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Burning for Biodiversity - Some Mosaic Mathematics

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What the Devil does *Coterminous* Mean?

The word *coterminous* is unfamiliar to most people. Well, it was to me, until a few years ago, when I read something about the "*coterminous United States*". This means those states of the union which have a common boundary, so excluding isolated states such as Alaska and Hawaii.

If we consider areas of natural vegetation in south-western Australia, then a coterminous area may be bounded by natural features, such as ocean, river or rock, or by a change in vegetation type, often connected with soil and topography. Coterminous boundaries may be simple, or convoluted, and coterminous areas may be entire, or perforated, a bit like an ocean with islands in it. Such islands may be ecologically important, in that their fire history and biota may be very different from the surrounding vegetation. They may serve as refuges for more fire sensitive plants or animals.

Within a coterminous area of fire prone vegetation, there will usually be a mosaic of vegetation patches, with different ages since the last visit by fire. Ecologists might call this "*seral diversity*", and most would agree that it is better to have a fine grained (many small patches) than a coarse grained (a few large patches) mosaic. A fine grained mosaic offers, within a given area, more variety of shelter and feeding opportunities, and more short-distance changes in microclimatic effects, such as shade and sunlight, shelter from wind, and soil moisture.

Oh Drat Them Mathematicks…

Any vegetation mosaic will have three fundamental properties. These are the number of patches at any year (**Pn**); the number of patches burnt over a run of years ($\mathbf{B_i}$); and the fire return period for that vegetation (**r**). If a mosaic has two, or more, adjacent patches with fuel of **r** years or more, then under unrestrained fire spread, such a mosaic will be unstable, in the sense that those patches will merge, so reducing $\mathbf{P_n}$. If all patches in a mosaic are of **r** years or less, then the mosaic is stable, with $\mathbf{P_n}$ constant, even under unrestrained fire spread.

It has been found, by investigation of a number of mosaics, that these three variables are connected in an interesting way. No proof is offered here, but may be presented in a later paper. However, the validity of the two expressions below can be checked by anyone, simply by inspection of a series of sketched mosaics.

Mosaic Formula 1:

$$P_n = \sum_{n-r+1}^{n} B_i$$

When the number of patches burnt each season is constant (**B**), as it may be under human management, then the above expression simplifies to:

Mosaic Formula 2:

$$P = Br$$

Scenarios can give Insight…

In many management situations, scenario writing can open a few mental doors. Professor Stephen Pyne, of Arizona State University, is the world's leading fire historian. A few years ago, in an essay called "*If I ran the Zoo*", he suggested four fire management options. These were:

1. Do Nothing, Let Burn.
2. Suppress Fire.
3. Do the Burning Yourself.
4. Change Combustibility.

Adapted to the West Australian context, we may consider the following four scenarios:

A. Terra Nullius, or Nature Knows Best.

If all human fighting and lighting is removed, but a "let burn" policy is adopted when lightning strikes, then the mosaic will, after a number of years, stabilize. It will however, be very coarse, with only **r** patches.

I believe this policy has been adopted in some parts of the U.S.A., such as Gila National Forest in New Mexico. Such large fires may spread for months, monitored by park staff. They are only tackled if they approach park boundaries or tourist facilities. I don't know what the fire return period is for Gila National Forest. It probably contains a number of coterminous vegetation types, each with its own characteristics. It would be interesting to see if each mosaic has yet stabilised, and what the range and median size of patches is.

It seems certain that, given twenty to forty lightning strikes in south-western Australia each summer, then large areas of the dry eucalypt forests and woodlands would have burnt each year before European arrival, regardless of Aboriginal activity. Since these forests and woodlands will carry fire every 2-4 years, then most points would inevitably, have been visited by fire at that frequency, due to lightning alone. Given continuous fuel, and no major fire suppression or obstruction, each fire would have been enormous.

