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Close Packing of Plants in Water Harvesting Systems

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[Submitted Paper]

Hello. My name is Halin Orion and a few of us run a Arid/Tropical Permaculture Research Facility in Western Australia's northern mountains. We have two adjacent houses on half an acre. One is our home and the other is a small backpackers called Nomad Heights. This backpackers accepts WWOOF and TERN members who wish to work for accommodation with our BIOTEKNOMADIC Research and Development facility. Although we've been going for over 11 years, not all of that time has been spent on permaculture, as the necessities of life and money have also consumed large amounts of personal time.

Region and climate

The region we are sited in is called the Pilbara or the North-West and is 1,500 km north of Perth. This area has a very extreme climate, with summer temperatures exceeding 45 °C and winter temperatures rarely below 4 °C. We have an extreme dryness which can be appreciated when you find that although we get 100-400 mm of rain per year, we always have at least 2.5 m of evaporation. This severe dryness is driven by the desert that lies 300 km to the east and south of these mountains. Whether it is summer or winter the wind from these directions is our major water thief. The main difference is that summer winds can blow very strongly all day and night for three to four days by which time the wind can burn the skin.

Because we are in the mountains between 350-1200 m above sea level, we have some very unusual weather patterns, rich and diverse soils and the highest rainfall of the region. This area is the highest country in WA and spans across the Tropic of Capricorn which is the natural boundary between the temperate and the monsoon climatic zones. So sometimes we get summer and winter rains, either one or the other and sometimes neither. The mountains also stand between the desert in the south and east whilst the ocean lies in the north and west.

This 'mountain' climate brings sudden and extreme changes in the weather such as full cloud and *no* sun for three weeks, or six consecutive weeks of bright hot days over 42 °C. Our summer rain is driven by cyclones, tropical depressions and electrical storms which can dump over 250 mm in one hour, with 12-50 mm per hour downpours being the norm during this hot period. Winter rain is almost always gentle and steady rain with little or no wind. Cyclonic wind speeds can reach over 250 km/h as they cross the coast and still be gusting at over 150 km/h when they are in the high mountains. Recent indications are that our changing weather patterns are going to see increases in all of these extremes, especially wind.

The many seasons that have come and gone have been an incredible teacher over the years. Slowly, out of the variety, the bigger cycles became more obvious. These cycles and many minor ones have all been conditioning my designs. The main aim has been to design for extremes even if we only see them every 12-50 years. This way, when times are good everything flourishes and when they're extreme everything not only survives but, with astute design, these peak events provide the energy to move the whole system to another level of order.

Some of the very important cycles in our climate are the rain, wind and temperature cycles. For our region our rain cycle spans 10-11 years between 'Superwets', during which we can get double our 'normal' year's rainfall. This has occurred in my time here between 1984/85 and again in 1994/95, when we received 850 mm in one year ('normally' it is 280 mm). In the period between, there was a three year drought which depleted the water table to the extent that average rainfall in the following two years did not achieve much. This protracted 5 year drought, as is common throughout Australia, was broken by the floods of the 'Superwet'.

Water harvesting

The weight of water on the landscape, as measured in mm/h, is a far more useful figure for designs than an annual or monthly rainfall figure. We could easily have an above average rainfall per annum but, if it came in 20 mm) increments every second day, the soil at 2 m or more deep could easily be dry. Under these conditions large, deep rooted plants can be dying while smaller adjacent plants, with shallower roots, are thriving. Also, by acknowledging mm/h figures and using 250 mm/h as an upper figure (that may only occur every 10-20 years) we can design a water harvesting system that won't be destroyed by big rains.

Our annual cycle however sees the opening rain start in December or February followed by a severe 6-8 week dry period without follow up rains until February or April. Then, within 4-8 weeks of this second rain period we get our finishing rains which can come monthly through to July if we're lucky.

By March/April, evaporation has slowed through a decrease in temperature and wind so that many second rain germinated plants get the follow up rains without dying. These 6-8 week gaps between major rainfalls are what we design our water harvesting around. When rainfalls exceed 12 mm/h surface flow occurs, which we trap in clay lined basins and channels to hold and compound it, so that it goes deeper into the soil (see Figure 1).

By getting the deeper soil damp for at least three weeks, the growing time of the plants nestled around each basin doubles. This extension of the growing time for 6-8 weeks gets us to the next rainfall and so plants that would normally start suffering, go on growing without having gone though a dry period.

