Biomass accumulation in grasslands and why it matters in south-east Australia [+]

John Morgan
La Trobe University, Bundoora

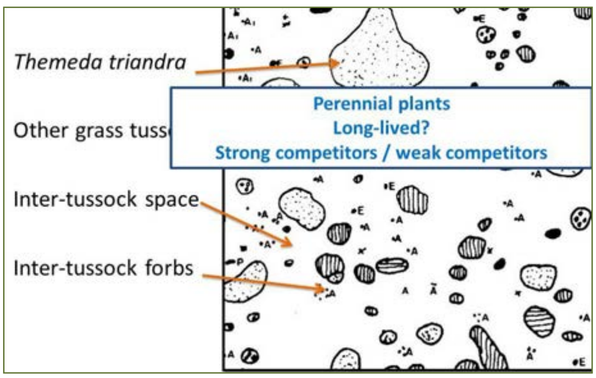
Abstract: Plant litter, in the form of the accumulation of dead grass leaves, is a key driver of vegetation dynamics in native grassland ecosystems in south-eastern Australia. Its impact on both plant and animal populations and their diversity has been long-recognised. With increasing biomass, plant diversity often declines and, when biomass remains high for extended periods, these declines are thought to be persistent. Accumulated plant material also contributes to the regulation of many ecosystem functions such as nutrient cycling, population dynamics and animal habitat suitability. Hence, understanding (i) the rate of biomass accumulation in relation to the time-since-last-disturbance and (ii) the implications of biomass accumulation on biodiversity is a crucial step towards the effective management of these endangered ecosystems. In this presentation, I discuss why biomass accumulates in grasslands, how to assess when the amounts of biomass might be seen as high, the implications for biota of high biomass, and techniques to reduce biomass to help reach management objectives such as maintaining species diversity and ecological function.

I am going to summarise my 20 years of research in the context of this forum. It will show a little of how we have thought about grasslands and the role that biomass plays in determining some of the key processes, such as plant conservation and animal habitat.

This perspective may be particularly related to Victoria but it certainly applies to the Monaro in southern NSW, and to other grassland regions of Australia such as Tasmania and East Gippsland. I would like you to think about what might or might not be relevant to your region.

When we first discovered grasslands in Victoria and also here in the ACT, we found them in places that might have had grazing by livestock but had been excluded from heavy grazing. We found them in places that had been frequently burnt, such as along roadside corridors, or railway lines, or cemeteries. Our best quality grasslands tended to be places that were not grazed heavily by stock, or, in Victoria, that tended to be burnt fairly frequently. That was where we saw the most plant biodiversity, such as in the photo at right.

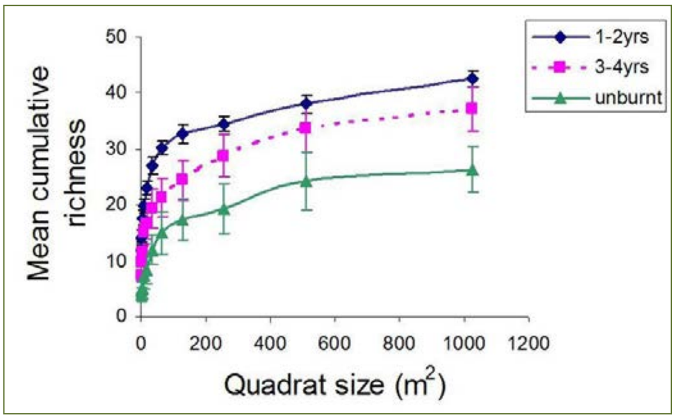
That got us thinking that probably disturbance plays a really key role in the values of grasslands, and we started to think about how grasslands are put together and why disturbance might be important. We looked at the classic hand-drawing from 1935 by Patton in Victoria (annotated, right; see also Wong & Morgan 2007), and it demonstrates the structure of grasslands that are typical all through the temperate zones of the world, and particularly in south-eastern Australia. Here there are tussock grasses such as Kangaroo



