Chapter S7 Managing disturbance

IF DISTURBANCE OCCURS AND IT IS CATASTROPHIC: WHAT YOU DO NEXT COULD BE AS BAD

Monkey Creek, Victoria. This Warm Temperate Rainforest began to regenerate after the 2007 wildfire, but fire regrowth acts like a magnet to Sambar, providing a smorgasbord of food (Mason 2008) and they are now the threat.

Fire management at the landscape scale

Overview

In general, rainforests occur in low fire risk areas of the landscape (gullies, moist slopes, river banks, coasts and islands or (summer rainfall zones such as the subtropics), which means that fire is one of several ***severe stochastic events*** that produce significant disturbance in these vegetation communities. In contrast, Gallery Rainforests along perennial streams rely in part on the humid atmosphere generated by the stream itself and retained by the closed canopy for their fire protection. It is amazing to see this fire protection in the field (Figures S278 and S279).

Rainforests are also inherently composed of low flammability species (particularly mature phase primary and late secondary species) (Figure S278 and Additional Reading: Ignition times) and the distribution of fuels is often discontinuous in mature stands, thereby breaking the fuel ladder. In addition, their dense canopies exclude sunlight and maintain higher moisture levels than surrounding forests. This moisture, in turn, seeps into the fine fuels below the canopy and this makes them more difficult to burn. Consequently, there are numerous examples in south-eastern Australia where rainforest has acted to dampen down fire intensity even if adjacent eucalypt dominated forest is consumed (Figures S278 and S279).

With the apparent change in scale (megafires), frequency 1939, 1983, 2002, 2006 and intensity of fire (2009) being attributed to climate change, what will happen to landscape scale fire and its effects? Will the past management of fire across the landscape be able to mitigate this threat? What implications does this have for rainforest management in south-eastern Australia?

Implied past use of fire to protect culturally valuable rainforest resources

The practice of Aboriginal protective burning around rainforests to specifically protect them from fire has been observed in detail and still occurs in the Northern Territory (Bowman 2000). Good records of Aboriginal fire-stick farming by traditional owners have been documented in the northern Territory (Jones 1975; Jones 1980). This practice involves seasonal burning to produce a mosaic of burnt patches that also assist in the annual cycle of hunting and food gathering and inturn conserves important food resource such as yams (Bowman 2000). The cessation of such practices has led to severe damage to these Monsoon Rainforests by late dry season wildfires (Bowman 2000) due to the excessive build-up of high fuel loads in the hinterlands of these rainforest stands. From the limited ethnographic evidence available, it is clear that Aborigines appear to have conserved fire-sensitive vegetation (Bowman 2000), including rainforests.

There is historical evidence of Aboriginal burning in similar savannah ecosystems (Plains Grassy Woodlands) where rainforests also grow around the Gippsland Lakes. In January 1840, McMillan was one of the first Europeans to cross the Red Gum Plains and arrive at Lake Victoria (Fletcher 1988) and W. A. Brodribb from 1841 cited in Fletcher (1988). Because such records are not contemporary, the reasons for such burning cannot be directly known. However, the beneficial effects on rainforest remain as physical evidence at one site known to the author on the Nicholson River at Pratt's Bluff (Figure S280 and Figure S281).

The ecological and anthropological significance of these observations is interpreted as follows:

1. The Littoral Rainforest dominants in this region recover following grass-fire intensity burns of the surrounding vegetation Plains Grassy Woodland (savannah) vegetation.
2. The Littoral Rainforest regenerative response to wildfire protects the margins of the rainforest from future wildfire through the extensive regeneration over the following year of fire-suppressant species. Ignition times are average seconds to ignition, with, for comparison, the ignition times for flammable pioneer and secondary species being 1.6-6.6 seconds (Additional Reading: Ignition times). The regenerating fire-suppressant species include: Purslane *Portulaca oleracea*, various Kangaroo Apple species (*S. aviculare*, *S. laciniatum, which* failed to ignite, and *S. vescum*), Common Boobialla *Myoporum insulare* (8 seconds) and Seaberry Saltbush Rhagodia candolleana (failed to ignite). The latter species is renowned for its fire-retardant properties: being widely planted locally as a firebreak species. Such regeneration can seal the edges of such stands for up to 20 years
3. Much of regeneration responses are of species that are were used for food by the local Koori people including: Scrambling Lily, Common Boobialla, Spiny-headed Mat-rush *Lomandra longifolia*, Slender Dock *Rumex brownii* and Gunyang) or materials including: Scrambling Lily, Spiny-headed Mat-rush and Kangaroo Grass *Themeda triandara* (Additional Reading: Koori cultural uses of Littoral Rainforests in south-eastern Australia).

GALLERY RAINFOREST SURVIVES CROWNING WILDFIRE USING HUMIDITY FROM THE RIVER

Figure S278. Brodribb River at Granite Creek, Bonang Highway Victoria. The Granite Creek wildfire was a crowning fire that began at 12.45 pm on 12 March 2006 (Kevin Giblin pers. comm.) as the result of an untended camp fire; this photograph was taken in August 2006. The fire was extremely hot and all of the eucalypts in this vicinity were defoliated. Even without topographic protection from fire, how miraculous then that this Gallery Rainforest along the river survived, with significant areas of its crown remaining unburnt ({ }). This was likely the result of:

- Kanooka *Tristaniopsis laurina* canopies having low volatile oil content and taking a long while to ignite into flame (12.8 seconds; Additional Reading: Ignition times: Figure AR105), further corroborated here by the withered unburnt leaves still on the trees 8 months later) (red arrows)
- In the absence of a topographic ***fire shadow***, it was the atmospheric humidity from the perennial stream (Brodribb River) which is retained by the closed canopy of Kanooka that kept the fine fuels and ground-fuels moist and so the ground fire did not penetrate far beneath the rainforest canopy.

There is additional circumstantial evidence in the region for Koori-based fire protection of other Littoral Rainforest stands and Warm Temperate Rainforests. Although this is a speculative correlation, an examination of the resources provided to the Koori population by Littoral Rainforests (only 1 of the 8 rainforest types in the region) showed that there were more than 240 uses for plants and animals (Additional Reading: Koori cultural uses of Littoral Rainforest in south-eastern Australia), suggests a stronger link. A significant proportion of these resources are not found outside rainforest. In addition, these rainforests had other cultural uses including: totems, burial and birthing.

CROWNING WILDFIRE DOES NOT DESTROY GALLERY RAINFOREST

Figure S279. Brodribb River at Granite Creek, Bonang Highway Victoria. The Granite Creek wildfire began in March 2006, but has still left the foliage on the Kanookas over the Gallery Rainforest ({ })even though all adjacent fine fuels in the eucalypt forest have been completely consumed (red arrow). Intact Gallery Rainforest is shown with the green arrow.

	
Figure S280. Pratt's Bluff, Nicholson River Victoria. This Littoral Rainforest stand is the first evidence located on the Gippsland Plain of fire protection afforded to Littoral Rainforest from low fuel levels associated with Plains Grassy Woodland (right). The remnant Littoral Rainforest trees are Muttonwood *Rapanea howittiana* and the Grassy Woodland grass comprises primarily Kangaroo Grass *Themeda triandara* and Red-leg Grass *Bothriochloa macra.* This stand's margin has been significantly degraded by more than 100 years of cattle grazing. This tree and the plants in Figure S281 are growing away from the topographic fire protection afforded by the bluff itself: burning of the Plains Grassy Woodland provides a plausible explanation for these observations when viewed with the response of these rainforest species (see the text and Figure S281).	Figure S281. Pratt's Bluff, Nicholson River Victoria. Despite the unnaturally high fire intensity (in this instance ignited from below the cliff) to control rampant infestations of Blackberry **Rubus anglocandicans* and African Boxthorn **Lycium ferocissimum,* and not from the Plains Grassy Woodland upslope, there was abundant fire resprouting of the Littoral Rainforest species: Scrambling Lily *Geitonoplesium cymosum* and Muttonwood *Myrsine howittiana.* Other Littoral Rainforest species to resprout following this fire included: Staff Creeper *Celastrus australis,* Sweet Bursaria *B. spinosa* and Tree Violet *Melicytus dentatus.* Richard's use of tree guards (though generally not recommended by the Manual), was absolutely necessary at this site, because no amount of poisoning could eliminate the rabbits at this site.

For Littoral Rainforests, these uses covered a staggering array of categories including:

- 3 that provided water
- 90 that provided foods as varied as: 1 cone, 32 fruits, 10 grains, 2 pods, 12 leafy greens, 4 gums, 1 manna, 1 flower, 5 nectar, 5 shoots,15 starchy roots or tubers, and 2 vegetable hearts.
- 7 fungi (1 for fire tinder, 4 were eaten and 2 were used for medicines)
- 25 animals used for food and technologies that included: sinews for binding and ligatures, bones for sowing clothing and fish hooks and so on (10 mammals, 7 birds, 6 insects, 1 reptile and 1 reptile group)
- 48 medicinal uses of plants and animal parts that included: 1 antiseptic, 1 (for asthma, coughs, colds), 1 for bandages,1 for bites or stings, 1 burn or wound dressing, 2 for coughs, colds and sinusitis, 1 for contraception, 7 decoctions (1 sedative/calmative tea, 1 stomach pain relief, 1 rheumatism, 1 gastrointestinal upsets, 1 for infant's wind, 1 for constipation, aches and pains, 1 as a lotion for strains), 1 as a diabetes treatment, 2 for dressings, 1 as a Dysentery remedy, 1 as an extract for sore eyes, 2 for headache treatment, 1 for indigestion, 3 ligatures (plant and animal parts), 1 local anaesthetic (animal), 2 poultices (1 for strains, another for sore eyes), 5 rheumatic pain treatments, 4 skin infections treatments, 1 sleep promoter, 1 snakebite treatment, 3 splints, 1 stingray sting treatment, 1 for syphilitic sores treated as an infusion or poultice, 1 toothache and cut treatment and 2 tonics used following illness for recovery
- 71 material uses ranging from knives, shields, wallets, bags, fishing nets to baby's swaddling.

The resources that were afforded by rainforests do not even attempt to divine the spiritual and cultural significance of such vegetation to the original people of the south-east. These included their male and female totems being rainforest birds, burial of their dead in the boughs of trees in rainforest and giving birth in rainforests at specified birthing places (Additional reading: Koori cultural uses of Littoral Rainforests in south Australia).

These data are based on both the literature and the cultural knowledge kindly shared by the Koori community with the author. Sadly, this represents just the tip of the iceberg because much of the knowledge may have been lost, corrupted or is no longer trustingly offered to us (Cameron pers. comm.).

If these rainforests were severely or regularly burnt by high-intensity wildfire, many of these species and their resources were at worst lost for decades or centuries and at best: severely depleted or disrupted. Given this cultural context, it is perhaps not surprising to find that there is landscape-scale evidence of the continued persistence of rainforest stands that are thought to be cultural artefacts in south-eastern Australia. In other words, these stands still exist despite having little or no identifiable topographic, climatic, vegetation or other fire protective mechanisms. One plausible explanation is that these stands were deliberately protected by the local Koori people for the physical resources and spiritual needs that they supplied. Examples other than Nicholson River in East Gippsland include: Littoral Rainforest stands along Ewings Marsh, at Wingan Point, Sandy Point on Mallacoota's Top Lake; others now extinct, but known, from the Palmers Road-Roadknight Street area of Eastern Creek at Lakes Entrance (Joe Stephens pers. comm.) and the largest area of Warm Temperate Rainforest (at least until the 1983 wildfires) in Victoria, at Jones Creek in the Genoa catchment. Whilst in New South Wales suspected Littoral Rainforest stands previously protected by Koori cultural burning include: Saltwater Creek Camping ground, north shore of Saltwater Creek, Leatherjacket Bay, Wallagoot Lake (northern shore) and Middle Lagoon Barrier Dune and the stands between Bithry Inlet and Middle Lagoon. See Landscape fire management of Littoral Rainforests: a model to guide the way forward for their recommended protection from fire during climate change.

Future use of fire to protect rainforest in a time of climate change

The direct impacts of altered fire regimes on each particular rainforest ecological vegetation class are specifically outlined in Chapter 4: Climate change: multiple threats, magnitudes and synergies. In general, however, the landscape-scale risk to rainforests during climate change in south-eastern Australia is related to the likelihood that landscape or other fire protection mechanisms that have proven adequate under past climate regimes will not be sufficient protection as the result of increased frequency, severity and scale of fires (mega-fires). It is clear that if we are to protect and restore rainforests in this region of Australia, a new and concerted landscape-scale effort is required to protect rainforests from wildfire.

In the absence of ongoing active landscape level anthropogenic fire protection interventions for rainforest stands, the risks to rainforest in the south-east of Australia increases on a yearly basis. This is all the more so given the forecast (and actual) increase in intensity and extent of wildfires that is now being attributed to climate change.

Although we have lost some of these stands that may be cultural artefacts, and others have been damaged, the risk to all stands (even those that had what was effective landscape fire protection under past climate regimes) is also increasing. There are now very strong arguments and an urgent need to take on the task left us where the Koori's landscape custodians have left off. We must recognise the cultural and biodiversity values of rainforests and immediately begin targeted fire mitigation strategies to protect all rainforest stands, especially given the risks of mega-fires during climate change.

Although local land managers will be most familiar with where these protective measures are required, given the projected changes in fire regimes, most, if not all, rainforest stands in the hinterland will require very active and consistent fire mitigation interventions. This will give land managers a chance to hold the line and to provide the necessary decades and centuries required for both natural and human-based restoration of those stands that have already been damaged by fire until the community stabilises the climate and fire regimes return to their pre-climate change states.

Landscape fire management of Littoral Rainforests: a model to guide the way forward
In Bowman's (2000) comprehensive review of factors that mediate rainforest distribution and persistence: 'Australian Rainforests Islands of green in a land of fire' he examined the paramount role of fire in rainforest distribution across the landscape. In Chapter 12: The fire theory versus aridity and the evolution of flammable landscapes, he concludes:

> "While these views are necessarily speculative, it is clear that the maintenance of diversity in modern Australian vegetation, including rainforests, requires that humans actively influence the distribution and frequency of fire. Letting nature take her course may see the ultimate dominance of fire-adapted plants at the expense of ancestral (rain) forests. Australians must use fire thoughtfully to manage their forest inheritance."
>
> Further: in his conclusion in Chapter 13 Bowman (2000) states:
>
> "Conservation of the Australian rainforest inheritance depends on fire management, which must be crafted to suit both the individual rainforest patch and the ecology of the surrounding landscapes. Because resources are limited, there is an urgent need to identify rainforest patches that require immediate attention. Meeting rainforest conservation objectives will require much creative research and good communication amongst land managers.

With respect to the rainforests of south-eastern Australia, we wholeheartedly agree.

Site specific recommendations for Littoral Rainforest stands in south-eastern Australia
The recommendations contained in this example section are designed to provide a model for "the good communication and coordination amongst land managers" with respect to fire and Littoral Rainforest management as a model for **all other** rainforests across south-eastern Australia.