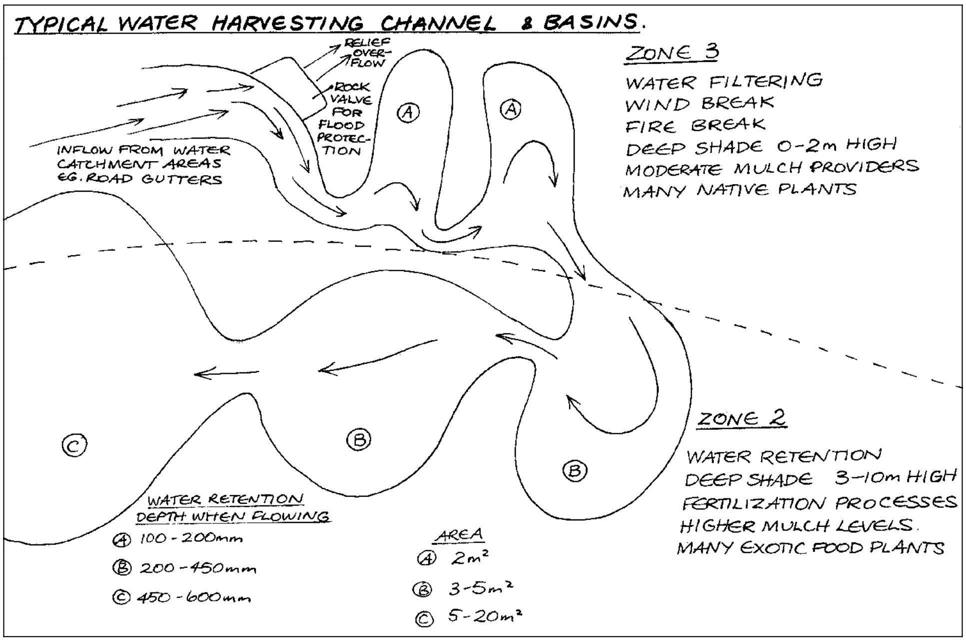

Figure 1: *Typical water harvesting channel and basins*

These basins are lined with 25-50 mm red clay and hold water between 100-600 mm deep before it can spill into the next basin. Each basin is roughly 1 m x 2 m in size and varies in depth according to its position in the catchment system. I initially designed for 50 mm/h downpours which might only occur once a year if we're lucky, but now I work with a lower figure for surface flow of 25 mm/h which can occur as often as 4 times a year.

The depths, dimensions and functions of each basin is determined by its position in the overall water harvesting channel and zone location. For instance, a basin at the beginning of the water harvest channel always gets the first flow from even light rains and is located in zone 3 or the outside edge of our intensive system.

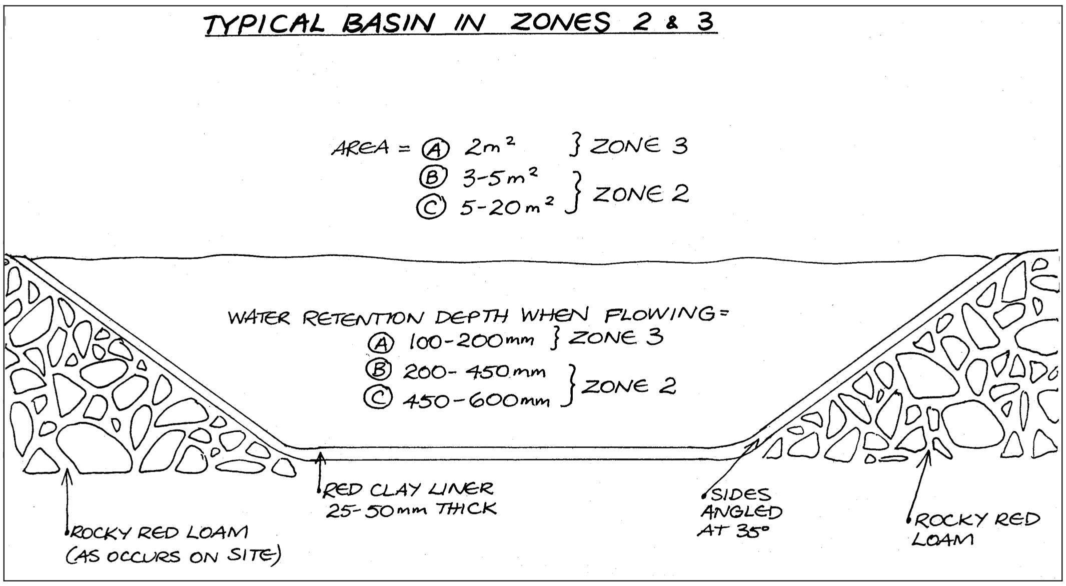

Figure 2: *Typical basin in Zones 2 and 3*

In zone 3 are our buffer plants against wind which are a very hardy mix of exotics and natives. These basins are therefore shallow (100-200 mm deep) while being long and sinuous to act as filters for removing unwanted materials and seeds from the water flow (see Figure 2). Basins further along the water channel are broader and deeper (200-450 mm deep) as they only get water from moderately heavy rainfalls. These basins water the larger (3-10 m) shade, mulch and fertiliser plants that are found in zone 2.