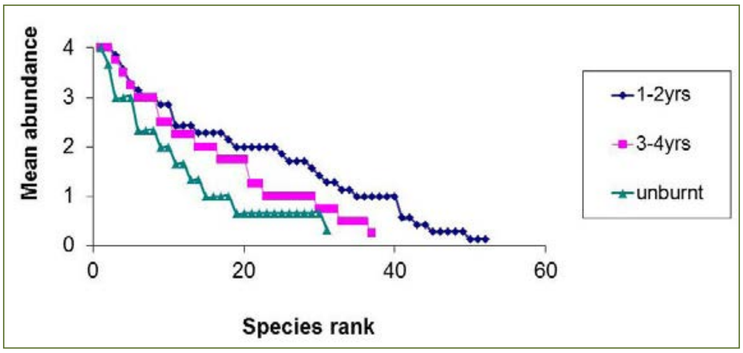
Grass *Themeda triandra*, and spear grasses with lots of inter-tussock space where all the other plant biodiversity resides. We have a structure with a dominant grass and everything else having to co-exist around it.

Based on that, we realised that the plants in grasslands are, by and large, perennial species. As a consequence, if they are long-lived, the number of species we might find in grasslands would depend on the dominance of some grasses over every other species. Remember, I am talking about our thinking 30 years ago. If this balance between grass and biodiversity is going to be a critical one, we need to understand that.

When we did our first surveys on grasslands we found again that the higher quality grasslands were the ones that tended to be burnt more often. The graph (right) shows the number of native species in grasslands we surveyed, counted in a range of quadrat sizes. This is important, because we want to know if good species richness carries through from small quadrats to the bigger scales, such as the scale of a whole site. Certainly in Victoria, we can see that there is 100% more plant biodiversity in frequently burnt grasslands (every 1–2 years) than in unmanaged, unburnt, ungrazed sites where Kangaroo Grass dominates.

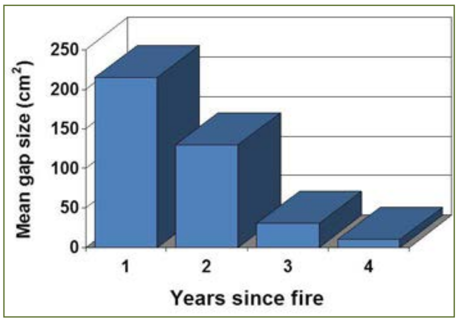


The next graph (right) shows that in the frequently burnt sites (blue dots; purple bars) there is a much broader distribution of abundances of plants. There are more species and they are more abundant. In thinking about why is this happening, the mechanism that allows this to happen, the key appears to be that sites that are being burnt are doing something different from sites that are being unmanaged. This is really interesting.



A not-so-friendly academic once described me as the guy who was studying nothing, because I wanted to know what was going on in gaps in grasslands. There often was not much going on in the gaps, depending on when I was looking. He used to ask me what I was finding and I would reply, 'Well actually, not much; there are no gaps; there isn't anything in them'. And I started making the link that gaps are really important for biodiversity of plants in grasslands.

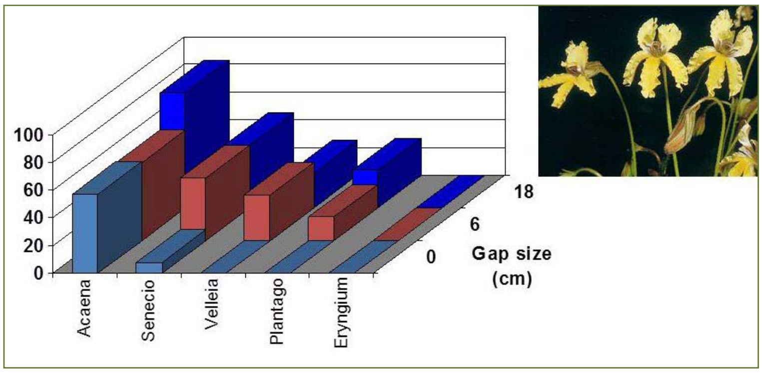
The gaps in grasslands are biggest immediately after a fire (bar chart right). Over time they diminish and become insignificant or not even present, which is interesting in itself. We needed to think about the implication of that. If the gaps are small, does that matter? And if they are big, why does that matter?



In 1992–93, 20 years ago, I started studying Button Wrinklewort *Rutidosis leptorrhynchoides*. It is found around Canberra and it also has a distribution in Victoria, and these populations are very distinct genetically. I chose Button Wrinklewort because people had pointed out that it is only found in the most open of the grasslands in Victoria. Wherever grasslands are dense it will not persist. If there are no gaps in a grassland, this little plant, which is a fairly weak competitor, would, in time, not be able to persist.