Although frequent fire represents a major threat to all rainforest types, this vegetation is capable of recovering from a single fire event and, over many decades, it can regain its original floristic and structural integrity. All of the Littoral Rainforest sites that were sampled for this section had experienced a single fire within the last 20-30 years, but were recovering to some degree. The extent of recovery was directly related to the wildfire intensity. Those that had flame heights of less than 4-8m were both floristically and structurally well-recovered (e.g. Wingan Camp), but those that experienced crown fires (e.g. some stands at Point Hicks and on Wingan Point) are still many decades off structural, let alone full, floristic recovery. Given that the area of Littoral Rainforest is so small, and the short to medium term damage wrought is so great, it should, wherever practicable, be conserved through protective burning. This advice is most applicable to any rainforest that is threatened by fire (a conclusion echoed by Bowman (2000).

The following recommendations refer to Littoral Rainforest sites that have a minimal level of topographic protection from fire and are a starting point for discussion and beginning the process for the more widespread application of the principle of landscape-level fire mitigation works for the protection of rainforest during climate change (while the risk of increased frequency, intensity and extent of fire remains highly likely).

One aspect of this mitigation strategy is used: fuel reduction burning. Given that this vegetation is Critically Endangered nationally and listed under the *EPBC Act* (Definitions and Synonymy), three scenarios have been proposed where protective burning of adjacent vegetation is required. Two are either beneficial or relatively neutral in their impact on the fringing vegetation (and consequently recommended as a management too); whereas the last is detrimental and not recommended.

The three scenarios are as follows:

1. Stands that have adjacent ecological vegetation classes whose regular burning provides ecological, biodiversity or asset protection benefits:
    - Grassy and forb-rich ecosystems: where regular burning that maintains low fuel loads also promotes maximum biodiversity of graminoids and forbs within the field layer. Such ecosystems include: Plains Grassy Woodland, Plains Grassy Forest, Damp Sands Herb-rich Woodland, Bega Valley Dry Grass Forest, Brogo Wet Vine Forest and Eurobodalla Headland Grassland (*sensu* Beukers and Miles in prep.). Localities where regular burning of these adjacent grassy or forb-rich ecosystems is recommended for the protection of Littoral Rainforest include:
        - Plains Grassy Woodlands and Damp Sands Herb-rich Woodlands adjacent to Littoral Rainforest stands that still persist on and adjacent to riverine cliffs on the Mitchell, Nicholson and Tambo Rivers
        - Plains Grassy Woodlands and Damp Sands Herb-rich Woodlands along their lower estuarine and foreshore reaches and on the northern shore of Lake King (including Jones Bay and Tambo Bay) when foreshore restoration with Littoral Rainforest is complete
        - Damp Sands Herb-rich Woodlands on the northern side of dunes in the Lakes Entrance Golf Links, Lake Bunga Foreshore Reserve;
        - Damp Sands Herb-rich Woodlands on the chenier (sand flat) behind the dunes at Corringle Beach west of Corringle Slips. Limited and careful burning at this site will not only provide ecological and biodiversity benefits to the Damp Sands Herb-rich Woodland, it will also provide some asset protection to the Corringle Slips Camp Ground. Note that Littoral Rainforest is regenerating in this area and burning should occur in those areas that are still Damp Sands Herb-rich Woodland and aim to create a mosaic between the two ecological vegetation classes and the Swamp Scrub on the western margin should not be burnt to allow it to mature to its old-growth phase for more fire protection;
        - Damp Sands Herb-rich Woodland to the north of the Banksia Bluff-Sailors Grave area of Cape Conran (this also will provide protection for the camping ground)
        - Plains Grassy Forest on the northern side of Ewings Marsh
        - Bega Valley Dry Grass Forest and Brogo Wet Vine Forest at Tanja
        - Bega Valley Dry Grass Forest, Brogo Wet Vine Forest and Themeda Headland Grasslands at Goalen Head where this does not conflict with the restoration of Littoral Rainforest at this site
        - Bega Valley Dry Grass Forest, Brogo Wet Vine Forest to the north of Coila Lake to protect Dry Rainforest and Littoral Rainforest stands that may still exist or are to be restored
        - Eurobodalla Themeda Headland Grasslands (themselves a *TSC Act*-listed community) at Cuttagee Point, Dr. Seatons Beach (Jaggers Beach), Marruna Point and Bingie Bingie Point.
2. Stands that have adjacent ecological vegetation classes whose regular burning provides minimal biodiversity or ecological benefits to the burnt vegetation, but whose burning will maximise the biodiversity and ecological benefits to the protected Littoral Rainforest stand:
    - In Victoria: adjacent Lowland Forest to the west of Lake Tyers (Ferny Arm western shore); Lowland Forest to the north and west of two stands downstream of the Genoa Fire Trail Jetty, and Lowland Forest surrounding Sandy Point Lake Mallacoota
    - In New South Wales: Coastal Dry Shrub Forest to the west of Saltwater Creek; Coastal Dry Shrub Forest surrounding Leatherjacket Bay; Coastal Dry Shrub Forest to the west of Fisheries Bay and Fisheries Beach; Coastal Dry Shrub Forest adjacent to Severs Beach; Wallagoot Lake (northern shore); Middle Lagoon Barrier Dune
    - In New South Wales: Coastal Dry Shrub Forest in Eurobodella National Park to the west of Mystery Bay south and Dune Dry Shrub Forest to the north west of Corunna Lake (north shore)

3. Where protective burning for Littoral Rainforests would directly contradict the requirements of other values in the adjacent ecosystem to be burnt to control the wildfire threat to the rainforest:
    - Heathland ecosystems: where burning at frequencies that protect Littoral Rainforest from fire may adversely impact or degrades the plant diversity and habitat for Eastern Bristle-birds *Dasyornus brachypteris* and Ground Parrots *Pezoporus wallicus*. Localities where regular burning of these adjacent heathland ecosystems may not therefore be suitable for the protection of Littoral Rainforest include:
        - Coast Sand Heathland at Cape Conran's West Cape
        - Wet Heathland between West Cape and Sailors Grave; north and north-west of Banksia Bluff Camp and eastward to Yeerung River mouth, the hinterland of Wingan Point.
    - Heathlands on Mueller's Track to protect incipient Littoral Rainforest at the mouth of the Mueller River
    - Clay Heathland between the Mallacoota Aerodrome and Betka River to protect stands on the Betka River spit, north and south of Nadgee River mouth and Newtons Creek to protect nearby stands; and clearly landscape protection of Littoral Rainforests in these localities would require more regular fuel reduction burning in the hinterland Lowland Forest or Banksia Woodland communities.

Priority management actions
In areas that are Littoral Rainforest or are near to Littoral Rainforest:
- As soon as is practical, implement a regime of protective burning in the areas nominated for the protection of the Littoral Rainforest stands listed
- Continue this regime in perpetuity, until climate change is brought back to pre-industrial levels or until contrary evidence is found to modify such management.

Agents responsible for action
Victoria: Parks Victoria, Department of Sustainability and Environment, East Gippsland Shire, landholders and Landcare groups.
New South Wales: National Parks and Wildlife Service, Bega Valley Shire, Eurobodalla Shire, landholders and Landcare groups.

Fire management at the local scale
In both the rural and urban contexts, management of fire risk is important for two reasons: your responsibilities to your neighbours and the risk to your restoration works. The same duty of care should be applied to urban restoration sites (where the risk of landscape fire is lower, but ignition events could be more frequent). Although mature rainforests are inherently less flammable than other vegetation types dominated by sclerophyll species, any plant material will burn under extreme fire weather conditions (*CFA* 2007). For two reasons it is very important for you to realise that there is no role for the individual rainforest restorer in protecting your restoration site in the event of a fire ecologically your restoration design will have inherently accommodated fire as an expected disturbance (so let it burn), and from a personal perspective: your safety is more important! Nonetheless fire prevention works are still very worthwhile, so some fire behaviour and fuel basics need to be established.

Fire is mediated by three main factors: weather, topography and fuels (Todd Chaudhry pers. comm.). We cannot control the weather (but must plan for the worst case scenario when the fire weather is bad); fortunately, rainforest habitat occurs in the most fire protected areas of the landscape (so topography is taken care of the stand for us, provided you are only restoring rainforest to its past habitat); while fuels are something that we can manage to mitigate risk.

The critical weather elements for fire are wind speed, direction, temperature, relative humidity and atmospheric stability. Topography influences fire behaviour through slope (flatter topography means fire generally moves more slowly); and aspect (which influences relative humidity and fuel moisture content); while elevation/locality mediates fire through a number of factors. These include coastal localities having higher relative humidity during summer compared with the inland (see Additional Reading: Regional climate) and can be influenced by moist sea breezes even during severe fire weather just a couple of kilometres inland. Coastal ranges are usually moister than inland slopes because prevailing winds off the ocean deliver more moisture to the seaward aspect through *orographic uplift*.

Fuel moisture is an overriding factor in fuel combustibility: wet fuels will not burn irrespective of whether they are alive or dead, their amount, their continuity or their coarseness. With regard to fuels, there are five principles that dictate fire behaviour and the combustibility of vegetation Greg McCarthy (pers. comm.):

1. The dead: live fuel ratio living material will not burn until its moisture content drops below 20%. To give you an idea, most living leaves have between twice and three times the moisture content of oven dried leaves (an advancing fire must therefore 'pre-cure' its fuels before their ignition can occur)
2. The amount of fine fuels present (defined as: dead fuels of ≤6mm diameter or live fuels of ≤2-3mm), these are what ignite immediately and give the advancing fire front its heat and power (heavier fuels burn later or have to be dried out before burning by the fire itself; e.g. the living crown)
3. The amount of continuous fuel strata (usually the litter on the groundlayer), but may occasionally include one or more shrub layers
4. The continuity or separation of fuel layers (the fuel ladder) that ensure horizontal and/or vertical fuels, continuity in either direction which helps to propagate the fire
5. Lastly (though rarely a contributing factor) the amount of fine fuel; for example, a bark pile at the base of a tree (See Appendix S18: worksheet: Figures: AS18-1 to AS18-5).

If you wish to investigate these fuels and their various levels further to assess the fuel hazard see DEH SA (2006).

Buried within these five principles are the reasons why mature rainforests are inherently less combustible than the adjacent eucalypt forests. So let's re-examine them, with the comparison explained for each point:

1. There is relatively less dead fuel in rainforests: the reason for this is the higher moisture levels in this vegetation compared with eucalypt forests. This higher moisture level allows for more rapid decomposition of the fallen fuels for incorporation into the soil (Additional Reading: Leaf litter: rainforest versus adjacent non-rainforest communities). There is however a highly localised exception associated with the bark piles that collect at the bases of the usually widely scattered gum-barked species, which are sometimes found in rainforests of the region such as Mountain Grey Gum *Eucalyptus cypellocarpa*, Manna Gum *E. viminalis,* etc. (see Appendix S18: worksheet*:* Figures: AS18-1 and AS18-2).
2. Higher fuel moisture is also a function of position in the landscape: many rainforests occupy wetter niches than the surrounding eucalypt forest. This not only increases the moisture level of dead fuels, but also the moisture levels of the component species' living foliage: even for the same species when compared with their counterparts from nearby drier niches (Additional Reading: Ignition times).
3. In addition, the living fine fuels in rainforests are inherently less flammable, including (remarkably) in the driest rainforest EVCs, with some mature phase primary and late secondary species failing to ignite in the experiments reported in Additional Reading: Ignition times.
4. The fine fuels (both living and dead) associated with Littoral Rainforests in exposed coastal positions become coated in salt, which makes them less flammable than those for the same species further inland (Additional Reading: Ignition times);
5. Fine fuels are present in both forest types, except that in rainforests there tends to be very little on the forest floor and the canopy is living: both inherently less flammable compared with the adjacent sclerophyll vegetation;
6. Often the only really continuous fine fuel strata in rainforest are in the canopy, and occasionally the groundlayer (but, remember, both of these are usually living: as Greg says by way of analogy: green lawns don't burn!).
7. Rainforest gaps and edges can be clothed in species that either do not burn (such as Seaberry Saltbush *Rhagodia candolleana* and Jungle Grape *Cissus hypoglauca*) or have long ignition times such as Coast Wattle *Acacia longifolia* ssp. *sophorae* that takes on average 33 seconds to ignite (Appendix S18 worksheet: Ignition times), Hop Bush *Dodonaea viscosa* (25 seconds), Musk Daisy Bush *Olearia argophylla* (21 seconds), Boobialla *Myoporum insulare* (8-24-43 seconds, depending on the moisture content), and Kangaroo Apple *Solanum aviculare* (29-40 seconds).
8. There is usually a significant distance between the living sparse ground fuels and the canopy.

Certain phases of rainforest restoration (and certain restoration methods) cause the vegetation to be more flammable than others (compare the high fire hazards associated with phases represented by the partially cleared landscape (the starting point Figure S112), the intermediate phase of low fuel hazard (Figure S113) and the return to high fuel hazard (Figure S114). However, the mature phase dominated by primary species is the least prone to fire (Figure S210 and Figures S278, 279) for the reasons described earlier. These series of photographs illustrate: that fuels and fire risk on your restoration site will wax and wane over time. The trick for you then, is to manage the fire risk while the site is under your management and the risks are high. Do not get too concerned by this issue, because in many cases your site will be on low-fire-risk landforms and often in fragmented areas of the landscape. But you do have a responsibility, so understand the five fire fuel principles that mediate fire behaviour so that you deal with any fire risk that may be posed by your rainforest restoration efforts. There are a plethora of lower ignition plant species available to most restoration sites (Appendix S18: worksheet: Ignition times). If the species that you have earmarked for your restoration works are not in Appendix S18), then the methods for the simple experiment that generated this data are easily applied to any other species that you may wish to use (Additional Reading: Ignition times: Foliage ignition times: gully versus ridge *Methods*). All you need is a butane jet lighter, a watch, a pen and paper. Remember that the results are only a guide to flammability and do not offer iron-clad guarantees that your site will not burn.

The other means of managing fire on your restoration site is to regulate the amount of flammable material on your restoration site during those early stages of restoration when your site could be dominated by the more flammable pioneer and early secondary species. So, analyse your site using the five principles that mediate fire behaviour. If, for example, you are undertaking Framework Method Restoration, it is inevitable that you will have a significant proportion of dead fine fuels (this is part of rainforest succession: returning nutrients to the soil as well as recharging the soil seed bank with the seed of native species that will regenerate after disturbance including fire). Likewise, it is almost certain that you will also have a lot of fine fuels (often in several layers) that are in continuous lateral and vertical contact and there will often be significant amounts of fuel. The strategy then is to reduce the risk of ignition and to maintain slashed green fire-breaks that have a dual role in allowing access for fire fighting vehicles as well as breaking up fuel continuity (Chapter 8: Site preparation: Vehicle access). Although fire planning is important, it should not be forgotten that for riparian situations at least, rainforest is the least fire prone part of the landscape: generally being wetter, cooler, with lower wind speeds, greater soil moisture (consequently higher fuel moisture levels), less flammable species, higher live to dead fuel ratios and have minimal slope (Todd Chaudhry pers. comm.)]. The relevant fire management agency in your area can assist in this planning. See Useful contacts reference: On the land Agricultural Fire Management Guidelines (CFA 2008).