The final basin in the water harvesting channel is the largest, being 450-600 mm deep and from 5-20 m^2 in area. This basin gets rain water only in the largest flows which occur when the rain is heavier than 25 mm/h.

Our entry point into the water harvesting channel is guarded by a special rock valve which is designed to 'blow out' when rainfall exceeds 100 mm/h (see Figure 3). This stops flooding within our system although we are restructuring to handle up to 250 mm/h with no spillage out of the system. We also have a water harvest channel that extends through zone 1 where, within the protection of zones 2 and 3 we grow most of our food plants.

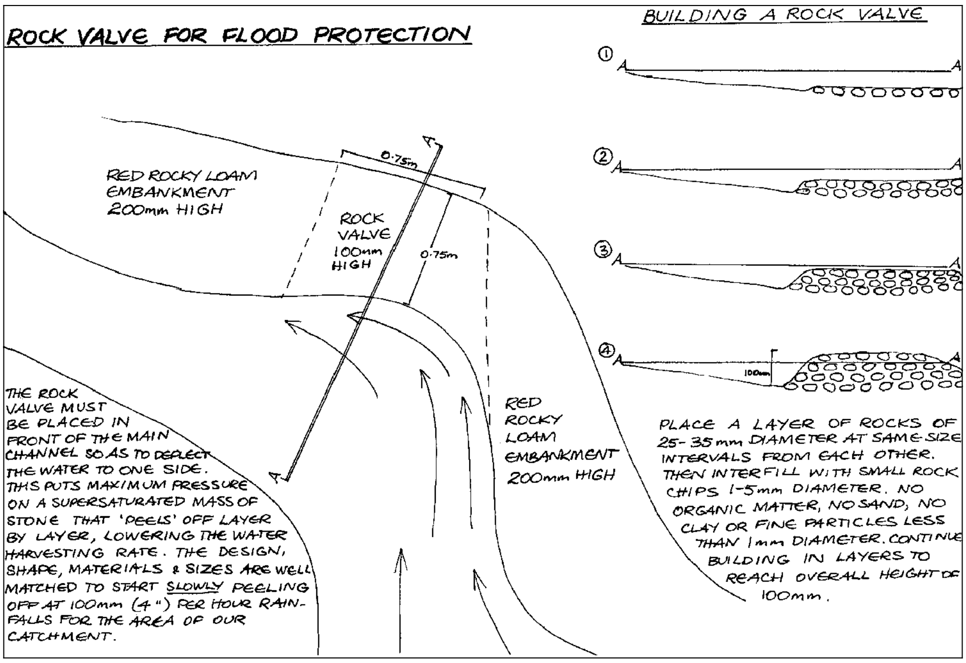

Figure 3: *Rock valve for flood protection*

Unlike the basins in the outer zones, all zone 1 basins are filled in with sand and organic material to create a 'sand dam' basin (see Figure 4). On the mid slopes, the heavy red rocky loams are low in organic material and far too heavy and dark to grow many of our food plants. So we turn basins into a large natural food pot full of a potting mix type soil for better growth and soil performance.

Each basin is already clay lined so depending on its depth, we select hardwood branches of a diameter roughly one third of the water depth (ie. if water depth is 100 mm then branch diameters are 30 mm maximum). We completely line the basin with these branches to a third of its depth, then spread a mix of sand and manure over this layer, filling any gaps between the closely layered branches. This layer about half fills the basin. The rest of our manure along with leaves, twigs, sand, loam and 15% clay is well mixed and used to almost fill the basin.

The very last layer is quartz sand from 10-15 mm deep which is our *mulch*. This layered sand dam basin is the best design we've yet achieved, after our experiments with many other structures, when integrated with a water harvest system. Also the sand and pebbles over clay is a common feature of our regional landscape. The exact mix of ingredients for a sand dam basin is relatively critical in relation to wood and clay content but can be varied quite a bit in relation to manure, sand, loam, leaf and twig content. These are varied slightly for plant type and depth of basin.