I went to a cemetery reserve near Melbourne, a good place for remnant plants, to explore the sensitivity of this species to gaps. I needed to determine whether gaps are important for the persistence of grassland plants. I focused on two grassland areas: one was fairly short and another was tall and rank. They differed in the time since they had been last burnt. When I planted a large number of plants of Button Wrinklewort in gaps of different sizes (0, 15, 30, 50, 100 cm) and followed their progress for one year, I found they survived best in the biggest gaps, and nowhere else in the short grassland. In the tall grassland area they did not survive at all. There was a bigger mean number of leaves and flowers in the big gaps – that is, the biggest gap (100 cm) and the next biggest gap (50 cm).

It seems that *R. leptorrhynchoides* is really sensitive to competition, probably for light. It does not grow in the base of tussock grasses. Therefore we need to understand the frequency at which we need to reduce that biomass if we are going to get *R. leptorrhynchoides* to survive. It is a little bit different in Canberra because here it tends to grow on fairly open sites, but that may be the key – that wherever it is dense it does not persist.

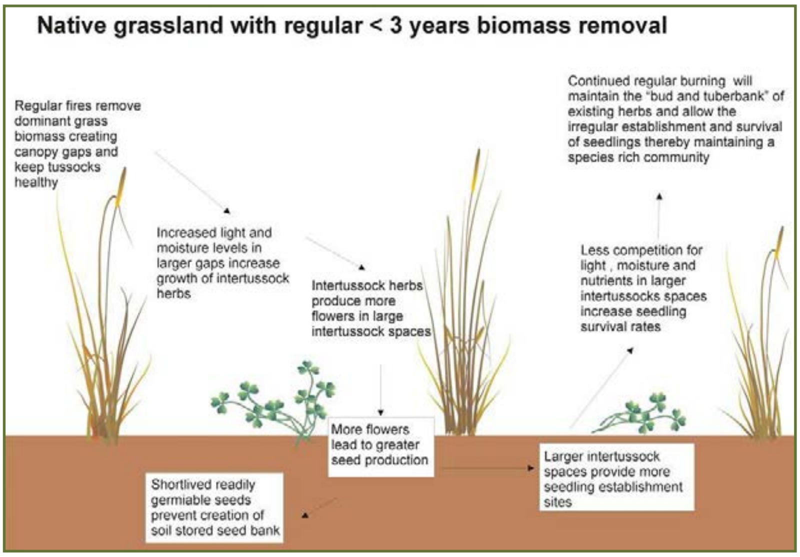


Extending this idea that gaps are important, I chose five common species and we did the same experiment. This time they were planted into very much smaller gaps (right). In the last trial, *R. leptorrhynchoides* was found to survive in 100 cm-wide gaps where there was effectively no grass competition. In this new trial there were either no gaps or small gaps or slightly bigger gaps. *Eryngium ovinum,* Blue Devil, did not survive anywhere, which set alarm bells ringing straight away ('what's going on with that species?'). But on average only 50% of individuals survived the first summer, even among the most resilient species, when growing in the absence of gaps. This seemed to indicate that gaps, their frequency and their size, become important when thinking about the persistence capacity of grassland plants, at least in productive grasslands.

It might be that where a grassland is really sparse and stays sparse, the key to the persistence of species in those grasslands might be that they are actually sparse. Biomass accumulates with time after a fire, which is why the gaps get smaller. It is probably critical that, with increasing biomass, light transmission down to the soil surface declines, so that once biomass reaches 5t/ha there is effectively no light at the ground level. For small light-loving species, that is not a great place to live.

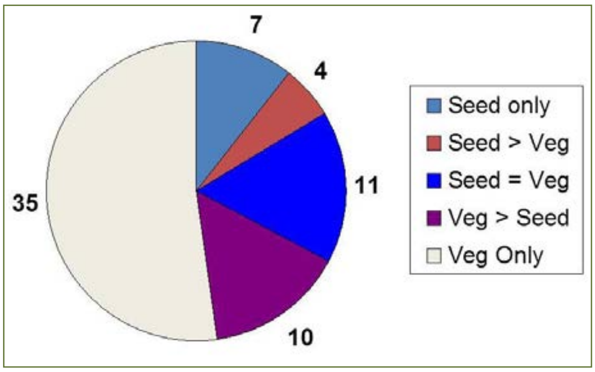
We started building the case that the management of biomass is critical for the management of biodiversity, in relation to plants at least, and put together a conceptual model (top of next page). 'We' was Ian Lunt and I and others who were working at that time in Victoria in the mid to late 1990s. There was great activity going on then; it was a fantastic time for students in grassland research.