To help you understand the types of fuels in rainforest restoration there are a number of sources of fuels, which we will look at in turn, so that you can appreciate the risks and adopt strategies to minimise the potential for fire to occur or propagate through your rainforest restoration site:

- Dry matter as the result of weed control
- Leaf litter
- Dense plantings of pioneer species.

Dry matter

If you have good perimeter fire breaks (and you should), the amount of dry matter within the site is less of a concern. In any case, care should be taken not to leave large areas of dry fuel standing near the perimeter of your site during high-fire-risk periods. This can be achieved by: regular weed control (this reduces the fuel load and separates otherwise continuous fuel strata); changing the timing of weed control to avoid these high risk fire seasons; altering the localities on your restoration site; and using methods that do not leave dry fuel (e.g. regular slashing of fire breaks rather than poisoning that leaves dead material as a mulch).

Leaf litter

Leaf litter is usually the place where the fire begins, but, irrespective of ignition point, it needs a continuous chain of fuels to spread along the ground or to spread vertically (***fuel ladders***) to set the canopy alight. Consequently, bare patches of ground can be an effective fire break. The effectiveness of such breaks is dependent on flame length (i.e. can it physically cross or reach out to your fuels to dry them out and allow ignition?) and wind speed (Todd Chaudhry pers. comm.). The other requirement for ignition is that the fuels need to be dry and the fuel load needs to be at moderate to high levels for the fire to propagate and spread. In mature rainforest, there can be areas of bare ground and fuel loads are usually low (<4mm in depth; Additional Reading: Leaf litter: rainforest versus non-rainforest communities: Table AR6,) which matches the low fuel load category (McCarthy *et. al*. 2003). Additionally, much of the fuel is living and such fuels normally have higher moisture content, and the deep shade and humid atmosphere created by the canopy ensures that the fine fuel moisture content will be higher; but this can change during drought: the time when fire risk is greatest. These mixes of factors contribute to the inherent combustibility of rainforests, which will vary according to circumstances and successional stage. Consequently, leaf litter in mature rainforest is not considered a significant fire risk.

However, the leaf litter that is produced by some pioneer plants can be combustible, especially those with high volatile oil content and on sites where restoration works have favoured species that have light-transparent crowns that allow ground fuels to dry out (Dogwoods *Cassinia* spp. and *Ozothamnus* spp.). Strategies to manage these risks are covered below..

Dense plantings of pioneer species
The same caveats apply as those listed under *Dry matter* (above) when dealing with dense plantings of pioneer species, which are inherently more flammable than the mature phase rainforest plants. Planting pioneer and secondary species on the site to recharge the soil seed bank to mimic ***secondary succession*** is necessary for successful rainforest restoration (Chapter S6: Successional planting), but these plantings represents an extreme elevated fuel risk (McCarthy *et. al*. 2003) (e.g. Figure S126), but the surface fine fuel hazard is negligible for the same site (e.g. Figure S180 and Figure S181). As a consequence, good site fire management is the key to undertaking this essential task: maintaining fire vehicle access and green or bare soil fire breaks with low fuels (Figure S116) or other pre-existing features in the landscape, such as roads (Figure S116), rivers (Figures S32) or lakes (Figure S40).

Good site management to mitigate fire risk can be achieved by using one or more of the following strategies:

- Planting hardy species (appropriate to the FC of the site) that resist ignition, which can include broad-leaved secondary species as well as others such as: Scurvy Weed *Commelina cyanea*, Rusty Fig *Ficus rubiginosa*, Hazel Pomaderris *P. aspera*, Seaberry Saltbush *Rhagodia candolleana*, Kangaroo Apples *Solanum aviculare*, *Solanum laciniatum*, etc. (Additional Reading: Ignition times) and New Zealand Spinach *Tetragonia tetragonioides* (which fails to ignite). It is important to use as many of these species as possible on the edges or along boundaries that need protection from fire (abutting assets, etc.) and from as many life-forms as are appropriate for the FC on your site. This will help to reduce both the horizontal and vertical spread of fire. Be aware, however, that some of these species can tend to swamp early successional stages of rainforest restoration if they are a ***gap maintaining species*** (e.g. Jungle Grape *Cissus hypoglauca*, Seaberry Saltbush *Rhagodia candolleana,* etc.): which will mean keeping an eye on their extent and growth.
- Repeat the experiments outlined in Additional Reading: Ignition times to discover the low flammability species that you might be able to deploy on your restoration site to reduce fire risk.
- Maintaining a firebreak between the works and the adjacent properties or assets;
- Planting isolated clumps
- Pruning up the base of pioneer species to achieve a break between ground fuels and the shrub's foliage (Dogwoods *Cassinia* spp., Everlastings *Ozothamnus* spp. etc.): at least on the perimeter (if ignition sources are most likely to come from neighbouring areas) and you are unable to plant or maintain a green fire break around your site.

Dense plantings of secondary species
Many late secondary species are trees that, because of their architecture, either establish a break between the vertical arrangement of fuels (Figure S113), which reduces the rate of fire spread (and/or its ability to crown), or they are themselves fire retardant: compare Blackwood *Acacia melanoxylon* with Black Wattle *A. mearnsii* (Additional Reading: Ignition times). These provide excellent opportunities to reduce fire risk on your restoration site, as well as to provide structural habitat diversity, which is a key determinant for the use of your site by animal groups such as birds, ground mammals and reptiles (Munro *et. al*. 2007).

Here are some ideas to help reduce your fire risk using secondary species:

- In high-fire-risk districts, localities or areas of your site, reduce the amount of combustible pioneer species in your planting mix by incorporating more late secondary and pioneer species that lack the volatile oil content and cast deeper shade (e.g. Blackwood *Acacia melanoxylon*, Blanket-leaf *Bedfordia arborescens*, Kangaroo Apples *Solanum* spp. and Hazel Pomaderris *P. aspera* and any others that you may discover).
- Reduce the density of plantings overall (generally not desirable for weed control, (unless you use larger species with a broader crown reach such as Blackwood or Rusty Fig).
- If these species are not available, use other strategies first, and only where necessary for fire risk.
- Mass plant fire-suppressant vegetation, but only using those species that are indigenous to the site. These species are both fleshy and contain high levels of salt: New Zealand Spinach *Tetragonia tetragonioides*, Common Boobialla *Myoporum insulare* and Seaberry Saltbush *Rhagodia candolleana*.
- Use old remnant stands of species such as Green Wattle *Acacia irrorata*, Black Wattle *A. mearnsii* (Figure S113) Bodalla Wattle *A. trachyphloia* and River Oak *Casuarina cunninghamii* that have a break in fuels between the ground and the canopy. Some Littoral Rainforest species have the same structure but also trap salt in their foliage and fine fuels. Those species in their old-growth form that provide good fire suppressant qualities include: Swamp Oak *Casuarina glauca*, Giant Honey-myrtle *Melaleuca armillaris* (Figure S341), Swamp Paperbark *Melaleuca ericifolia* and Coast Tea-tree *Leptospermum laevigatum.* They act in this way because fuel continuity is broken, and their crowns are green and retain high moisture contents (Greg McCarthy pers. comm.), but even so may still be flammable (with Coast Tea-tree taking on average 7.4 seconds to ignite) should a fire reach their canopy.

So, take the appropriate precautions on your site (where you can and where they will be effective), especially if assets are nearby, such as: people and buildings. This advice is doubly important given the relationship between fire behaviour and climate change (Chapter S7: Fire management at the landscape scale). Fuel reducing adjacent non-rainforest vegetation can also be effective. Beginning your restoration efforts early where rural agricultural land is being converted into suburban housing (Figure M22), ensures your early establishment works are remote from built assets and the fire threat that they may pose is not much larger than a paddock full of dry grass itself. By the time the housing ends up cheek by jowl with your restoration plot, you will have a lower flammability mature rainforest in place (Chapter S8: Views: Figures S338 and S339).

Bonfire trees

Surprises will always await the unwary: be aware that: even a single eucalypt presents a significant combustion source to rainforest during wildfires when it can become a ***bonfire tree*** even where buried deep within the mature rainforest. But eucalypts are not equally fire prone: Ironbarks (Appendix S18: Fire and soil disturbance response worksheet: Figure AS18-3) and Box trees are a very low risk because they do not have bark piles and their bark is very difficult to ignite (because it is not a fine fuel). Stringybarks are more of a risk because the stringiness of the bark is a fine fuel. The most sustained radiant heat is generated by bonfire trees that are the gum-barked species, which develop bark piles at their bases over the decades between the fire events. In larger and older trees, such piles are often augmented by sloughed limbs. The larger tree, the larger the bark pile will be and the position of the tree is important: those on the margins of rainforest will have their bark piles consumed by fire more regularly and so will not get as large, whereas those buried deep within the rainforest are likely to miss out on ignition from smaller lower intensity fires. This allows the bark piles to get very large and to have sloughed limbs in their midst, so that when the catastrophic wildfire does allow a trickling ground-fire to enter the rainforest stand due to critically low fuel moisture levels, the resulting combustion of the bark pile will be longer lasting (Appendix S18: Fire and soil disturbance response worksheet: Figures AS18-1 and AS18-2), and the radiant heat more damaging (Figure AS18-4 and AS18-5).

So how does the bonfire tree phenomenon operate? A trickling wildfire that moves with minimal damage through the leaf litter of the rainforest can erupt when it gets into the bark pile at the base of the gum-barked eucalypts. These piles ignite then burn over long periods sending a sustained burst of radiant heat outwards and upwards. Because bark thickness is the principle factor governing temperature rise at the cambium during a fire, which leads to thermal damage and scarring (Gould *et. al.* 2007), and because most rainforest plants have very thin bark (and therefore poor insulation against heat), a sustained heat source nearby (such as that generated by burning bark piles), literally cooks the sap-conducting cambium and so kills or severely damages these heat-sensitive plants (Greg McCarthy pers. comm.). Remarkably, even though these fires burn with intense heat, (temperatures of >600°C sterilising the adjacent soil for many metres), the tree that produces the pile and is in the thick of the fire, usually survives very well.

In reality, there is nothing you can or should do to modify this state of affairs, especially given the considerable and unique ecological benefits that rainforest eucalypts convey to these plant communities (Chapter S4: The importance of eucalypts in rainforest ecology). The rare ignition of bonfire trees is a natural process and helps maintain these leviathan eucalypts deep within many rainforest stands in south-eastern Australia. Their presence and ignition, even within small linear stands of rainforest, does not lead to the rainforest's destruction when they become bonfire trees following these rare wildfire events because the rainforest has decades if not centuries to recover between fires, Interestingly, however, a much maligned species, the Bellbird, may to assist in the 'weeding out' of these trees in rainforests and their margins and thereby helping to 'protect rainforests from the fire within' (Chapter S4: Bellbirds: rainforest-protectors?).

Disturbance

Introduction

Rainforests are subjected to a range of disturbance types and severities and have a myriad of ways to respond to their disruption. Some of these responses are dependent on the disturbance type, while others are common across disturbance types. In most cases, the damage experienced by rainforests can recover over years, decades or centuries. If you comprehend the types and frequency of disturbance events likely to be experienced by your restoration site, then you will better understand the steps we have suggested to 'future-disturbance-adapt' it.

A good example of the variability of the rainforest response on the same site differing according to the disturbance type has been recorded in the monitoring undertaken by Snowy River Riparian Pty. Ltd. at Boulder Creek following the 2007 wildfire there (Chris Coulton pers. comm.). The pioneer and secondary species that responded were largely from the soil seed bank, with eucalypts the major exception with their seed rain falling onto the newly bared earth (following the fire's passage). In rainforest that had fire disturbance only, the dominant secondary species to occupy the site was Blanket-leaf *Bedfordia arborescens*. In contrast, where there was soil disturbance as the result of machinery activity, the dominant secondary species were Hazel Pomaderris *P. aspera* and Victorian Christmas Bush *Prostanthera lasianthos*. Interestingly, the early monitoring showed a plethora of eucalypts germinating and getting to about 5-10cm in height. Species represented included Mountain Grey Gum *Eucalyptus cypellocarpa*, River Peppermint *E. elata* and Yellow Stringybark *E. muelleriana*. Most of these have disappeared: apparently out-competed in the rainforest's habitat by its colonising pioneer and secondary species (some of which are mentioned above). Today, members of this eucalypt regeneration cohort are hard to find. The majority of those surviving being River Peppermint (because they were the most prevalent emergent eucalypts above the rainforest in this creek system), suggesting that there is some other mechanism that sees them succeed on the river flat compared with their counterparts from the adjacent hills.

The lessons here are that there is a reason why species occur where they do. The action then is that we must follow their distribution and niche requirements when planting in restoration projects; and ensure that we take out insurance for our restoration sites by planting the pioneer, secondary and emergent trees that will repopulate the site when a major disturbance passes that way again in the future. Failure to take note of these obvious mechanisms will see your site fail its ultimate test: resilience and re-establishment following disturbance (particularly severe stochastic events); at a time when you are unlikely to be there to assist.

Fire

Even though rainforests occur within fire-protected positions in the landscape, they rarely escape fire completely. Within south-eastern Australia, fire is almost inevitable at most restoration sites. Good rainforest restoration takes this into account by planting pioneer species that grow quickly, set seed and store this in the soil seed bank. Following fire these species germinate abundantly and establish quickly setting up the first stages of rainforest succession. Many rainforest species have adaptations to survive or regenerate following fire, others do not. Appendix S18 lists these features and tolerances while in the same appendix Worksheet: Figures AS18-1 to AS18-14 provide a pictorial representation of these responses from a Warm Temperate Rainforest stand in the headwaters of Monkey Creek (north of Bruthen in Victoria). The photographs were taken 10 months following the Great Divide Alpine Fires of 2007 after a very good series of winter and spring rains. To date, 231 species have had their response to fire and/or soil disturbance recorded in Appendix S18.

Apart from the structural damage that fire may inflict on your rainforest, and the possible loss of individual plants and animals, it is also a time of gap repair, rainforest renewal and, in some instances, rainforest expansion. How can this be? Gaps will form during inter-fire periods. Some of these will not actually repair, either because the disturbance did not occur in a place where there were young primary species already present to fill the gap, or the disturbance event was insufficient to set-off the germination of pioneer and secondary tree and shrub species. Fire provides a disturbance that is sufficiently robust as to begin the cycle of gap repair (through resprouting, germination from the soil seed bank, or from seed rain released by fire: *Banksia*, *Hakea*, *Grevillea*, *Telopea,* etc.) whereas Figure S282 illustrates an example where soil disturbance will not produce this result.

During ***gap phase regeneration***, the gaps are filled by primary and secondary species, which, in turn, seals the gap: raising humidity and allowing epiphytes to proliferate. Establishment of dense ***wheat-field regeneration*** of rainforest pioneer and secondary species keeps sclerophyll species at bay, which in time allows primary species to establish beneath (provided there is an undamaged or recovering core patch nearby to supply the seed) (Coulton *et. al.* 2009).

