores will move to areas of greater feed abundance so that as an area is grazed down by them it becomes less attractive to them and they move elsewhere. This would provide the plants with periods of rest from grazing and perhaps permit recovery. However, in pastoral ecosystems with set-stocking, this does not occur because movements are restricted by fences and the location of waters, although during droughts sheep will walk more quickly through areas of low forage abundance around waters in order to reach less eaten out areas (Stafford Smith 1988).

Of course in practice, close to the water point grazing pressure is so high and defoliation so frequent that saltbush plants are eliminated and are replaced by short-lived ephemeral species. However, it is thought that under a constant stocking level a balance exists at some distance from water between grazing impact and the recovery of the plants (Stafford Smith 1988). The piosphere once established is therefore often thought to be stable with no further change in its size over time.

It is feasible that in many years a balance could occur between defoliation and the recovery of the perennial shrubs at some distance from water, with little apparent degradation resulting. But in a highly variable environment such as the Australian rangelands, where episodic events and short term fluctuations in climate are typical, plant growth and herbivore consumption functions will not be constant so it seems unlikely that a balance would always exist. Hence piospheres are probably dynamic rather than stable features of arid grazing systems (Andrew 1988) and at certain times the grazing rate at a certain distance from water may exceed the recovery of the vegetation. For example, during droughts (ie. when winter rains fail) the bushes are unable to recover from the grazing of the previous summer but grazing also continues to occur. This reduces the vigour of the plants which may inhibit or reduce flowering, seed production and recruitment and increase bush mortality causing a reduction in plant density (Hunt 1990). This degradation will be manifested as an increase in the size of the piosphere (Warren and Maizels 1977). This can often occur quite rapidly while the process of recovery is normally much slower (Friedel 1991), particularly if it involves the recruitment of new individuals. If saltbush plants have been heavily grazed, at least two consecutive good seasons or episodic heavy rainfall is required for recruitment to occur. During these periods grazing of the bushes is reduced sufficiently at a certain distance from water to allow recovery. This recovery will be seen as a reduction in the size of the piosphere, demonstrating the dynamic nature of piospheres.

However under set-stocking, recovery is less likely to occur than degradation. This is because of the slowness of the rehabilitation process, requiring favourable conditions to be maintained over a longer period than that in which degradation took place. It seems likely then that rather than a balance between grazing and recovery of the plant population existing over the long term, set-stocking causes sudden increases in piosphere size during droughts which are not reversed at other times. This could continue up to the maximum distance that the livestock were able to graze from water. This is supported by one study which showed that a piosphere continued to develop during 45 years of grazing so that almost all the palatable perennial plants were removed for up to two kilometres from water (Fatchen 1978).

APPLICATION OF THE STATE-AND-TRANSITION MODEL TO PIOSPHERES

It would appear from the above discussion that 'abnormal' seasons or a series of them, are critical in terms of both the degradation and recovery of piospheres. The idea that unusual years are important in degradation and recovery is consistent with the ideas behind the state-and-transition model, so it seems possible if not logical, to apply the model to the piosphere (ie. apply the model spatially thus integrating some aspects of the spatial and temporal heterogeneity of arid grazing systems). Hence the piosphere can be considered as a number of roughly concentric zones around a water point in which the vegetation in each zone is in one of the states possible under the state-and-transition model. As transitions between states occur these zones will be seen to move either towards or away from the water point, decreasing or increasing the size of the piosphere, depending on the requirements for transition.

This approach should help in the understanding and management of vegetation change where grazing is an important factor in determining transitions between vegetation states, such as in overcoming the problem of sudden increases in piosphere size in the chenopod shrublands under set-stocking.

STATES AND TRANSITIONS IN THE CHENOPOD SHRUBLANDS OF SOUTH AUSTRALIA

Three vegetation states can be identified around water points in the South Australian chenopod shrublands, where mean annual rainfall is approximately 200-300 mm and the soils are generally loam to clay-loams. Two of these states are persistent stable states, while the other is transient. The catalogue of states and transitions for these shrublands is presented in **Box 1**. The position of the states around a hypothetical water point and how they 'move' away from the water under set-stocking are shown in **Fig. 1**. This is represented in **Fig. 2** in terms of the sigmoidal pattern of impact reported by Graetz and Ludwig (1978).