We started thinking that this is how grasslands work and species persist, with the regular removal of biomass, whether by burning, or grazing, or slashing. At this the time we were just looking at burning. Something removes the dominant grass and that creates greater gaps, creates light conditions that allow species first to persist and then to grow and flower.



To seed or not to seed?

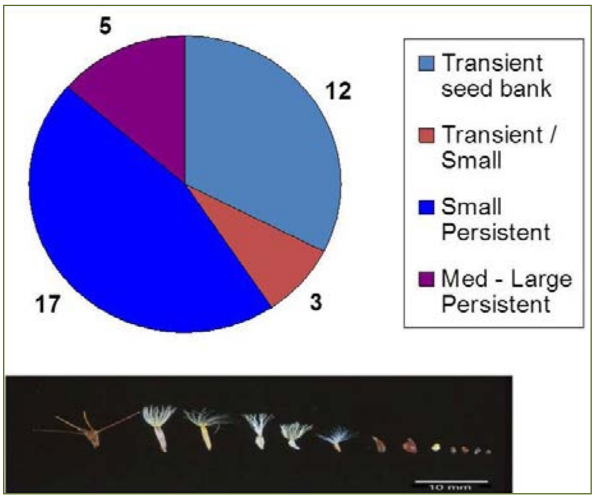
Ian Lunt did some beautiful work that showed that once biomass starts accumulating we get more seed production. At the time we thought that was relatively short-lived but this becomes important. With a lot of seed being produced, there are opportunities for regeneration. The regeneration gaps in grasslands are important because that is where seedlings survive, because there is less competition for moisture, light and nutrients. As a consequence, if we regularly disturb the canopy of productive grasslands, we give ourselves the best opportunity to maintain plant biodiversity.



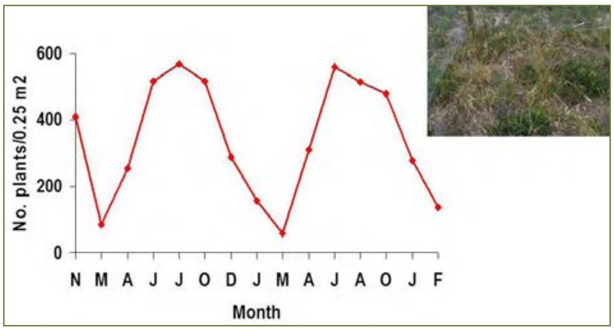
It took us 7–8 years to reach that point. We needed some critical data, including the persistence of seed in grasslands. If seed is long-lived, then when accumulated biomass is finally removed, seedlings can just pop up. That happened in this particular example (right) in Victoria, and many of the species occur also up here in Canberra and New South Wales, so I suspect the situation is similar. In this grassland example, at least 50% of species reproduce vegetatively and there is no evidence of their seed in the seed bank. They must persist each year by just re-sprouting, again and again. They throw seeds out that occasionally germinate but there is no long term storage. Very few species out of the 67 – at a guess, about 12% – relied entirely on seed regeneration. These are annual-type native species and they do not persist by vegetative means at all. Others rely on both seed and vegetative means. So if we take those two categories there are about 65–70% of grassland species we work with that primarily persist through time as vegetative plants, with little evidence of seed banks. This is important because it tells us what happens when they die, when gaps close up, and they cannot come back from seed.

To confirm that, we collected seed from soils and sowed them out on trays, and treated them variously, e.g. by smoking or heating them. I even sowed seeds in bags sunk in the ground, and then pulled them out at intervals to see how many were still there. It was tedious and I recommend not doing it.

It became evident that we had many grassland species, again similar species to the ones in this region, with what we call 'transient seed banks'; that is, a seed bank that lives less than one year. So the seed produced this spring will not be there next spring. Seed that is produced this year needs to germinate in the next germination-cycle of autumn.