FIRE: POTENTIALLY A TIME OF RENEWAL IN RAINFORESTS: SOIL DISTURBANCE NOT NECESARILLY SO

Figure S282. McKenzie River, Victoria. Following soil disturbance on this mineral earth fire break during the 2007 Boulder Creek fire, there is rampant seed germination of herbaceous species (more than 10 species at this spot), including two species of ferns that are resprouting. There are no woody species in this mix: meaning that this gap is unlikely to return to a mature rainforest canopy as a result of this round of disturbance.

Another noticeable event following fires is the germination of ferns on sterilised sections of earth where the fire has burnt particularly hotly (in old stumps or where logs have burnt out. These fern germination niches seem to be possible because no vascular plant seed can survive such high temperatures and leaf litter has been removed (Figure S283). The only other disturbance scenario that sees the leaf-litter removed, and a similar ***bryophyte*** and fern regeneration response (to the author's knowledge), is the deposition of mud following flood events [Chapter S4: Mosses and ferns: when and how they arrive (Figure S156) and volcanic eruptions.

The key threats following fire in rainforest are the germination of weed species (Figure S284) or resprouting of weeds and the reinvasion of pest animals such as Sambar (Opener), any of which can deflect regeneration pathways and trajectories and severely impact upon the site's recovery. This provides a great opportunity to hit pest plants and animals. Transforming weeds can be targeted when they are weak or small, because the fire depletes the soil seed bank. Sambar congregate in large numbers on or near farmland following fire (because resources are scarce and they require the pasture to survive) and during these periods of stress they suspend breeding and go into survival mode (Mason 2008). At such times, Sambar can also be targeted because these congregations are accessible and may have nowhere else to go.

OUT OF THE FIRES OF HELL

Figure S283. McKenzie River, Victoria. 2007 Boulder Creek Fire: ground-ferns germinating on the clay surrounding the burnt-out roots of a eucalypt in Warm Temperate Rainforest. The high temperatures are indicated by the orange colour of the clay (oxidation of iron), and its aggregation structure has changed, which only occurs when fire temperatures exceed 600°C (Tolhurst and McCarthy undated). The soil has been sterilised and all vascular plants seed in the soil seed bank has been killed. Given the fire's temperatures it is most likely that the spores floated in or rained in after the fire to start the germination and renewal.

Flood and flood-mud regeneration

For sites along major streams and short-course catchments, flooding is going to occur. You can roughly gauge the likelihood and extent of flooding by the presence and area of the floodplain. Rainforest species that occur naturally along such streams are well adapted to either survive flooding or to regenerate following the event, with ***flood-mud regenerators*** a classic example. For this reason, it is important to follow the species lists provided in Appendix S5. Planting species that are not indigenous to the site is really a waste of time. So plant species from the correct rainforest ecological vegetation class in the appropriate flood zone that match the frequency and intensity of flood disturbance for that part of the river bank (Chapter S1: Rainforest types covered by the Manual).

These flood zones along rivers are the major determinant of rainforest type and this is related to stream size, climate and position on the bank. These translate into flooding frequency, flood force (see Figure AS5-1 in Appendix S5), sediment deposition (depth and composition; see Figures AS5-2 to AS5-8 in Appendix S5), and period of inundation. To determine what species grow in what zone on any river bank, locate a vegetated reference site along a stream reach with the same characteristics as your restoration site and start making species lists based on the physical features and flood history of the site. Factors that must be similar include stream order, catchment size and the level of valley constraint operating on both sites (Chapter S1: Gallery Rainforest).

FIRE SHOULD BE A TIME OF VIGILANCE IN RAINFORESTS: WATCH FOR WEED THREATS

Figure S284. McKenzie River, Victoria. 2007 Boulder Creek fire: Queensland Bramble *Rubus moloccanus* ssp. *triloba* (red arrows), a native with Blackberry **Rubus anglocandicans* (blue arrows) have germinated together (perhaps from the same scat) following fire. Controlling this threat requires good eyes and focused weed control in order to conserve the native regeneration, which in this instance requires hand pulling or cutting and painting.

Weeds also flourish following floods. Floods transport seed and fragments, and management of these is best tailored to what you see on the site. If disturbance has been extensive, then expect a lot of sun weeds, but in shaded areas, or if the flood damage has been minimal, look out for shade weeds (especially those transported as fragments such as Wandering Jew **Tradescantia fluminensis*). The latter need not be sought out until 6-12 months after the flood, when they will be apparent but still easily controlled (Figure 9.21).

Floods also provide a classic opportunity for rainforest regeneration that rarely occurs at any other time in the life-cycle of floodplain rainforests, through a process we have called flood-mud regeneration. The regeneration occurs even after gentle floods where there has been no physical disruption to the pre-existing vegetation or canopy. Species so far identified in this group have been listed in Appendix S5 and currently number 41 (this does not include the many primary successional stage mosses, liverworts and ferns that are yet to be identified). Often these plants are secondary species that have trouble regenerating in leaf litter in rainforests; but the list also includes rainforest primary species that are well adapted to regenerating in leaf litter.

The secondary species in this group are very interesting. Because high litter loads in rainforests represent regeneration barriers for these secondary species (as is the case also with mosses and ferns), the flood event's deposition of mud provides an important opportunity for regeneration in rainforest niches that would not otherwise be available to these taxa (except after fire or catastrophic flooding). Interestingly, many of the species listed as flood-mud regenerators in rainforest are traditionally thought of as only regenerating exclusively after fire.

This important discovery confirms that the species listed in Appendix S5 are species of rainforest that do not require fire for regeneration in rainforest niches. These observations go a long way to explaining the presence of these traditionally perceived 'fire-dependent sclerophyll species' in riverine rainforests that show no evidence of fire. In that vein, and given that the taxa so far identified as regenerating in this manner, it raises the suspicion that many other taxa thought of as 'fire-dependent' for regeneration, but which occur in rainforest, will also be recorded as flood-mud regenerators in the future. Here is a guess as to which taxa might in future be included as flood-mud regenerators:

- Oyster Bay Pine *Callitris rhomboidea*
- Other members of the family Asteraceae: Cassinias *Cassinia* spp., Cudweeds *Euchiton* spp.
- Other floodplain eucalypts: Coast Grey Box *E. bosistoana*, River Peppermint *E. elata* and Blue Gum *E. globulus*
- Other members of the family Myrtaceae: River Bottlebrush *Callistemon seeberi*, Kunzeas *Kunzea* spp., Tea-trees *Leptospermum* spp. and Melaleuca (one at least confirmed several weeks later with Swamp Paperbark *M. ericifolia* added to the list of flood-mud regenerators)
- Other members of the family Proteaceae. Coast Banksia *B. integrifolia*; Small-flower Grevillea *G. linearifolia* and Gippsland Waratah *Telopea oreades*.

The type of sediment also seems important: silts and sands allow germination from below the deposited sediment from the existing seed bank (compare Figure AS5-6 with Figure AS5-7). The mud presents a germination barrier to the soil seed bank (Figure AS5-4), providing a competition free environment for the establishment of the species listed as flood-mud regenerators in Appendix S5 (see Figures AS5-1 to AS5-8). The seed sources are therefore what arrives during the flood, either in the flood's mud, in the water, or post the flood from wind, animals or seed dispersed by gravity after the mud's deposition.

Keep your eyes peeled for this important phenomenon and add any new species that you discover to the list in Appendix S5!

Drought

Drought is a regular feature of the Australian landscape and has to be taken into account when undertaking restoration. Because it is a normal part of the ecology and evolution of rainforests within south-eastern Australia, it may reasonably be expected to be a factor that can work both in the favour of the restorer and against your broader aims. It is therefore important to understand what the important features of drought are and how these can be used to your advantage in bush regeneration.

That being said, it is also likely that climate change in south-eastern Australia will see increased frequency and severity of drought. This is more difficult to plan for and is likely to have a more significant effect than 'normal' or pre-existing drought cycles and magnitudes. The future in that regard is unknown, but the warnings are dire, and observed impacts are already severe.

Nonetheless we must still deal with drought. Droughts predictably place serious limitations on what can be achieved in a restoration project (moisture-dependent species fail to establish or flourish), but can also provide unexpected opportunities. With the advent of seasonal outlook forecasting by the Bureau of Meteorology, some idea of the season ahead can be deduced and planning your works program can proceed with some certainty. To do this jump onto a web search engine and type in <http://bom.gov.au> and follow the prompts to Climate Services then Seasonal Outlooks then ENSO (*El Niño*--Southern Oscillation), then National three-month outlook (archive), then click on the state that covers the area of your restoration site or sites. If you want to see how bad it can get, go to the Seasonal Climate Outlook Rainfall Archive under Seasonal Outlooks. Figures S285, S286 and S287 show how to use these forecasts for rainforest restoration (and that even during the worst drought recorded in East Gippsland), we were able to make significant progress on three major rainforest restoration sites in the region Figure S287). Take note, though, that this fact does not translate into planting advice during drought years for southern New South Wales (Chapter S8: Table S30: Planting seasons for rainforest restoration by region across the south-eastern Australia).

USE SEASONAL OUTLOOKS TO PLAN YOUR RAINFOREST RESTORATION WORKS

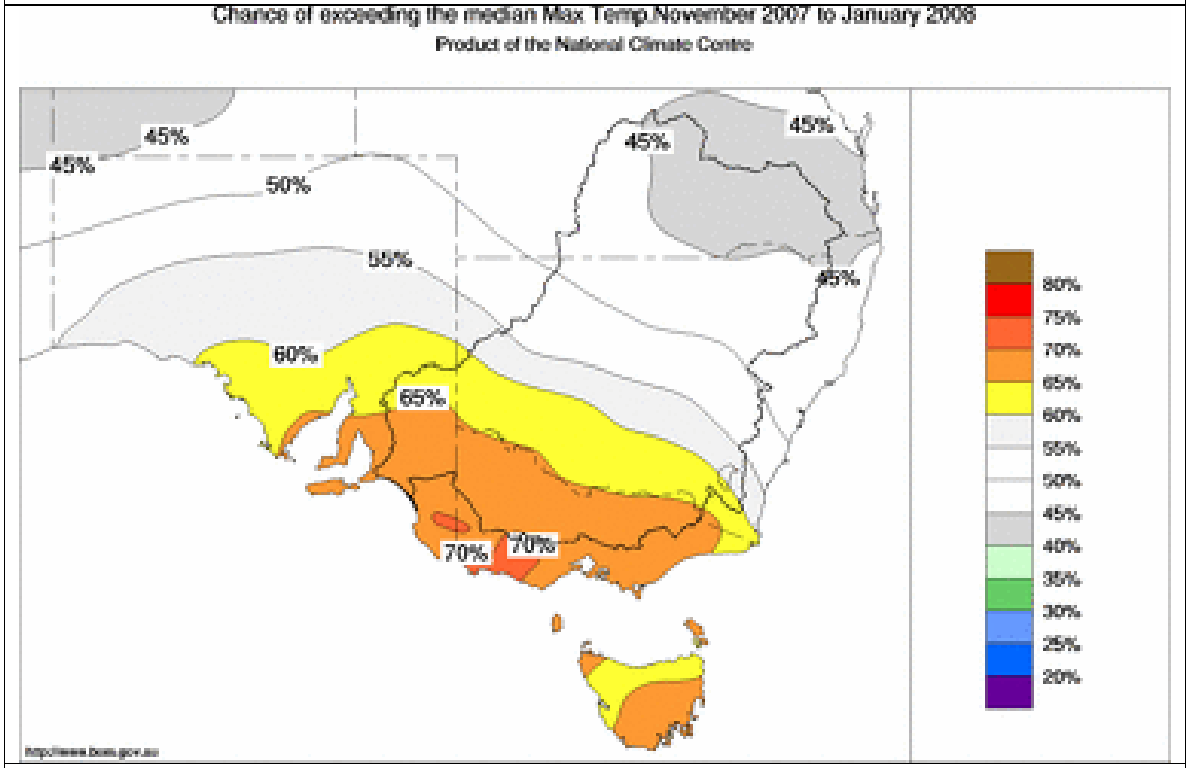

Figure S285. Seasonal outlooks during La Niña are generally favourable for rainforest restoration as the chances for above average temperatures is generally low for most of the region except the south and west (western parts of East Gippsland, Central Highlands, Strzeleckis and Otway Ranges. Source: <www.bom.gov.au>.

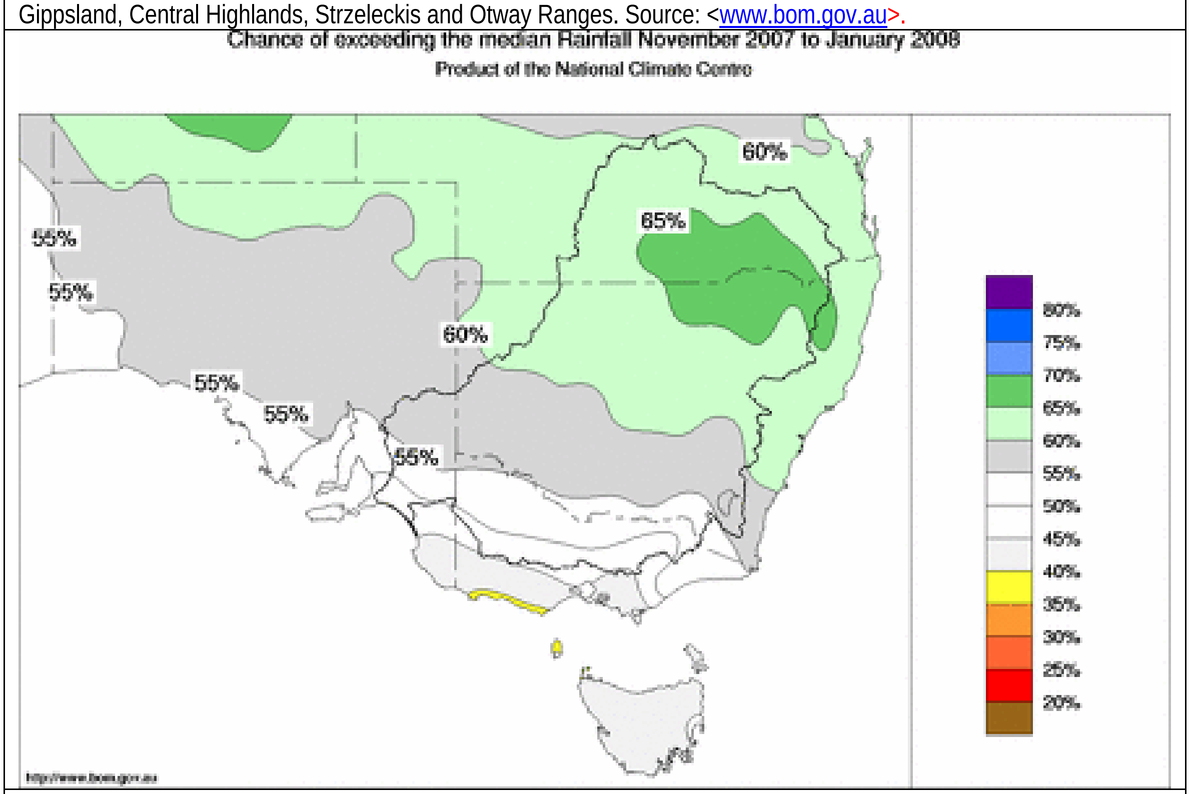

Figure S286. Seasonal outlooks during *La Niña* are good for above average rainfall. Source: <www.bom.gov.au>.