Even as recently as the 1920s, such large, creeping fires, burning for months, were known. Although large in area, the flame height, in light fuel, would have been generally low – the sort of fire a human, or kangaroo, could easily jump over. Sometimes the Forests Department sent a man on a bicycle, with an axe on the crossbar. On arrival, he would cut a sapling (red gum were the best, being juicier and heavier than other trees), and swat the fire out.

In over a hundred days of fire season, without human interference, a handful of trickling fires moving at only a modest kilometre a day could have burnt out a third of the total dry eucalypt area. In extreme conditions of wind and heat, fires in these forests can move at more than eight kilometres an hour.

A let burn policy may be appropriate for some remote parts of Western Australia, if a coarse seral mosaic is acceptable. This is a matter of conservation biology, but the research questions need to be objectively, rather than emotionally, chosen. The use of a let burn policy in areas of heavy fuel accumulation, due to long fire exclusion, needs caution. The mathematics will be correct, but the fires may, in the first few years, due to heavy fuel, be uncontrollable, dangerous, and ecologically damaging.

B. Ignis Nullius, or the Green Dream.

Some conservationists see Australian landscapes through a European cultural filter. They yearn for lush greenery, and see blackened country as "destroyed". They would, therefore, like to see fire excluded indefinitely from large areas. They would like all lightning fires to be immediately suppressed. The trouble is that this may be impossible when such fires occur in remote or difficult country, or there are multiple lightning strikes, and fire crews are too thin on the ground. So a fire will, eventually, and inevitably, occur.

The above formulae show, clearly, that if fire is excluded from an entire mosaic for a period exceeding the potential return period (**r**), then the mosaic becomes highly unstable. The next fire will, if unrestrained, burn out the whole mosaic, simplifying down to only one patch. This has happened several times in the south-west in recent years, where "*no planned burn areas*" have been attempted in National Parks or Reserves. Past seral diversity has been obliterated.

A single, large patch will be stable, provided it is burnt every **r** years. However, it will have low seral diversity. The few animals that survive the inaugural, extensive, fierce fire will, for a while, have no food or shelter. Such a policy would be (already is) damaging, leading to gross simplification, and impoverished ecosystems.

C. Noongars Knew Best – Black Lightning.

If, every year, any patch that will burn (**r**+), is burnt, then the mosaic will be stable, and the number of patches (**P**) in the mosaic will be maintained. Lighting whatever will carry a fire is the only way to maintain an initial seral diversity within a mosaic. Excluding fire from even some patches leads, inevitably, to patch merging, and a coarser mosaic. It is important that fire managers, conservationists, and politicians, clearly understand this.

Given a stable mosaic, fire suppression cost and danger will be greatly reduced, since no fire can spread beyond its own patch. This is probably what Noongars did in much of their country, although they were, on occasion, seen swatting fires out with green branches (see next scenario).

D. Light, Fight & Stabilise. – did Noongars know even better?

Their occasional fire suppression, and knowledge of the effects on fire of wind, slope, humidity, shade, and fuel quantity, suggest that Noongars probably knew even better than the previous scenario suggests.

If fire is skilfully timed, and placed, so that only part patches burn, or the fire is deliberately suppressed once part of a patch has burnt, then the mosaic will be enriched by the addition of extra, smaller patches. Given sufficient ignitions each year, such an enriched mosaic will stabilise, and can be maintained indefinitely.

With our present capacity for weather forecasting, fire detection, monitoring, and suppression, this is probably the best option for current fire management. Technology can be used to work with nature. In general, the more ignitions can be crammed into a mosaic, the more diverse will be the end result, and the easier it will be to maintain.

In the past, this mode of maximal burning, with some splitting of patches, would have enhanced microhabitat for the animals which Noongars hunted. It would also have maintained, or even enhanced, the high plant diversity seen in south-western Australia today.

Is this useful?