That is important. Seventeen of our species, in this particular study at least (diagram, right), had a small persistent seed bank, meaning there is some evidence that seed is present; it germinated but at very low densities. So if we lose tens or hundreds of plants they will not be replaced in similar numbers. We only found five species in this study that had large persistent seed banks, and many of them were sedges. Sedges and carexes tend to accumulate seed banks; if they disappear from the vegetation aboveground they can come back from seed. However, many of these species will not regenerate well if the aboveground vegetative plants are lost from the grassland.



From a detailed (tedious) demographic study, in which I marked individuals in quadrats and counted them at several-month intervals over time, I found there is a beautiful seasonal dynamic (graph, right). In summer, very few plants are present. Then in autumn lots of species re-sprout rather than germinating from seed, and the cycle turns again and again. So our seasonal dynamic of grasslands is the coming and going of perennial vegetative plants, without seedling plants necessarily contributing to it.

From all this I hope that you are starting to see that grassland sensitivity, at least in the temperate grasslands of southern Victoria, is about vegetative plants and their relationship with dominant grasses. Some of these plants live probably for a century. We have greatly underestimated the longevity of grassland herbs.

Ptilotus macrocphalus thickened root

I don’t know if you get *Ptilotus macrocephalus* up here (photos, right). If not, that is your loss! All it does each year is put up a couple of leaves and a flower. But below ground when you try to dig up this plant there is an enormous root stock – a big thick woody root stock, almost as thick as your arm, living off a couple of leaves each year. We tried to dig one out and it snapped off at 55 cm. We think it probably extended 80 cm or 90 cm down the soil profile. We have also dug up other species (because of a housing sub-division) with a view to translocation. You can learn a lot from doing that and we have started to suspect that many grassland plants have long-lived root stocks.

This implies that the ecology of these species does not include rapid turnover at all but persistence – persistence in time – instead. Who knows how long these plants live for? We have no idea. I suspect that *Ptilotus macrocephalus* succeeds because of its ability to survive competition with dominant grasses. Its life history is not dependent on producing lots of seedlings. In fact we have hardly ever seen any seedlings of this plant.

In relation to biomass management, we can ask why do grasslands have so many plant species? The photo on the next page is a composite photo of a site in March and in October. Studying

it throughout that period of time we found that many of the species regenerated vegetatively, and that reducing biomass allowed many of them to spread vegetatively. It also created opportunities for the survival of seedlings, rare as they are. I spent my whole PhD looking at seedlings and found very few. That is why I was ‘the guy studying nothing’!

In the 20 years since I completed my PhD study we have only seen one pulse recruitment year in natural grasslands in Victoria. Therefore we think that this means the grassland plants have to ‘hang on for dear life’ for possibly a couple of decades. This situation may vary between climatic zones and therefore may be different in the ACT region, but it is likely to be driven by the type of life history of the species. Many of our plants are vegetative species.

Critical adults

A critical point that emerges from these observations is that adult plants are more valuable than seedlings in grasslands, at least in temperate environments, because they are the plants that persist through time. We need to make opportunities for seedling recruitment – which only happens in gaps according to our work – but we also need to think about not losing adults. Anything that imperils adult plants really imperils plant diversity. It is hard to get them back quickly. We have coined the phrase ‘the bud and tuber bank’, meaning you need to maintain bud and tuber banks rather than rely on soil seed banks to recover grasslands. In Victoria, if you lose adults you lose species.

My point here is that we need to understand the life history of the species that we manage. It is a really powerful tool for understanding their dynamics and their management requirements. We should not assume all grassland species live in the same way.

One of our most important pieces of work followed the visit by Ian Lunt and me to a grassland that he had worked on for his Honours degree. The first thing he noticed, when we went back after 10 years, was that it had changed considerably. The grassland that had formerly been grazed at conservative rates had been de-stocked and the Kangaroo Grass had become thick and had not been burnt for quite some time, apart from some patches.