PROVIDED SOIL MOISTURE IS PRESENT DURING COOLER MONTHS: RESTORATION CAN PROCEED

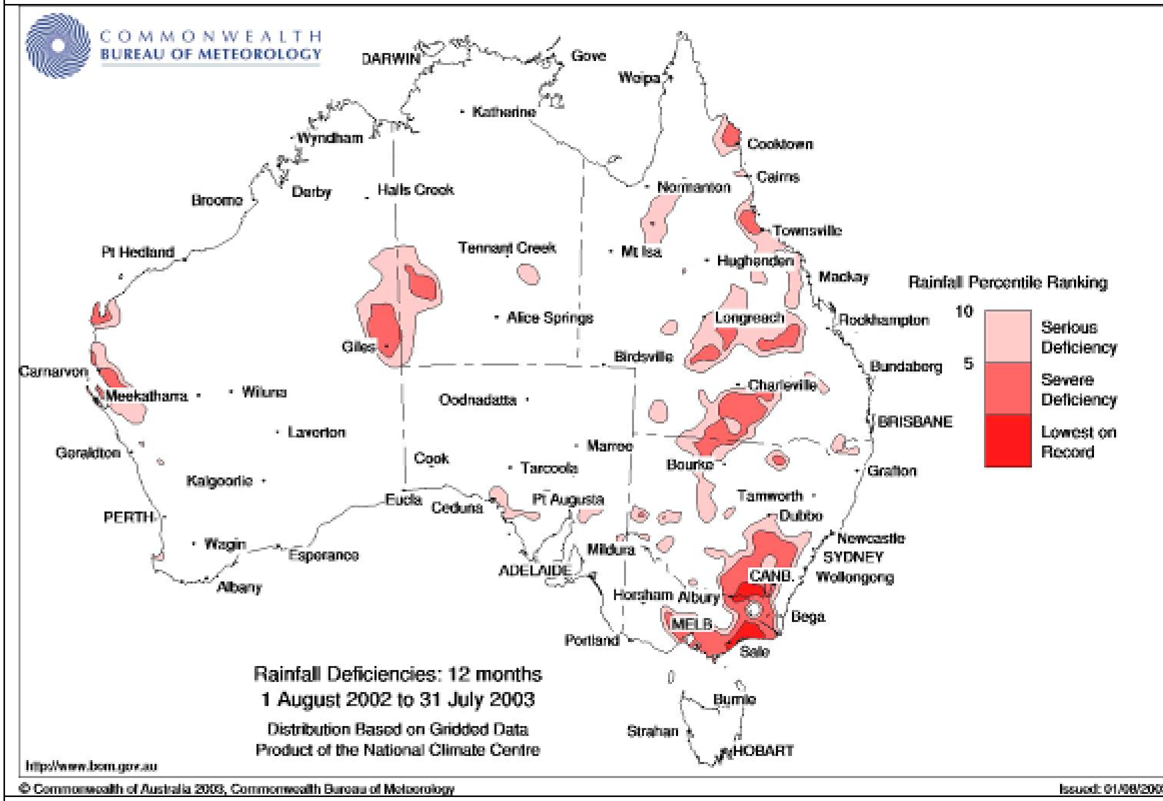

Figure S287. Significant progress was made on rainforest restoration during this *El Niño* phase, which was the worst drought in East Gippsland recorded since Bureau of Meteorology records began. However, the same cannot be said for attempting rainforest restoration works in southern New South Wales during drought periods. Source: <www.bom.gov.au>.

Knowing the basic features of drought, the restorer can develop an approach that will maximise the work done during dry times. The important features of drought as they affect rainforest restoration are:

- Soil moisture may never reach levels suitable to begin planting: especially in southern New South Wales (but usually just means a shorter planting seasons in East Gippsland, i.e. late autumn to mid-winter rather than early autumn to early summer).
- If suitable soil moisture levels are reached to allow planting to begin, follow-up rain may not occur, so late season (spring) planting is not recommended.
- Under greenhouse conditions, droughts are now accompanied by more elevated temperatures compared with past droughts.
- Droughts mean less rain, which means less cloud cover, which for winter time means more frosts that are more severe over longer period. For example, frost records at Orbost on the lower Snowy River kept by Jurg Hepp showed 45 frosts in an *El Niño* year compared with 3 or 4 for other years.

On the face of it, it does not seem as though there is much opportunity for the rainforest restorer. However, the features of drought listed above provide the following opportunities:

Planting

- Plant in perennially moist niches, shorelines of lakes or along the toe of river banks or gully floors where the water table is closer to the surface in most years.
- Shift your planting species mix towards the more drought-hardy species in the floristic community being restored: often full sun pioneers in the daisy family (Everlastings: *Bracteantha* sp., *Ozothamnus* spp., *Olearia lirata,* etc.), and, if appropriate, in estuary areas or coastal sites: salt-bushes (*Einadia* spp., *Rhagodia* sp., *Atriplex* sp.) *Tetragonia* and *Myoporum*. Many of these species also establish from seed at this time as well, and being well adapted these dry conditions, they not only germinate but grow prolifically as well (Appendix S19).

- Conversely, avoid planting broad-leaved secondary species that require adequate moisture during their early establishment phase (e.g. Blanket-leaf *Bedfordia arborescens*).
- If you would normally plant frost-sensitive species (*Pittosporum undulatum* and *Syzygium smithii*, etc.) in the open during average years when frosts are moderate or absent, only plant such species under the cover of pioneer or secondary during drought years or risk the result shown in Figure S288.

Flowering and seeding

- Drought years can also stimulate major flowering events, but these may be late by up to 2-3 months in species that can be sporadic flowering (Appendix S19). Some important species that respond in this way include: Yellowwood *Acronychia oblongifolia,* Bursarias *Bursaria* spp., Jungle Grape *Cissus hypoglauca*, Blue Box *Eucalyptus baueriana,* Coast Grey Box *E. bosistoana*, Forest Red Gum *E. tereticornis* ssp. *medianus*, Blue Oliveberry *Elaeocarpus reticulatus*, River Lomatia *Lomatia myricoides* and Lilly Pilly *Syzygium smithii*. Such flowering events should be closely watched because they can provide a bonanza for those whose seed only comes along sporadically.
- Do not assume that seed will not be set during drought years. Concentrate your work effort on seed collection because some species can provide abundant seed crops (Appendix S19): Scrambling Lily *Geitonoplesium cymosum*, Large Mock-olive *Notelaea venosa*, Austral Sarsaparilla *Smilax australis,* etc.

Patience

- Drought mediated or made more severe or frequent by climate change can be very scary (Figure 4.13). Nonetheless, we should not jump to conclusions and believe that the end of the world is nigh. As discussed in the caption to Figure 4.13, this significant event has had some benefits to another component of this rainforest floristic community's flora. We noted a similar outcome in *Alluvial Terraces* Warm Temperate Rainforest on the lower Snowy with regard to New Zealand Spinach *Tetragonia tetragonioides* and other drought-tolerant species. So stop, watch and learn from these events.

Weed control

- Take the time to do extra weed control because your planting duties are reduced, but be careful to do herbicide work only after rain or when the weed is actively growing.
- Undertaking weed control within earlier plantings or remnants can be especially useful during these years because it reduces competition for moisture and this aids both plant establishment (Figure S289) as well as facilitating seed germination of native species when the rains arrive (Figure S270). Such drought-mediated regeneration pulses are a major feature of Littoral Rainforests in south-eastern Australia (Figure S290).
- Controlling weed competition is especially important for successful establishment of pioneer species (native "weeds"), which themselves do not like competition. During drought years this can be critical, especially for frost sensitive species such as Kangaroo Apples *Solanum* spp., which need the maximum height and canopy growth possible to withstand the coming frosts of winter. Although mowing may be an effective weed control measure in the early years with advanced tree-based planting methods, herbaceous pioneer species (e.g. *Solanum* and *Senecio*) will not tolerate competition from grasses (Figure S289) and will not regenerate in the mown sward. This is because they need bare ground as their seed bed. Herbicide control is therefore recommended (Figure S291).

Pest animal control

- As with fire, drought limits resources: the amount of food, its quality and water). All animals are dependent on those resources that become scarce during drought. In places where these resources remain relatively abundant (such as in landscape refugia during drought), significant aggregations of animals will occur during these times of landscape stress to take advantage of the relative abundance of these resources. If pest animals are included in such aggregations, then this provides land managers with a significant opportunity to control them.

  During the 2003 drought, when the mighty Mitchell River was reduced to a trickle that you could literally step across, hundreds of Sambar congregated in the remote gorge country of the Mitchell River National Park (Joe Stephens pers. comm.). While there, these starving and thirsty animals caused enormous damage to the riverside vegetation including: Warm Temperate Rainforest, Gallery Rainforest and Dry Rainforest. Even during normal years, Sambar have severe impacts on local rainforests and their constituent plants because they are favoured vegetation types (Peel *et. al*. 2005) in which they congregate to feed, rut and rest. This is why they have been listed as a threatening process under both the Victorian *Flora and Fauna Guarantee Act* 1998 and New South Wales *Threatened Species Conservation Act* (1995).

Climatically induced resource shortages that create much larger aggregations provide the perfect opportunity for organised culling, which has the potential to virtually wipe out such climatically vulnerable populations. Sambar reproduce at the rate of 1.2 calves per year so that after significant disturbance events such as fire, which devastate their numbers, it will take a decade or longer for numbers to rebuild to their former levels (Mason 2008). These reproduction statistics provide land managers with an important opportunity. By culling the majority of Sambar in such drought-induced aggregations their numbers could be sufficiently reduced so as to allow the vegetation that they have so severely degraded to recover when the drought breaks.

With what is known of their breeding biology, such management actions are likely to have a profound and reasonably long-lasting benefit for the nearby or favoured vegetation upon which they feed. Given that Hennessy *et al.* (2008) are predicting that drought events are going to become more frequent and more severe with climate change[1], such control measures for this pest are not only an imperative, but if they prove effective, they should become the rule.

If drought-induced congregations do become more frequent (and if culled at that time), it may leave Sambar fewer years in which to increase their populations to the point where they can continue to degrade the vegetation (especially at critical recovery times following the breaking of the drought). Our adaptation to this changing frequency of drought (and the opportunity for pest control that comes with it), may actually improve the land managers' ability to have a greater impact on the Sambar population and thereby reduce its unnatural pest impacts on the Australian environment.

Frost and frost management

Introduction

At Clouds Creek (northern New South Wales) an increase in ground frosts that resulted from forest fragmentation delayed and, in some cases, prevented rainforest regeneration (Adam 1994). Frost is one of the most important disturbance types that will affect your ability to restore rainforests in south-eastern Australia. Unlike all of the other disturbance types previously discussed, it is seasonal and, in most localities, will return each year. It is significant because most of the primary rainforest plants in the lowlands of south-eastern Australia are adversely affected by frost (especially when young, with some being killed) and these are the species that become the dominant plants in mature rainforest. These include most of the rainforest's plant diversity and the most important structural elements (trees, shrubs, vines and ferns). All life-form categories are affected. Appendix S20 provides definitions of frost sensitivity, as well as listing the known frost sensitivity of many of the region's lowland rainforest plants. Using this data, you can anticipate frost as a disturbance type on your restoration site and take steps to manage for frost it in your planning and execution of the project if it is going to be a factor.

The sub-zero temperatures required for a frost to set can be caused by two processes: radiated heat loss from the earth to the atmosphere at night and catabatic (down slope) cold winds (breezes really) that also occur at night. The former can be counteracted by the establishment of a blanketing canopy of frost hardy pioneer species (like a doona for warmth), while the latter can be counteracted by a number of actions including: where you begin works and the types, structure, configuration and composition of your early plantings (Figure S292). Your planted forest can warm amazingly cold air (Figure S293).

As a general rule, frosts are more severe the further south you are in the region and the further inland your site is located. In fact, frost is one of the determinants that set the inland limit for lowland rainforest types. However, there are other factors at work that can produce severe frosts in unexpected places within the region.

So, what are the factors that mediate frost occurrence and severity? Can these factors combine and make some places worse for frosts and other places nearby warmer? Can these factors be used to model frost zones in the landscape?

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[1] Drought is a combination of high temperature, low rainfall and low humidity. From the reference period 1900-2007, the area affected by exceptionally high temperatures was 4.6% and by 2010–2040 it is modelled to cover 76% of the Victorian-Tasmanian region; exceptionally low rainfall was 5.4% of the region and by 2010–2040 it is modelled to cover 9.7% of the Victorian-Tasmanian region; and the return periods for such events for both variables (rainfall and temperature) are expected to change from 16.8 years to 9.4 years).

BEWARE THE FROST (ESPECIALLY DURING DROUGHT): PLANT TO PREVENT THIS KIND OF DAMAGE

Figure S288. Snowy River Riparian and Rainforest Restoration Demonstration Site, Orbost Victoria. Significant edge effects: two-year-old primary canopy species on the edge of a restoration site opposite Orbost on the lower Snowy River. Frost burn has resulted from the combined impacts of sub-zero temperatures and cold winds following the worst frosts in 25 years that occurred during 2003 drought (the worst recorded); compare Figure 7.7 two years later.

Factors that mediate frost in the landscape

Here are some of the factors that we have used to model frost occurrence and severity in the landscapes of south-eastern Australia:

- Climate change: under higher emissions Orbost's current 18 frosts a year will drop to 2, Lakes Entrance's current 6 will drop to 0.
- Latitude: there are no frosts on the coast north of 30°S which is about Coffs Harbour (Crowder 1995).
- In the subtropical climate zone: there are fewer and less severe frosts on the coast south from Coffs to Aragannu Beach, but note that in the last 30 years the temperature isotherms have been moving pole-ward at the rate of 35 miles per decade. If emissions of Greenhouse Gases continue at their current rate, then this trend will double over the next century to 70 miles per decade (Hanson 2006), so the subtropics are coming: under higher range emissions scenario it is projected that by 2070 Orbost will have the current temperature regime of Nowra but the current rainfall of Bairnsdale (DSE 2008).
- Altitude: inversions mean that ridges, slopes and foothills can be warmer than the valleys below that collect cold air drainage overnight. These phenomena can be accentuated by mountain fogs, which help to reduce the chances of frosts in our region from forming on those landforms). These differences can be quite striking. In August 2006 at 8.00 am on the valley floor on the Princes Highway in East Gippsland at Carlo Creek, it was 2°C while in its headwaters 400 m higher at Mount Drummer the temperature was relatively speaking: a balmy 8°C. Similarly in the early evening the differences were again beginning to appear. At 7.00 pm (on the return trip), Carlo Creek was 6°C and Mount Drummer was at 8°C. Bigger differences are likely on frosty nights, but were not recorded at the time.