Clearly, the above formulae are powerful tools for prescribing a fire regime and mosaic grain for any coterminous area of vegetation, with a known potential fire return period. The final seral patchiness of the mosaic, once it stabilises, can be predicted. The formulae are dimensionless – patches could be a few metres across (micro-mosaic), or kilometres across (macro-mosaic). We need to work at many scales. There is an upper size limit, in that unrestrained fire might only have time, in the average fire season, to travel, say, a hundred kilometres or so, before autumn rain intervenes.

I hope fire managers will find this useful. The model has far reaching implications. It is based on geometry, rather than the dubious probability approach of some other models. Some models are based on the questionable assumption that random (modelers seem to prefer the word *stochastic*) fire intervals at any point favour greater biodiversity. I am unaware of any hard evidence that this is so, and common sense would suggest that it is not, given that most plants have a fairly regular longevity and life cycle. Varying fire intervals at any point may disadvantage them. In the jarrah, wandoo and tuart forests of south-western Australia, icon species such as grasstrees and zamias are blatantly declining under irregular burning. Even the eucalypts themselves are in decline, and Vic Jurskis, working in New South Wales, has suggested that this widespread malaise is connected with inappropriate fire exclusion.

Other models, based on plant life cycles, are strangely blind to the diversity of fire behaviour, for example failing to distinguish between a trickling fire in light fuel a few years old, and a roaring holocaust in heavy, twenty year old fuel. Both fires are assumed to have the same ecological effect, and kill all "*fire sensitive*" plant and animals in the area. Many botanists and zoologists are startlingly unaware on this point – perhaps they have never been close to a real fire, and felt the obvious difference in radiant heat alone. Any fire-fighter is vividly aware of the great difference in heat yield between light and heavy fuels. In truth, sensitivity to fire must be variable, even within the same species, depending on the nature of the fire, the age and health of the plant, moisture content at the time, and probably other factors.

Finally, this geometric model explains why grasstree research shows that, in the past, fire was surprisingly regular at many places, whether due to lightning or humans. The regularity was due to the inevitable cycling of fire, in unrestrained conditions, at the minimum fire return period for that particular vegetation type. The life cycles of the plants and animals must have meshed with this. Any that could not tolerate it died, fled, or retreated into the fire refuges which are so numerous in the dry eucalypt areas.

The diversity within any coterminous mosaic lay not in different fire frequencies, but in the fine grain of the mosaic, which gave a high seral mix. At the broader scale, there was diversity of fire frequency between adjacent coterminous areas, due to different vegetation with different fire return periods. It took me a while to get my head around this concept, but, once grasped, it seems obvious. Biodiversity is by no means as well defined as some seem to believe.

What next?

The next step for the Department of Conservation & Land Management (CALM) might be to test this model by prescribing fire mosaics in Ecological Conservation Units. A few should be tried first, and increasing confidence can lead to other, and larger areas. As stable mosaics are established throughout State Forest and National Parks, the cost, and danger, of wildfire suppression will dwindle. Controlled burning will be easier, with fewer escapes. The native plants and animals will definitely benefit, and the Noongar community will be delighted to see the bush "cleaned up" once more. After all, if our State Premier, Dr. Gallop, is as good as his word, Noongars may soon be having a large say in managing natural areas.

For plants and animals at the upper end of the fire sensitivity scale, fire refuges will be better protected by frequent burns around them, than by attempts at total fire exclusion from large areas. Small, unburnt islands in a sea of frequent burning are demonstrably sustainable. Such "*sacred groves*" and "*gallery forests*" are well known in Africa, and other parts. To attempt the inverse, islands of frequently burnt in a sea of fire exclusion, is "*mission impossible*". For some decades after World War I, the former West Australian Forests Department tried to maintain "*five chain breaks*" around long unburnt forest blocks. The disastrous results are described in Departmental Annual Reports.

I thought a preview of the idea might be useful to fire managers as summer approaches. Might it be wiser to let some wildfires burn, where there is no danger to human life or property? Or might CALM apply partial suppression, so leading to a richer mosaic? How patchy do you want it to be? Use the formulae and find out…

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