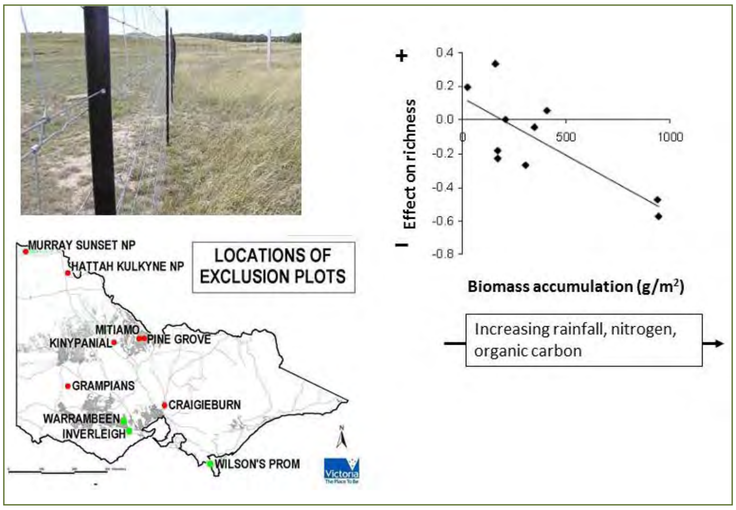
We did a little study to demonstrate just how important biomass accumulation is, even to the dominant grass species in this grassland. Kangaroo Grass re-sprouts after fire and the chart at right illustrates its growth cycle through time. Straight after fire it re-sprouts, and as with all grassland grasses its leaves only persist for one year and die off in winter. Each year there is new growth and then that dies and adds to the accumulation rather than breaking down. After about 6 years there are about 5 t/ha of biomass, most of it dead material, smothering out not only all the biodiversity but the Kangaroo Grass itself. And after 11 years the Kangaroo Grass has crashed. It has smothered itself out. The litter mulches itself out to the extent that it is mostly dead, with a little tiny bit of live growth trying to push through. Ultimately in these sites the grass dies off and is replaced by other species.

In other words, we find that management of biomass accumulation is as critical for a dominant species as it is for all the other species. Clearly, reduction of biomass plays an important role in the maintenance of grassland health.

Managing biomass

One way to maintain grasslands in vigorous health is by applying fire. Kangaroo Grass survives fire really well. We marked 300 tussocks and tracked how many of them were still alive or dead after fire. Only four of the marked tussocks died – not just small ones but also one or two big ones. The way fire tends to go over the top of Kangaroo Grass allows it to survive, so if fire is used to reduce biomass in Kangaroo Grass the grassland still retains the structure of the Kangaroo Grass, creating opportunities for other species to get going.

Do our observations apply in grasslands everywhere? Is biomass accumulation a problem everywhere and do we need to deal with it?



Our next study was in grasslands ranging from Wilsons Promontory on the south coast of Victoria with high rainfall, all the way up to the Murray Sunset National Park at the north-west corner of the state (see map, right). Not all these grasslands were dominated by Kangaroo Grass. We went to places where exclusion plots had been in place for around 8–9 years. That meant nothing had been disturbing the grassland, and biomass should have been accumulating. If our observations above applied everywhere, these high biomass sites should have experienced a reduction in biodiversity.

We did a simple fenceline experiment – looking at biomass and species diversity outside the fence and inside the fence (photo above). At very high rainfall sites there was a large amount of biomass and a substantial reduction in species diversity, as we had predicted. At low rainfall sites there was low productivity, and we saw that exclosure was good for enhancing diversity.

From this we concluded that removing disturbance in productive ecosystems creates negative outcomes, but removing disturbance in unproductive areas may be beneficial because removal of the biomass there may stress that system too much. That is, biomass accumulation and removal have this nuance that they do not have the same impacts everywhere.

The key lesson is that biomass reduction in *productive* grasslands is critical for the co-existence of species and for grassland condition.

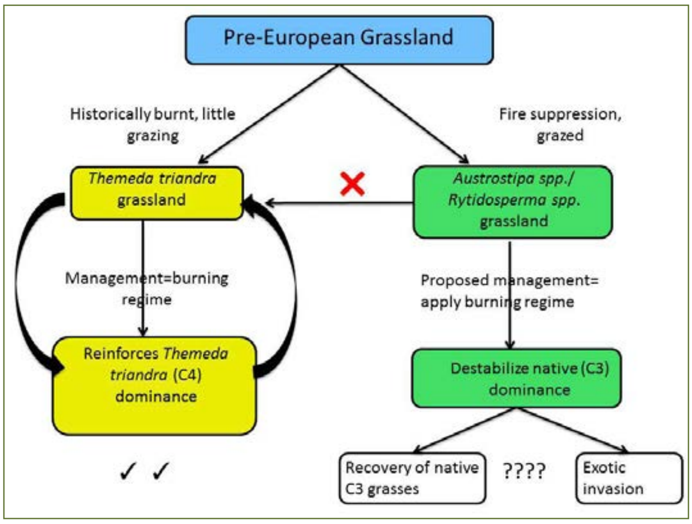
In the past we have burnt grasslands, and we know that burning does not kill off many of the plant attributes that we are interested in – you can see in this photo (right) that the fire does not even go all the way down to the ground. It actually scorches vegetation rather than removing entire tussocks. The vegetation comes back very quickly, largely because of re-sprouting. We think that if you keep burning sites, they will just keep going on doing their thing.