- Sea surface temperature: for the same latitude, differences of as little as 2ºC in mean sea winter surface temperature and 3ºC in mean sea summer surface temperature can be manifest in altitudinal habitat differences of up to 600m for cold-dependent rainforest types such as Cool Temperate Rainforests (Peel 1999). This is possible because of the immense influence on climate (and temperature in particular) of the ocean's immense heat storage capacity on coastal landforms where frosts would otherwise be more common;
- Continentality: for the same latitude, frosts are more common and severe inland than they are on the coast. The reason for this are several-fold and include the different heating and cooling rates of land versus water and the humidity of coasts that influence the subsequent formation of clouds, fogs or dews (all conditions that do not favour the development of frosts). Water heats and cools more slowly than the land and so any body of water can have an effect on the local minimum temperature: the bigger the body of water the more widespread the impact of this warming on the adjacent land. This is illustrated by two examples:
    - Maringa Creek: the presence or absence of water in an ephemeral creek (2m wide and 30cm deep) warmed the air temperature of the adjacent grassy bank in an open paddock by as much as 2ºC on frosty nights;
    - Comparisons between Lakes Entrance (55m elevation on the coast) and the hinterland at Bairnsdale (49m elevation 20km inland) (Bureau of Meteorology 2003):
        - Months where frosts of <2ºC occur: 5 for the coast (May to September) and 8 for the hinterland (April to November): a three-month frost occurrence differential.
        - Mean frost days of <2.0ºC: 6.6 days for the coast and 30.4 for the hinterland: a 23.8 day differential.
        - Months where severe frost of <0.0ºC occur: 2 for the coast (June to July), 6 for the hinterland (May to October): a 4-month frost occurrence differential.
        - Mean frost days of <0.0ºC: 1.5 days for the coast and 9.7 for the hinterland: an 8.2-day differential.
        - Total mean frost days annually: 8.1 days for the coast and 40.1 for the hinterland: 38-day differential.

One of the major pilot sites for rainforest restoration in south-eastern Australia, Maringa Creek at Nyerimilang, is in a rainforest gully not more than 700m from the coast, but which regularly experiences frosts of -7ºC from May to October! It had a frost of -12 ºC in September 2004. To say we weren't expecting frost to be a problem is an understatement (we did consult the weather records for nearby Lakes Entrance, where frosts are rare) and these records showed no evidence of how severe frost were going to be on our newly chosen rainforest restoration site.

Our first mistake was that the original weather station at Lakes was on the lake shore (a warm spot) and when it was moved it went onto a hill beside the lake (another warm spot). Maringa Creek is a small catchment, with many of its remaining vegetated gullies still with Warm Temperate Rainforest present. The site being restored has good historic records that show that it was rainforest when first cleared in the late 1800s, and then it was abandoned and had regenerated as rainforest and was again cleared in the 1950s. Why shouldn't rainforest still be easy to restore to the site?

There are several answers to this conundrum. One of the answers is that the climate has changed. In general, of course, the climate is warming, but in and around the Gippsland Lakes there have been other changes: firstly the average rainfall is dropping (this means less cloud, more clear nights and more frost events); and secondly the catchment of Maringa Creek has been largely cleared (only about 25% of the area of the catchment remains under bush). The land clearing has had the affect of removing the doona from the bed on a cold night: the forests used to act as a warm blanket that reduced the rate of ground cooling. The other factor is that the gully (like all valleys) suffers from cold-air drainage (*catabatic winds*). At night, as the land in the upper catchment rapidly loses heat because the forest has been removed, it cools the air just above the ground. This denser and heavier air begins to flow down hill under the influence of gravity: producing a cold catabatic wind. It then pools at the bottom of the catchment where temperatures now more frequently fall below zero than they did in the past because of land clearing. We know this because of comparative frost monitoring that was conducted in 2005. The results are shown in Figure S294. The comparison was between a forested catchment (Goldsmith's) and a largely cleared catchment on Maringa Creek (Figure S295) only several kilometres apart and both adjacent to the Gippsland Lakes.

Even so, within the existing secondary species-dominated regrowth remnant along the creek, frost-sensitive rainforest plants are thriving and so the project is still proceeding to restore the rainforest. All that has changed is that we have learnt to adapt our planting compositions and sequences (Figure S296) and the time of planting to adjust to the now better-understood climatic realities of the site.

WEED CONTROL WHEN ESTABLISHINNG PIONEER SPECIES IS ESSENTIAL

Figure S289. Frenchmans Gully, Lakes Entrance Victoria. Lee Davies in his sediment in-filled gully in the first few months of his Maximum Diversity Method rainforest restoration, with a prime example of the value of weed control when establishing pioneer species in general, and Fireweed Groundsel *Senecio linearifolius* in particular. Those to his right have been planted with one blanket spray beforehand, those to his left were not and would have failed to establish had it not been for a subsequent blanket spray (made all the harder by the need to avoid the small struggling natives already planted).

In 2005, the effect of the early plantings (2 years old) was to warm the air entering the Top Flat by 1.5^{o}C by the time it reached the Bottom Flat on a -0.5^{o}C night (Figure S294). By 2008, with ongoing growth (density, cover and height), this differential between the Top and Bottom Flat for -6^{o}C frost night had improved to a whopping +4.5^{o}C. The difference between the open paddock (at the start of the Top Flat) and a dense stand of Black Wattle that we had planted (no more than 200m downstream) was an even more impressive +6^{o}C. These differentials even held up when there was a -9^{o}C frost several nights later, which even allows the establishment of frost-sensitive Kangaroo Apple (Figure S293) on that flat in the shelter of the Black Wattles.

The other interesting feature of these figures is that difference that can be attributed to frost derived from radiated cooling, and the cooling that arrives from catabatic winds flowing onto the site through the Top Flat. Because the minimum temperature on the Bottom and Middle Flats are the same, this can be attributed to the radiated heat lost to the atmosphere on a cold night (because the catabatic wind does not reach these vegetated places). So, for example, on the radiated frost night of -4^{o}C (Bottom and Middle Flats), the catabatic wind takes away another -3^{o}C off, so that the Top Flat is -7^{o}C. The -3^{o}C difference can be attributed to the cooling effects of the catabatic wind and the cold air drainage that it brings onto your site. Get out and measure what is going on in your local catchment **before your start restoration!**

These figures go to show that your rainforest restoration efforts can warm a restoration site, even where only 25% of the catchment's original forest still remains. This ability to change local climate, means that frost-susceptible primary species can (and are) establishing beneath our original Framework plantings, and in time mature rainforest should be able to re-establish for a third time on this site.

DROUGHTS CAN PREPARE THE GROUND FOR REGENERATION PULSES IN RAINFORESTS

Figure S290. Middle Lagoon, New South Wales. Here a drought-killed Tree Broom-heath *Monotoca elliptica* provides partial shade that has allowed this major regeneration pulse of rainforest species to establish when the drought broke in 2004. Species pictured regenerating include: Groundsels *Senecio* spp., Sweet Pittosporum *P. undulatum*, *Solanums* and many rainforest herbs.

Early warning signs of possible frost problems

We hope to be able to help you avoid the grief of undiagnosed frost issues on your site. Fortunately, there are several ways of detecting whether your potential restoration site has a frost problem. This is especially important where your nearest weather station is not nearby, or on the same landform, and may consequently lull you into a false sense of security (as it did with us at Maringa Creek). The most obvious way is to take minimum temperature readings over autumn-winter-spring. Conventionally, frost measurements are taken at permanent weather stations using a minimum temperature thermometer inside a Stevenson Screen. This is an enclosed, slatted white box with the thermometers placed at about 1.5m off the ground. Have you ever wondered why the Bureau predicts a frost with a minimum temperature forecast of 2^{o}C (but you I both know that water doesn't freeze until it reaches 0^{o}C)? Now you know the answer: frost initially forms on the ground not at 1.5m in the air (inside white wood slatted box): so when the temperature in the Stevenson Screen is +2^{o}C, it is usually at freezing point on the ground. This is important because you (as the rainforest restorer) need to know what the temperature is at the ground level because this is where the effects of frost will damage your plants. You **must** therefore measure your temperature using a minimum-maximum thermometer that is **placed on the ground** and in the open (because overhanging foliage keeps the ground warm on cold nights) (Figure S295). Amazingly, our data shows that even the bare branches of a willow can keep the ground beneath 0.5°C warmer!

There is however, a quicker rule of thumb that may be of use to you. Kikuyu is a summer growing grass that is widespread in pastures on a broad range of soils in the region. It is frost sensitive and will not be dominant in sites with severe frosts. If areas in full sun such as valley floors have no or very little Kikuyu present, and they are instead dominated by other grasses such as Yorkshire Fog or Perennial Rye-grass, severe frost is likely to be the cause. This can be further corroborated if Kikuyu is present on the nearby (warmer valley slopes). A note of caution though: Kikuyu does not like wet feet and it may be absent in frost-benign sites if the water table is high (Chapter 7: Undefined (swamped) riparian systems).

A more moderate frost regime is also detectable using Kikuyu as your 'canary in the coal mine'. As previously stated, the presence of Kikuyu on the valley floors indicates a relatively frost-benign site. Kikuyu, however, is sensitive to most levels of frost and shows this in winter by having the leaves 'burnt-off'; i.e. they change from green to brown and dry. If Kikuyu is abundant but gets burnt-off, then the most frost sensitive species will still need to be planted under frost hardy pioneer species.

NATURAL REGENERATION MAY NEED BARE SOIL AND GOOD WEED CONTROL

Figure S291. Bottom Flat Maringa Creek, Nyerimilang Heritage Park, Victoria. Good weed control at this site has seen a fabulous pulse of natural regeneration of Kangaroo Apple Solanum aviculare following a summer thunderstorm. The seed was stored in the soil seed bank. Without good summer weed control, this regeneration would not have occurred.

FOUR WAYS OF WARMING YOUR FROST-PRONE RESTORATION SITE

Figure S292. Top Flat Maringa Creek, Nyerimilang in Victoria. Frost is being dealt with by four elements of this Framework Method planting:

- Firstly, the scattered Blue Gum *Eucalyptus globulus* ssp. *bicostata* (planted at 10m intervals) will form a long-lived overstorey that will significantly reduce the radiated heat loss and allow the establishment of a frost-sensitive rainforest canopy beneath.
- Secondly the shrubby plantings of Fireweed Groundsel *Senecio linearifolius* (the yellow daisy) and the Showy Cassinia *Apalochlamys spectabilis* (the grey plant) deal with both the radiated heat loss component of frosts as well as the catabatic wind element. They do this by having a dense canopy and a thick growth habit that reduces catabatic wind penetration and also traps sunlight producing heat wells that release heat slowly from the ground overnight by warming the air above in the immediate vicinity. Trials have shown that frost-sensitive primary rainforest canopy species such as Muttonwood *Myrsine howittiana*, Sweet Pittosporum *P*. *undulatum* and Lilly Pilly *Syzygium smithii* can now be established even when the frosts experienced on adjacent open grass areas are regularly between -6^{o}C to -9^{o}C and as low as -12^{o}C.
- The third element is the dense planting of Black Wattle *Acacia mearnsii* (middle ground right) that is used to slow the catabatic wind's movement down the valley. In the process, this permeable barrier also warms the cold air moving in beneath the wattle's canopy and prevents it from losing more heat to radiated heat loss in a -7^{o}C frost, warming the site to -0.5^{o}C (a difference of +6.5^{o}C) (see also Figure S293).
- The fourth and final mechanism is visible at the top right of the photo where the valley slope plantings absorb and warm the cold air moving down off the ridge-top paddocks, before it settles on the gully floor.

AIR WARMED BY PLANTINGS ENSURES FROST SENSITIVE SPECIES CAN SURVIVE IN THE OPEN

Figure S293. Top Flat Maringa Creek, Nyerimilang in Victoria. This stand of Black Wattle *Acacia mearnsii* has intercepted catabatic winds as cold as -10.5°C that then flows out of the young forest (Figure S292) and preserves this naturally regenerated copse of Kangaroo Apple *Solanum aviculare*. Upstream of this stand, all Kangaroo Apple has been frost burnt to ground level (see Figure S295). The catabatic winds move from right to left in this photograph. For the landscape context see Figure S292 above.

Although frost can be very destructive, and can actually prevent the restoration of rainforest on sites that once carried rainforest if preventative steps are not taken, it can be combated. The steps you can take to anticipate and deal with frost effects are diverse and effective. In general these include:

- Take minimum temperature readings over autumn, winter and early spring to define the length of the frost season and its severity, use the placement of minimum-maximum thermometers to discover the frost-benign areas on your restoration site. Be careful not to place your thermometer near a water body (creek or dam) as this will increase your minimum temperature readings by at least 2°C;
- Bias your frost-hardy plantings on edges where cold wind and frost do most damage (unlike our opposite planting strategy demonstrated in Figure S288 where frost sensitive species were placed on the edge).
- Plant tall dense frost-hardy species at the upstream end of your site to slow down and warm frost-bearing catabatic winds (Figure S292 and S293); as well as on smaller gullies and slopes.
- Know your site: there will be frost moderated niches available (northern aspects slopes and banks), open water (creeks, rivers, estuaries, the sea), sun wells where soils heat during the day (releasing their heat overnight to reduce the severity of nightly frosts), beneath existing tree cover etc.
- As a general rule, plant frost-hardy species (pioneer plants) first and perhaps only to the Framework Restoration level over most of the site.
- Begin frost hardy plantings on the upstream end of gullies and concentrate frost hardy plantings in broader valleys on the edge of your site where cold air drains onto your works area (this includes eucalypts).
- Use the Full Restoration Method only in the warmest or most sheltered sites and beneath existing frost hardy canopies (Figures S296 and S297).

Frost hardiness of advanced plants

On frosty sites, special attention needs to be paid to the tolerance of the advanced plants to the frosts experienced at different points across the site. This can be evaluated by planting out several ‘sacrificial plants’ across the site and placing minimum-maximum thermometers near them. If a plant or a number of plants die, this can be correlated to minimum temperatures and planting can be delayed until the warmer months. It is not recommended that advanced plants be watered in on frosty sites during winter as the wet soil may freeze and cause the death of the plant. Instead, ensure that there is good soil moisture at least to the depth of planting, a good chance of follow-up rains and that the advanced plants are well watered a day before planting out.

It has been noted that young advanced Blackwoods trees (2.5cm at base of the trunk) planted in early winter are killed (ringbarked) by frosts (-5^{o}C or worse) whereas established saplings are frost-hardy and will survive temperatures as low as (-10^{o}C). Advanced plant stock with a trunk diameter of 1.5cm or less of Blue Gum *Eucalyptus globulus* and River Peppermint *E. elata* planted at the same time in the same locality also died as the result of regular sever frosts of >-5^{o}C (Table S26). On such sites, delaying planting until spring will avoid frost deaths. Five years later, these species are able to thrive on the site with regular frosts of -6^{o}C.