This state-and-transition model description differs from that of Westoby *et al* (1989) for saltbush shrublands on the Riverine Plain of NSW. In their description the transient state (State II) consisted of a substantial soil seed bank or seedling population of saltbush but no adults and the vegetation was dominated by *Danthonia caespitosa* (a perennial grass) and short-lived chenopods. This is said to result because when short-lived species provide the bulk of the feed (ie. normally winter) there is little grazing pressure on saltbush so presumably flowering and seeding continue unaffected. But once the short-lived species have been consumed, complete defoliation and death of saltbush is rapid within grazing range of water, leaving only the soil seed bank or seedling population. Experience in SA though suggests that considerable grazing of the saltbush closest to water occurs in many years reducing plant vigour (but not significantly increasing mortality) and preventing flowering so that over a number of years the soil seed bank becomes depleted (transition 1), creating the transient state. Then when significant mortality of these plants occurs during drought years (transition 2), almost nothing remains of the saltbush population at these locations (State III). However, the plants further from water which are normally lightly grazed are better able to withstand the heavy grazing they experience during drought and little mortality of these occurs. A further difference is that whereas State III is considered just as desirable as State I on the Riverine Plain because it is dominated by useful perennial grasses, in the SA shrublands State III is dominated by ephemeral species making it much less desirable than State I. Hence, although the stable states in each description of the model are basically similar, the transient state and transitions between states are different. This might arise because the subspecies of saltbush found on the Riverine Plain may be less tolerant of grazing even though higher rainfall and different soil characteristics may make the Riverine Plain a more favourable environment for saltbush. Higher and more reliable rainfall may also produce more ephemeral forage so that overall, grazing of saltbush on the Riverine Plain is lower and less frequent.

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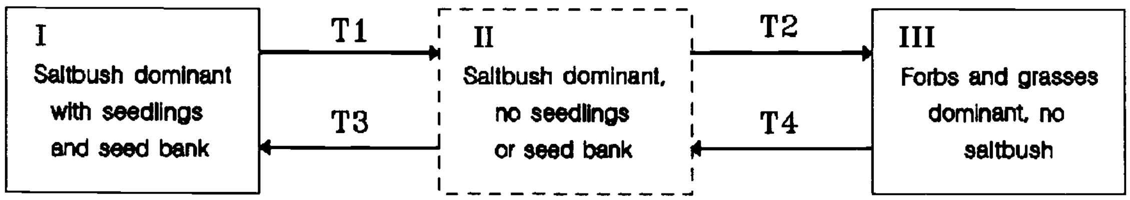
Box 1. State-and-transition diagram and catalogues for a bladder saltbush (*Atriplex vesicaria)* piosphere in the chenopod shrublands of SA. (after Westoby *et al* 1989).



<u>Catalogue of States</u>

<u>State I</u> Saltbush is dominant. Saltbush seedlings and a soil seed bank of saltbush are present. A small proportion of ephemerals and perennial grasses.

<u>State II</u> Saltbush is dominant but with reduced vigour and with a moderate contribution of biomass by ephemerals and/or perennial grasses depending on seasonal rainfall. There are neither saltbush seedlings nor a soil seed bank of saltbush. This is a transient state.

<u>State III</u> After adequate rainfall ephemeral forbs and/or perennial grasses are dominant otherwise the ground is bare. All saltbushes are dead and there is no saltbush soil seed bank. The soil surface cryptogamic crust is destroyed and erosion is accelerated.

In each of these states perennial chenopods which are more resistant to grazing (eg. *Maireana sedifolia*) may be present.

<u>Catalogue of Transitions</u>

<u>Transition 1</u> Continued moderate grazing of saltbush over 3-5 'average' or dry years without sufficient rest periods, leading to a reduction in plant vigour. This inhibits flowering so there is no input to the seed bank. Seed bank becomes depleted through predation of seeds by ants (Williams 1972 cited by Briese 1982) and decay. This prevents the appearance of new seedlings.

<u>Transition 2</u> Drought together with continued heavy grazing will kill most saltbushes with already reduced vigour. Actual mortality rate will depend on drought duration. This is a relatively rapid transition which may take as little as one year. It leads to an increase in piosphere size.

<u>Transition 3</u> Protection from grazing and rainfall to stimulate bush growth, flowering, seed production, germination and establishment. Plants in poor condition need considerable time for vigour to increase sufficiently to be capable of flowering and setting seed in significant quantities, so several good years or rainfall events in succession are necessary. Consequently this will be a slow transition which may be delayed by the infrequent occurrence of suitable conditions.

<u>Transition 4</u> For this to occur in a reasonable period of time (5 years), it requires the introduction of saltbush seed by management (saltbush seed is not very mobile [Williams 1979] so it is unlikely to be naturally transported from areas in State I) and protection from grazing, together with rainfall for seedling germination, establishment and growth. It may also require the creation of germination sites by furrowing or pitting of the soil. The probability of success is low and the treatments can be expensive.