Further examining the hypothesis

What happens in sites that have not been burnt but have been grazed? They are often dominated by different species. To manage those grasslands should we continue to graze them, or should we change the management and apply burning? Given that we know that burning is good in some places, is it good everywhere?

We do not know.

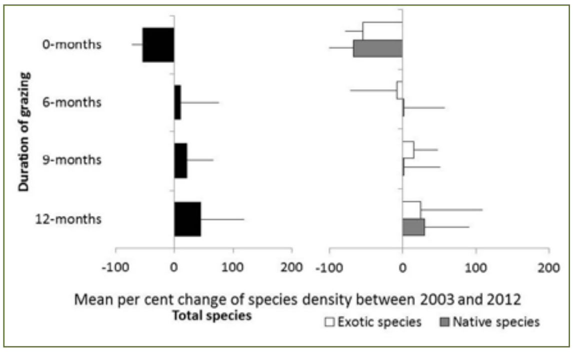
We do know that if you stop burning grasslands that were previously burnt frequently – with a number of fires over, say, a 12-year period – almost all the native species will be lost, whereas if we had burnt those sites frequently we would have lost fewer species.

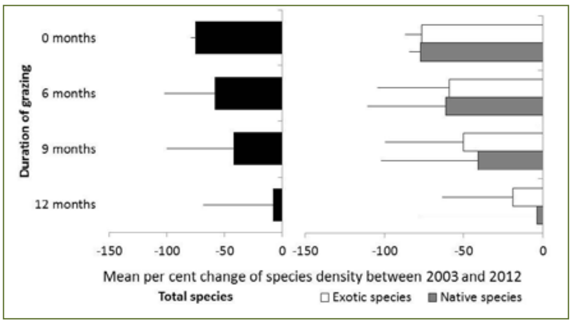


Can we use grazing to do the same job of removing biomass and advancing native species?

Currently if a grassland is grazed all the time, we would expect it would not change; and if we remove grazing completely and do not replace it with anything else we can expect a decline in diversity. Therefore, if we are aiming for some pre-grazed state (flow chart, right) we can assume that we have to have something between these two.

Can we use duration of grazing to manage biomass?





We have tested this question. We stopped grazing some experimental grassland sites and left the biomass unmanaged, and we saw the expected big decline in diversity. When we applied continuous grazing, in this particular example for 12 months, we found the system improved to some extent (top chart, right). But there is a big confidence interval here; it crosses zero so we see the system did not actually change. Natives and exotics respond in exactly the same way.

At some sites we found much bigger negative effects (lower chart), showing us that site-specific factors come in. Again, no grazing is not good; continuing to graze in sites that have historically been grazed looks better. However, the intensity of grazing matters.

Summary

In summary, biomass accumulation is clearly a threatening process in grasslands. In productive (sufficient rainfall) ecosystems, it leads to ecosystem collapse and transformation of the identity of the grassland. We have 20 years of data that indicate this.

Why does it happen? Because niches are being lost; environmental degradation can occur, nutrient cycles are changed; and biotic processes are altered, meaning that the competitive interactions going on are very different from the historical ones.

So, if we want to maintain grasslands in this kind of condition, biomass accumulation and its management has to be central to our thinking about how to do that.

References

Wong N. & Morgan J.W. (2007) Review of Grassland Management in south-eastern Australia. Parks Victoria Technical Report No. 39. Parks Victoria, Melbourne.

Dr John Morgan is a plant ecologist at the Department of Botany, La Trobe University. He is interested in long-term vegetation dynamics of natural ecosystems. In particular, he studies how changes in environmental filters and competitive processes, in the context of disturbance, land use change and climate change, shape plant communities.

+ This record of the talk given at the forum has been checked by the presenter, but not peer-reviewed. To find out more, contact the presenter, via their institution or by email to: info@fog.org.au/.