Planting frost hardy species

We have provided what we know (or the literature tells us) of the frost-hardiness of rainforest plants for south-eastern Australia in Appendix S20. In general, if the frost hardiness of a plant is not known, then you can take several steps to infer its frost hardiness before committing to planting large areas with your selected species:

- Do your candidate frost hardy plant/s live in cold environments?
    - Look for pioneer species that live in frosty habitats (shaded but open areas, southern aspects, open areas in valley or gully floors).
    - Get out in the early mornings and learn where the frosts lie in your district. This will teach not only the frost niches of individual plants, but also where frost occurs in relation to frost moderating features (forest, water bodies the coast etc.).
    - This will enable you to make a ‘landscape judgement’ about your sites frost risk.
    - Look for cooler climate zone elements of your pioneer rainforest flora at lower elevations. So, on sites in niches where species from your rainforest community are found at higher elevations in relatively colder climates: Warm Temperate Rainforest areas at higher elevations for Subtropical Rainforest plantings and Cool Temperate Rainforests at higher elevations for Warm Temperate Rainforest plantings. Fireweed Groundsel *Senecio linearifolius* is a classic example of a cooler climate zone species that is an ideal frost-hardy pioneer for both warmer rainforest EVC restoration sites. This is believed to reflect a temperature-based habitat preference partitioning of the one site by species whereby the pioneers (being more cold-temperature and frost-adapted) occupy the site early in the successional sequence when there is an abundance of exposed niches, which give way in successional terms to the primary species that prefer the warmer niches available on your site once it has been warmed by the pioneer and secondary species that came before.
- Plant sacrificial plants out in exposed sites known to be subjected to frosts and see if they survive or flourish.
- Observe your sites and visit areas that are known to be frost affected during periods of severe frost or prolonged frost and:
    - List the species present
    - Note their frost response: killed; severely damaged and weakened; affected but not badly; not affected; completely unaffected and actively growing;
    - Record the durability of such species to extended periods of frost, one frost may damage, two may debilitate and then the third or tenth may kill
- Select your pioneer frost-hardy species from those categories that show minimal frost or no frost impacts or those that continue to actively grow under such conditions.

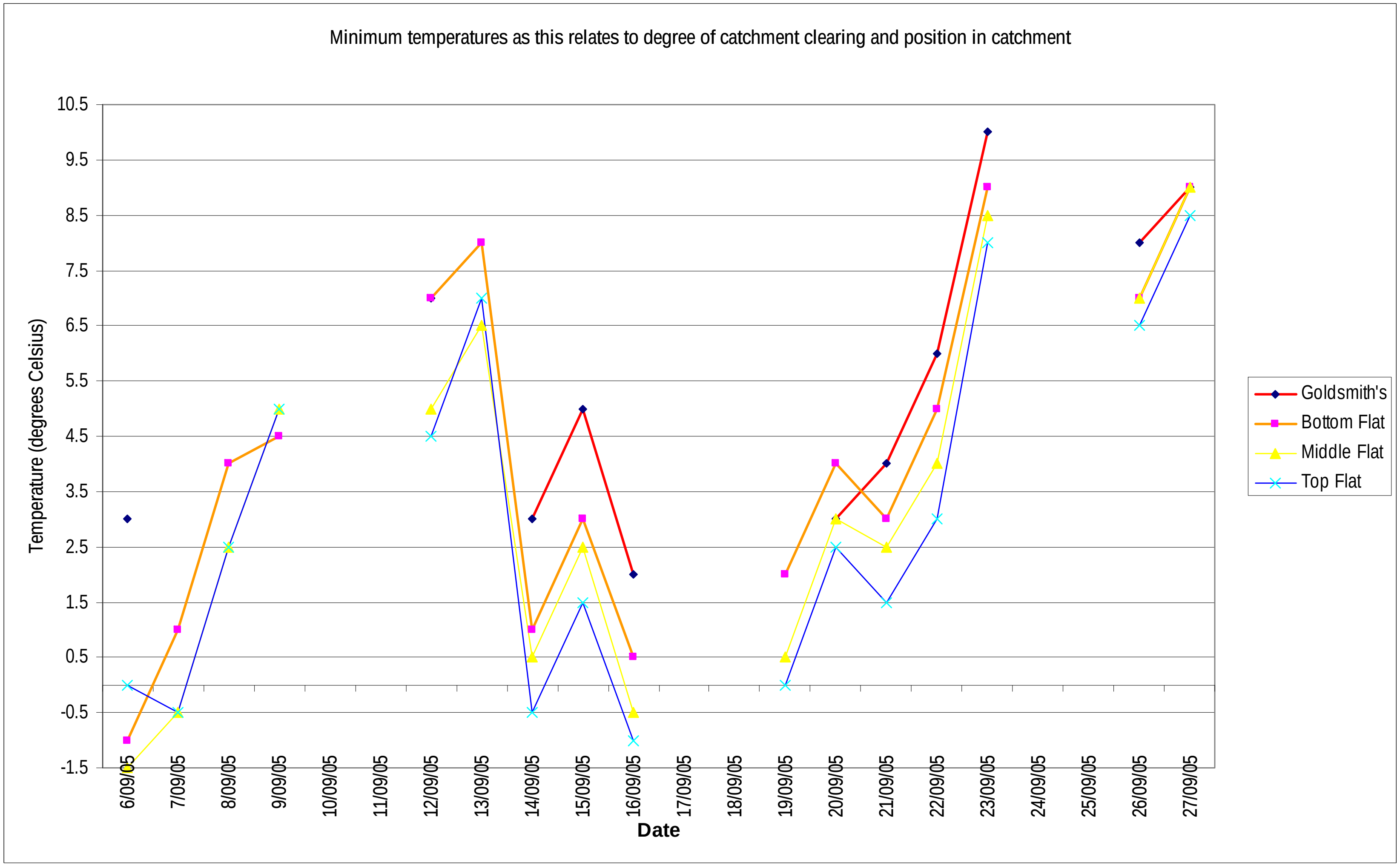

Figure S294. Frost data from a rainforest site at Goldsmith's (red) that has a 75% forested catchment compared with Maringa Creek at Nyerimilang that has only 25% of its catchment forested; three measuring stations: on the Bottom Flat (orange), Middle Flat (yellow); and Top Flat (blue) show the effect of cold air pooling and catabatic winds (see the text for an explanation).

It is important when investigating the effects of frost, and thereby selecting frost-hardy species from your district, that you visit your restoration site before frosts and note the vigour and health of the plant species present, their distribution across the site and their occupation of potentially frosted areas. It is useful to take initial photos of candidate species and individuals and monitor their response until spring. Visit the sites regularly, but especially after severe of frequent frosts. If time permits, place minimum-maximum thermometers next to your monitoring sites (in the open) and link the response of plants to specific minimum temperatures. In so doing, you can then take minimum temperatures in your district at new restoration sites and design your plantings accordingly because you now know what species you can, and will, use. It is also useful to know the temperature beneath the canopy because you may be able to plant primary species there due to of the frost shelter of the canopy.

Warming frost-prone sites by planting
It is important to realise that you can change the local climate through your actions. With respect to rainforest restoration, sites can be warmed by your plantings. Data from Maringa Creek at Nyerimilang indicates that some areas of the site have been warmed by up to 8^{o}C in the last 4 years as the direct result of the rainforest restoration works on the site! This can mean the difference between not being able to restore rainforest at all to being able to plant at any time of year and establishing frost tender species in the open.

MONITOR MINIMUM TEMPERATURES BEFORE STARTING: TO AVOID THIS KIND OF DISASTER

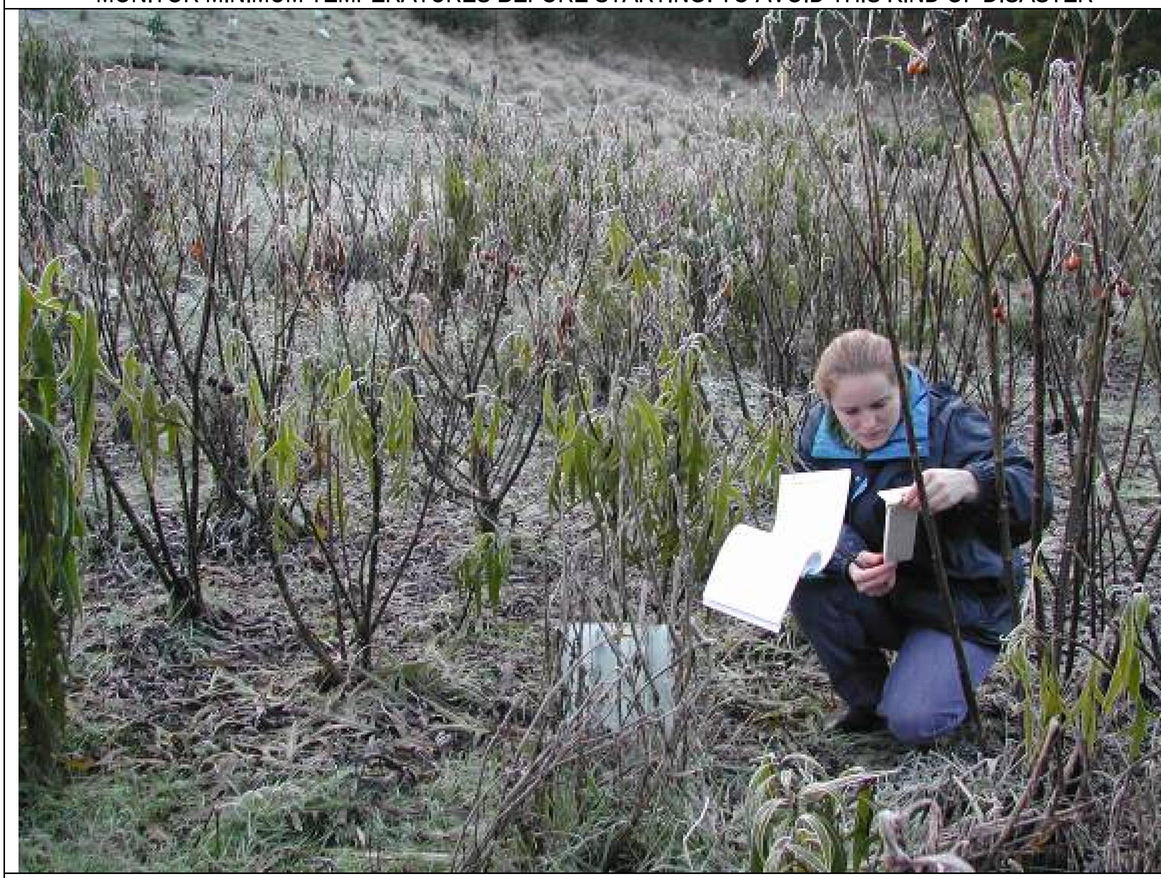

Figure S295. Maringa Creek, Nyerimilang Heritage Park, Victoria. Anastasia Brown – at the time a Forestech student, a rainforest restoration volunteer and work experience student (and one of the finest intuitive ecological minds we have come across) – courageously monitoring minimum temperatures at Nyerimilang. But, as she said (having been brought up in Germany), from the human perspective there is not much difference between -5^{o}C and –20^{o}C! But alas, there is a lot in it for our local plants. Anastasia was enlisted to help after we discovered that our anti-deer browsing wonder-plant: Kangaroo Apple had an Achilles Heel: frost! Don't make the same mistake. Figure S292 shows our response to this new local knowledge and Figure S296 the result years down the track.

PLANT A VARIETY OF FROST HARDY PIONEER SPECIES TO PROTECT THE SITE IN PERPETUITY

Figure S296. Middle Flat Maringa Creek, Nyerimilang, Victoria. This rainforest restoration site is progressing well now that a range of frost-tolerant pioneer and secondary species has been planted to provide cover for the frost-tender primary rainforest species. These plantings have now actually warmed the site by up to 8°C. These frost-hardy species include:

Pioneer Species

1. Tree Everlasting *Ozothamnus ferrugineus*
2. Fireweed Groundsel *Senecio linearifolius*,
3. Naturally regenerating Kangaroo Apple *Solanum aviculare*
4. Before the background plantings warmed the site, all of the previously planted specimens of Kangaroo Apple lived for a spring and summer before dying in the frosts of late autumn (see also Additional Reading Opener: bottom image, which is of the same site taken from the right of this photograph)

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Secondary Species

A. Black Wattle *Acacia mearnsii*
B. Blackwood *A. melanoxylon*
C. Varnish Wattle *A. vernicaflua*
D. River Peppermint *Eucalyptus elata*
E. Eurabbie *E. globulus* ssp. *bicostata*
F. Hazel Pomaderris *P. aspera*

.

Plantings reduce frost impacts by:

- Physically slowing or stopping catabatic (down slope) air movement: keeping cold air off your site that in combination with frost fences may be further ameliorated (Figure S244)
- Warming cold air as it slowly travels through the warmer atmosphere beneath the canopy (Figure S293)
- Creating or maintaining sun-wells (Figure S146) that allow penetration of sunlight into still air and on to the ground: this leads to heating during the day; heat that is then slowly released back into the atmosphere at night. These can be sheltered sunny gaps or north aspect track networks (Figure S100) or roads (Figure S220).
- Protecting the ground (and the air beneath the canopy) from radiated heat loss into the atmosphere on clear nights (Figures S85, S292).
- Providing more structural variation (variable canopy structure, gaps with shelter from wind that conserve moisture) so that there is a greater chance for dews to form which enhance near-ground atmospheric

humidity and reduce the chances of a frost forming (remembering that the structure of weeds can do this task for you: Figure S273). This structural variation is good for animals too (Munro *et. al*. 2007).

- Providing a moister atmosphere through the increased transpiration of trees and shrubs than is possible with pasture alone (Figure S296).

A PRE-EXISTING CANOPY CAN SAVE YOU LOTS OF GRIEF WHEN IT COMES TO FROST

Figure S297. Lower Tambo River, Swan Reach-Bruthen Road Victoria. August 2006: the end of winter. A pre-existing Blackwood *Acacia melanoxylon* on a new restoration site is providing frost shelter beneath its canopy as illustrated by the frost burnt area of Kikuyu outside the canopy's protection (to the right of the red dashed line). The Maximum Diversity Method can safely be practiced beneath the canopy in its frost shelter, whereas only the Framework Method, which aims to create a similar structure to that of the existing Blackwood, can be practised in the open frosty area. This conclusion is verified nearby where frost-sensitive Sweet Pittosporum *P. undulatum* is growing in the frost shelter of Silver Wattle *Acacia dealbata*.