This transition can occur naturally over a period of 20-50 years simply by protection from grazing. Areas in State II will respond to protection from grazing and adequate rains so that seeds are produced and seedlings established. Gradually bushes will establish closer to the water as conditions allow, so that the area in State III slowly contracts (c.f. Hall et al 1964). However this will occur too slowly to be of practical use to management. This transition leads to a reduction in piosphere size.

Opportunities and Hazards

Because a dense cover of saltbush contributes to the stability of pastoral production and protects the soil from erosion, State I is highly desirable. This state also has conservation value. State III is the most undesirable, so the proportion of a paddock in this state should be kept to a minimum. State II is thus the critical condition because while transition 2 is rapid, transition 4 is slow and difficult to achieve. Transition 2 must be avoided by preventing heavy grazing in drought. The opportunities for flowering and seeding (transition 3) should also be utilised since it is inevitable that transition 1 will occur at some distance from water. Managers however, may be reluctant to utilise these opportunities because they involve the short-term cost of lower stocking rates.

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In addition to the vegetation states described above, a further state is possible on duplex soils, as pointed out by Westoby *et al*. (1989). Here, following the removal of the perennial shrubs, erosion can remove the topsoil leaving a scald devoid of vegetative cover. This is obviously the most undesirable state.

DISCUSSION

Westoby *et al* (1989) proposed the state-and-transition model as a useful way to organise information about vegetation change for management, so it follows that it should be applied in a way that reflects how domestic livestock utilise paddocks. Ignoring spatial patterns of vegetation utilisation by livestock will lead to confusion about what changes are occurring to the vegetation of a paddock and the reasons for those changes. Management will need to assess and monitor vegetation condition over complete paddocks but the focus of attention will need to be on those parts of the paddock which are favoured by livestock. Decisions based on an assessment at only one or two points in a paddock or on areas only lightly utilised will not give a true indication of changes caused by livestock.

To achieve this spatial application in a way that management can use our ideas about vegetation change will need to be integrated with models which predict livestock distribution and susceptibility to erosion. This is particularly important where paddocks are very large and there is more than one focus of livestock activity (eg. multiple waters and shade locations and several different vegetation communities within a single paddock). Understanding and predicting vegetation response to grazing is an important step in preventing over-grazing, erosion and a loss of production. Of course, our understanding of vegetation response will include the effect grazing has on plant population dynamics and associated processes.

Where water point location is the dominant factor affecting livestock distribution, vegetation changes within the piosphere and the distance of these changes from water will be the important indicators for management to monitor. Management decisions will revolve around the possible transitions between vegetation states and will involve taking the opportunities for reductions in piosphere size and evading the hazards which may lead to an increase in piosphere size. These decisions will depend on what is considered an acceptable size for a piosphere.

Researchers will also need to consider spatial heterogeneity when investigating the causes of vegetation change, particularly under grazing. Experimental plots will need to be located at a number of distances from water or alternatively results from small plot regression experiments must be interpreted in conjunction with measures of stocking intensity across actual paddocks. Greater effort is also needed in integrating changes in vegetation with computer models of animal distribution and erosion. Management recommendations and grazing systems derived from this work then need to be integrated into the economic framework of the pastoral industry.

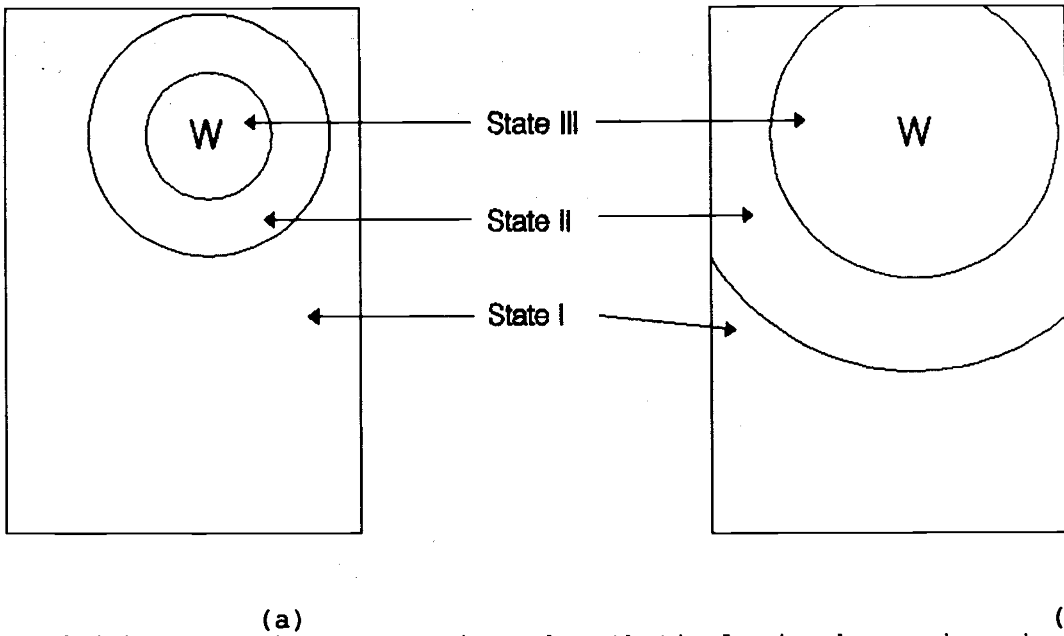

Figure 1.(a) Vegetation states in a hypothetical piosphere, ignoring the effects of wind etc. (b) The same piosphere showing further degradation, which may follow many years of continuous stocking. W is the water point.

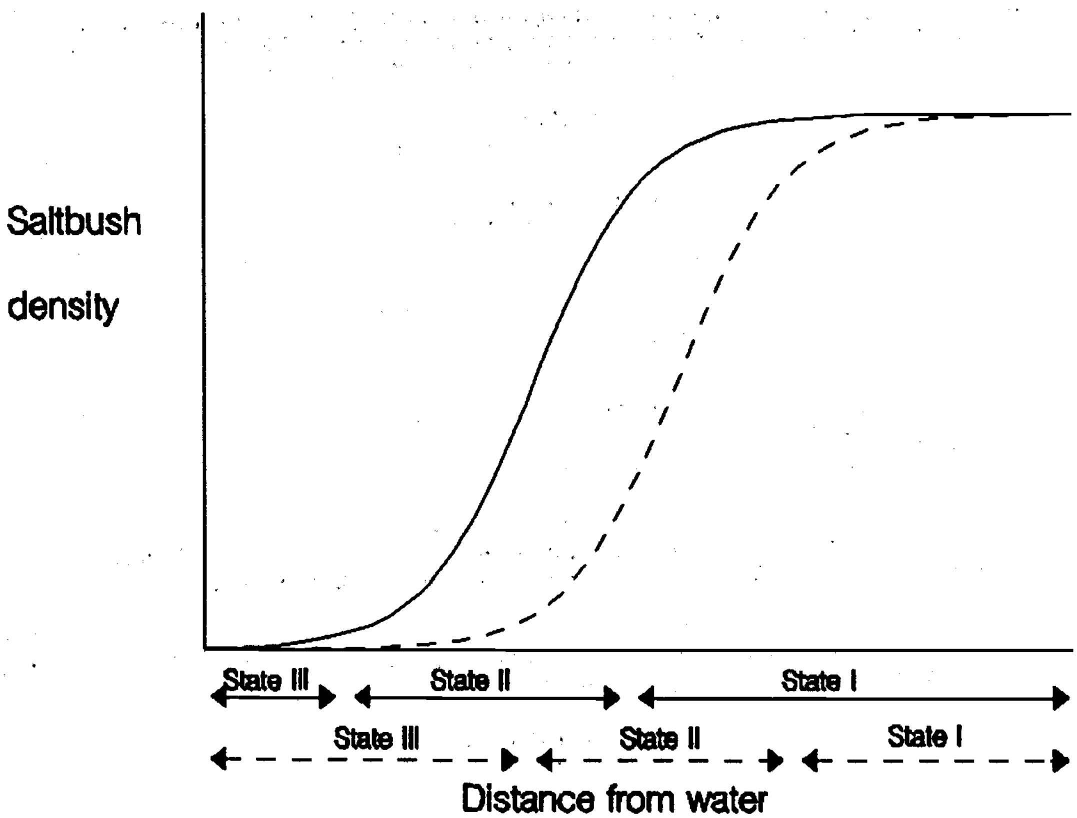

Figure 2. Postulated changes in a piosphere in terms of the logistic response curve and how the vegetation states in Box 1 relate to this. Solid line and arrows represent earlier condition while broken ones are after further degradation.

In addition it should be realised that the state-and-transition model will not necessarily be useful in all rangeland types all of the time. For example, in the chenopod shrublands sudden reductions in the number of saltbush plants and the difficulty of getting an increase in numbers, which are important events for management, are well described by the state-and-transition model. But in the long-term, removal of grazing will lead to an increase in shrub numbers, a process better described by the range succession model. This is because the state-and-transition model is a tool for achieving specific range management goals and not a theoretical model of vegetation change. However, to maximise its usefulness where it is relevant to management, it is important that it be applied in a spatial context.

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