Table S26. Advanced tree frost tolerance

Species	Time of planting	Frost survival	Frost-mediated plant death
		Beneath canopy	
Myrsine howittiana *Syzygium smithii*	Autumn	Survives intact under Black Wattle canopy where temperatures range down to -1°C and temperatures outside regularly drop to between -3 and -7 °C	Aerial portions killed under Black Wattle canopy where temperatures are lower than -2°C and temperatures outside drop to -9 °C.
		Open site plantings	
Acacia melanoxylon	Autumn	Regular minima of -3.0°C	Regular minima lower than -3.0°C
Acacia mearnsii	Autumn-winter	Regular minima of -3.0°C	Not known
Syzygium smithii	Spring	Regular minima of -3.0°C to -6.0°C and up to -8.0°C	Planting in spring seems to ensure hardening over autumn to allow tolerance up to and perhaps >-8°C
Eucalyptus elata	Autumn-winter	Regular minima of -3.0°C	Regular minima lower than -3.0°C
Eucalyptus globulus	Autumn-winter	Regular minima of -7 to -10 °C	Not known (single -12 °C tolerated)

The best effects are achieved through planting a dense vertically integrated patch of vegetation rather than a thin veil (rather like one layer of thin clothes) will provide little insulation and protection from heat loss. The same principle applies in warming your site. It is also important to plant for a long-term effect. Don't plant just one species, or a couple of species, that will all die off at the same time (Figure S116). By planting multiple layers and species that have different life-spans, the site becomes self maintaining and retains its frost modifying capacity in perpetuity (Figure S296).

Canopy types and frost protection
Different species provide different levels of frost protection. This appears in part to be associated with canopy density, canopy depth, size of stand and deciduousness and the time of leaf fall (i.e. plants that drop leaves early in the season such as Willows *Salix* spp. offer less protection than Kangaroo Apple *Solanum aviculare*, which may experience only partial canopy thinning or lose leaves half-way through winter). Table S27 illustrates some of our results.

Frost edging
Frosts penetrate from cleared land (open areas) onto restoration sites, as is well illustrated by a nursery photograph (Figure S298). So, there is a planning component to abating frost effects on your site. If you are lucky enough to have forest upstream of your worksite, it is very important to begin your plantings at the forest's edge. This has two immediate benefits:

1. It uses the warm air flowing out of the forested area upslope of your restoration site
2. It insulates the existing stand from the edge effects of frost and wind entry by planting frost-hardy species on its downslope side (Figures S296, S297, S298 and S299).

Such an approach also helps in seed dispersal of rainforest plants onto your site. It is not without its downside, however, because you can encourage the rapid colonisation of your site by browsing species. Provided these are not feral deer, the techniques advocated to deal with this issue (Chapter 8: Pest management) should overcome any inconvenience caused by native animals entering the site early on. Remember that they also disperse rainforest seed for you (Appendix S10; Figure S176).

Other situations where frost enters along edges include:

- Along track networks (Figure S300)
- Along waterways or gully lines
- Down valley sides that are not vegetated (Figure S292)
- Along fence-lines of linear plantings (e.g. along riparian zones) that face open paddocks on large floodplains
- Along the edge of your restoration area
- Along your property boundary; where the neighbours' land use does not include trees (urban areas for instance).

It is also important to regard your restoration site as larger than the original rainforest extent: the whole of the fenced area. For instance, even though you may be planting the gully floor with rainforest, if the hill sides remain unplanted, then the site remains vulnerable to frost impacts from cold air moving down the adjacent hill (as apposed to along the valley floor from areas upstream). This is why ecotones and a chunk of the surrounding non-rainforest land should (if possible) also be rehabilitated in frost-prone landscapes (Figure S292). To test this for yourselves; go to your restoration site on a cold and frosty night and using a torch, follow the path of your foggy breath relative to your position on the site and the landform on which you are standing.

Frost edging entails biasing your plantings along such edges by using species that are very frost hardy and will provide a range of frost cover over years to centuries (by planting herbs to long-lived eucalypts). Do not shy away from planting particular life-forms (e.g. emergent trees) because all of the life-form categories contribute to frost protection in their own way, have a variety of impacts on frost (Table S27) and act over different timescales. This can completely overcome the problem, especially in sites that are not exposed to strong winds.

The other thing to remember is that these frost ameliorating benefits are still poorly understood and it is worth taking the precautionary approach here: any species that were there originally are likely to play an important role and we should not presume to exclude them on the basis that we know all of its values or importance to the site and to the vegetation we are trying to reinstate. Do not exclude a species out of convenience or because it does not seem attractive.

Table S27. Canopy types and the frost protection that they afford.

Species	Canopy type	Leaf fall	Temperature advantage outside cover	Frost sensitive species survival
Large stands				
Black Wattle *Acacia mearnsii*	Deep+dense	Retains leaves	+7°C in a -7.5°C frost	Sweet Pittosporum *P. undulatum*, Lilly Pilly *Syzygium smithii*,
Fireweed Groundsel *Senecio linearifolius*	Shallow+dense	Retains leaves	+4°C in a -3.5°C frost	Sweet Pittosporum *P. undulatum*, Lilly Pilly *Syzygium smithii*,
Kangaroo Apple *Solanum aviculare*	Shallow+thinning	Leaves lost in April return late September	+0.5°C	Advanced Muttonwood *Myrsine howittiana and* Lilly Pilly *Syzygium smithii*
Copse (2 or more trees)				
Black Wattle *Acacia mearnsii*	Deep+dense	Retains leaves	+7°C in a -8.5°C frost	Staff Climber *Celastrus australis*, Seaberry Saltbush *Rhagodia candolleana*, Forest Nightshade *Solanum prinophyllum*, Eastern Nightshade *S. pungetium*, New Zealand Spinach *Tetragonia tetragonioides*
Single plants				
Blackwood *Acacia melanoxylon*	Deep+dense	Retains leaves	+6°C in a -7°C frost	Common Boobialla *Myoporum insulare*, Sweet Pittosporum *P. undulatum*, Kangaroo Apple *Solanum aviculare,* Lilly Pilly *Syzygium smithii*,
Tree Everlasting *Ozothamnus ferrugineus*	Shallow+dense	Retains leaves	+4°C in a -3.5°C frost	Seaberry Saltbush *Rhagodia candolleana*, New Zealand Spinach *Tetragonia tetragonioides*
Willow *Salix* spp.	No leaves: thin branch network	Leaves lost in March; return late September	+0.5°C in a subzero frost (degree not recorded)	None recorded

FROST EFFECTS OCCUR IN OPEN AREAS AND ALONG THE VEGETATED EDGES

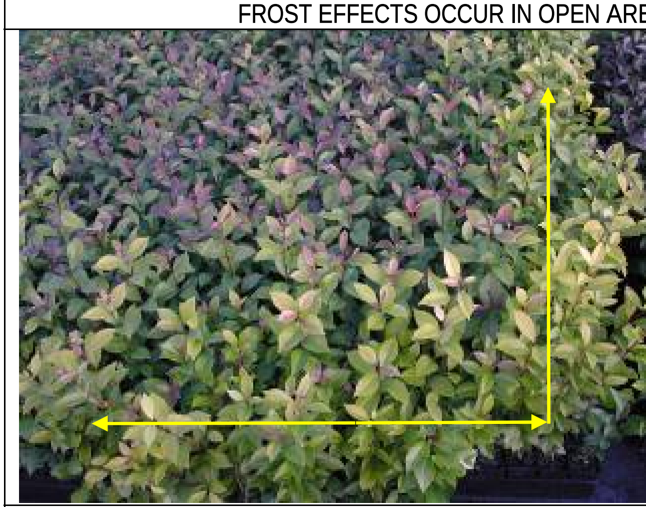

Figure S298. Kanooka Eastern Native Flora Nursery, Orbost Victoria. Here a tray of Lilly Pilly *Syzygium smithii* (left), show the early signs of frost affects: and illustrate that the effects of frost are not uniform. Note the affected plants are along the exposed edges of the trays that face out onto a nursery path (yellow arrows). Exactly the same principles apply in restoration plantings: reinforce your edges with extra frost-hardy species

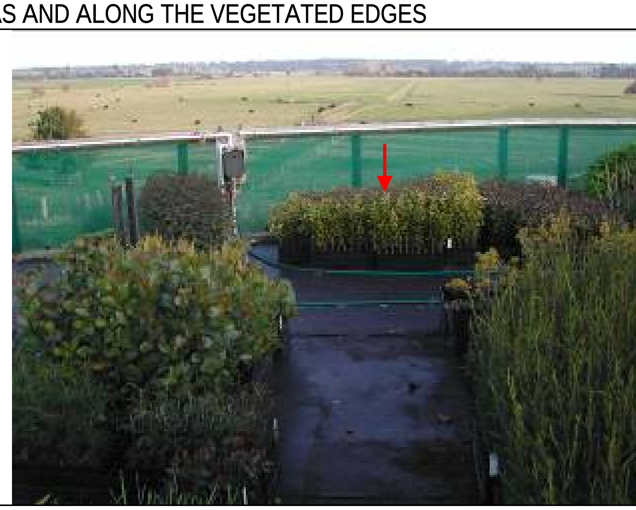

Figure S299. Kanooka Eastern Native Flora Nursery, Orbost Victoria. Frost hardy species (*Acacias*, *Apalochlamys*, *Eucalyptus* and *Melaleucas*) are located immediately around the affected Lilly Pilly (red arrow) from Figure S298, but show no evidence of frost damage.

(see Figure 299).	

However, in the situation illustrated in Figure S288, where wind is added on a cold night, the effects can extend beneath an existing canopy. This added effect of wind is one of the classic edge effects. Once more the advice in this regard is to make the edge planting thick, multilayered and composed of multiple species that will not all senesce at the same time (Figure S116). Choose species from Appendix S20 that are indigenous to the rainforest floristic community that you are restoring and plan your frost edging from day one of the project.

Frost fences
One novel way we came up with to deal with cold air drainage was to erect what we called frost fences (Figure S300). They are simple to construct, but, at least for us on Maringa Creek, the depth of the cold air was too great to have any measurable effect over the single winter in which we took comparative temperatures. This does not mean that they will not work elsewhere where conditions are a bit more benign. They are not expensive, so give them a try in your area.

The theory on how they should work is as follows. The fence runs across the track and into fringing frost hardy vegetation on either side of the fence. The 'river' of cold air should be forced off the track by the fence into the surrounding vegetation, which has two functions. Firstly it slows the rate of shallow-depth cold air movement onto your restoration site by passing it through the dense vegetation; and secondly it pushes it off the track into the frost-hardy plantings (where radiated cooling has been prevented by the canopy) where the air can be slowed and then warmed. If the cold air is warmed enough, it becomes buoyant and gravity no longer carries it further down slope. Such fences are dismantled during spring and will be permanently removed when access is no longer needed: with the track being planted out at the end of the restoration process.

FROST FENCES HELP DIVERT COLD CATABATIC WINDS INTO PLANTINGS WHERE THEY ARE WARMED

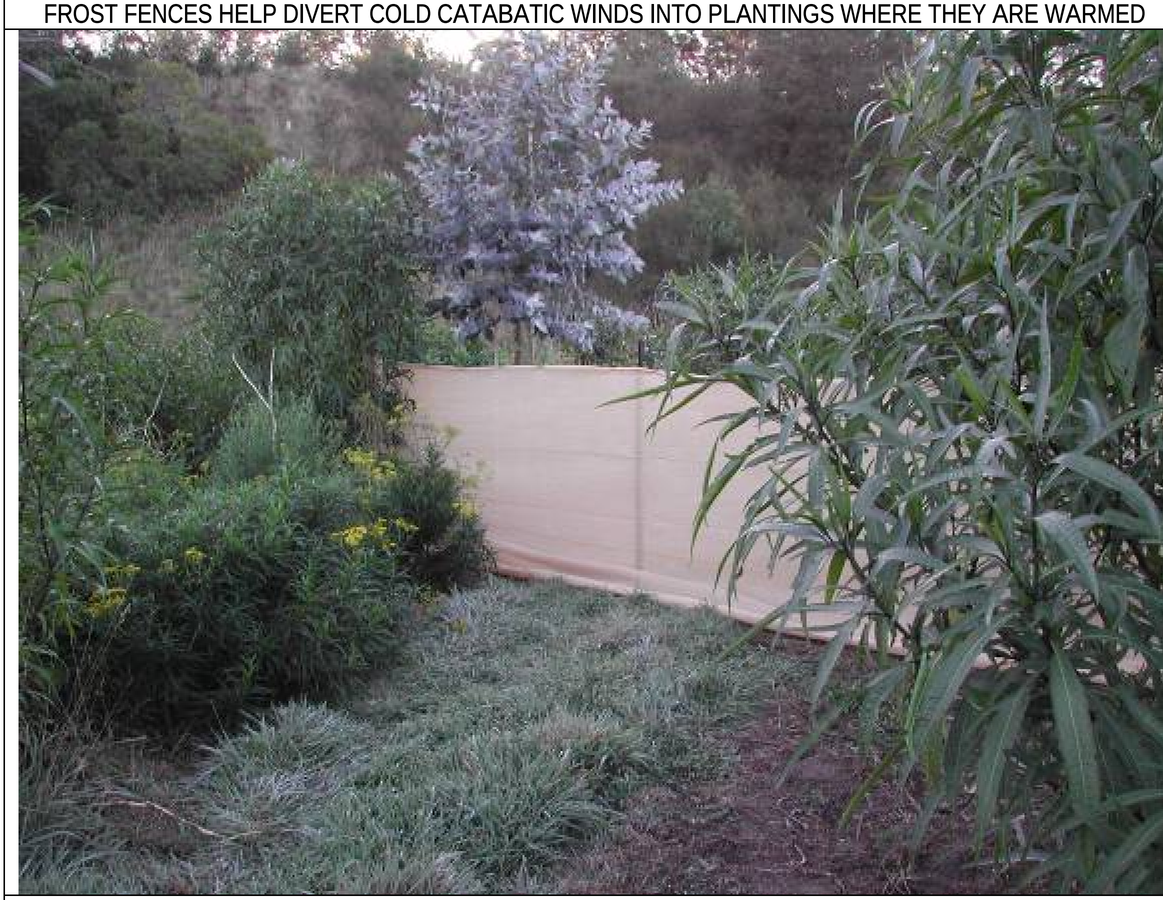

Figure S300. Maringa Creek Top Flat, Nyerimilang Heritage Park, Victoria. Frost fence across an access track on Maringa Creek at Nyerimilang. Temperatures can improve by more than 3^{o}C between frost fences, whether that is due to their interception of cold air drainage is still not clear.

SUMMARY	
COMPREHENSION: STOP	Although the landscape scale impacts of fire, frost, drought and climate are beyond our individual influence, collectively we have tools to influence their behaviour and consequently their impact on our rainforest restoration sites and the rainforest estate as a whole.
KNOWLEDGE: THINK	The knowledge of these landscape (and in some cases planetary) processes will inform you as to what you can expect to 'receive' from your neighbourhood and how your site might react should some disturbance come to visit your rainforest or restoration site. Although few of us have the ability to influence these planetary or landscape processes directly, being well informed about them will ensure that you do a better job on your restoration site. Over time, you may wish to participate in the social and strategic forums that deal with these issues.
WHAT TO DO?: ACTION	Become aware of what disturbance factors may have an on impact your rainforest restoration site. Take out insurance, by undertaking informed site planning, appropriate planting procedures and sequences etc., to ameliorate the impacts of these disturbances. Prepare your sites as best you can for these major landscape scale processes.
WHAT NEXT?	You now need to get up to speed on genetics, plants, plant ordering, nurseries and regional planting seasons. Then you can really get stuck into your rainforest restoration project!