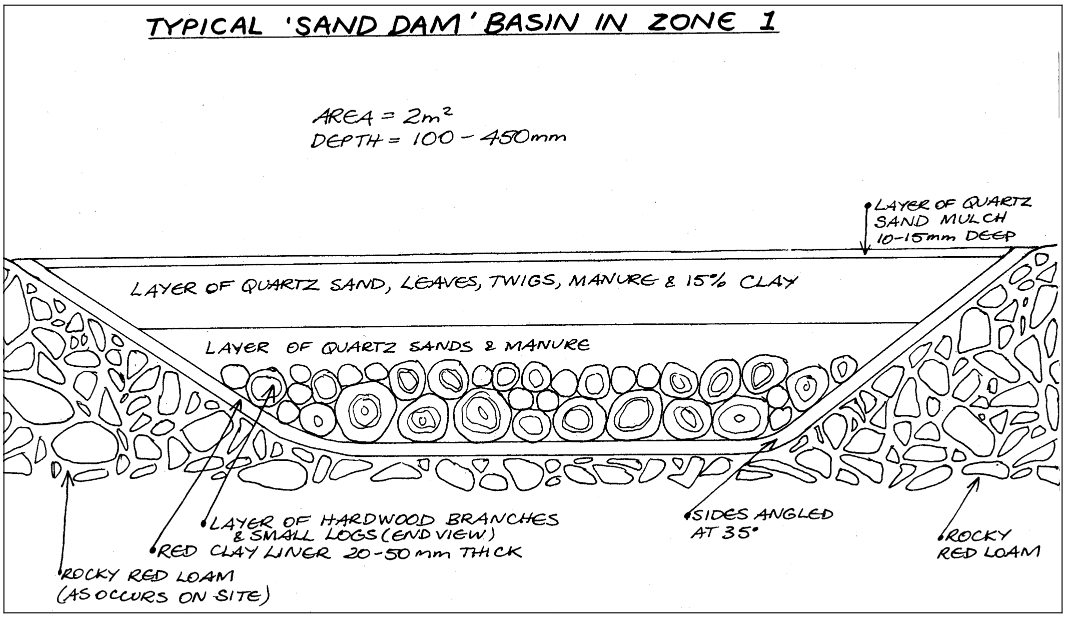

Figure 4: *Typical "Sand Dam" basin in Zone 1*

Sand dam mixture:

- 30% (min) hardwood branches and/or logs
- 15% (max) clay, 30% sand OR 10% clay, 15% sand, 20% loam
- 15% manure
- 10% leaves and twigs

The virtue of a sand dam basin is best described by the special attributes each of the materials have.

Clay

Clay lining provides a water seal and slows downward losses while providing many minerals not so common on the mid slopes where we are sited. It also provides a definite underground boundary of nutrient and moisture that larger plants send a fine mat of feeder roots into. Within 3-6 years, when it has been invaded and altered by these roots, they are then basin shaped and our clay liner is slowly replaced by a similar shaped root net which performs in a similar manner to the clay.

Keeping the clay content below 15% of the total mix avoids a common problem when these soils dry out in that they can set like concrete if higher levels of clay are used.

Clay also acts to give the soil more ionic character thereby helping water to mobilise nutrients, although too much can create nutrient binding.

Woody material

The next layer of woody material is a must in most Australian soils and is often totally overlooked by the excessive attention applied to mulch and compost. Within a year mulch and compost can totally disappear into the soil, as it breaks down into very fine compounds doing often only a mediocre job of improving the soil structure and long term soil fertility. This leads to large annual applications of compost and mulch to keep soil health happening.

A quick observation of nature reveals one of the backbones of Australia's soil improvement processes are the activities of perennial acacias and other short lived *woody* herbs and shrubs. Not only when they die do they leave vast quantities of woody matter in the form of dead roots behind, but even as they live, dead sticks and a huge variety of fibrous woody pod material is constantly returning to the soil.

This woody material, unlike grass, compost or mulch, is particularly rich in lignin. This resists breakdown and is very attractive to wood mould, soil fungi and other micro-organisms which, like many of us, prefer a more permanent home than an annual tent city. Once established within such a semipermanent home, these soil organisms get busy creating many compounds our composts and mulches would find difficult to match.

The woody matter retains moisture better, distributes it better and can easily persist from 1-4 years. Also, let us remember that the fungi are often the micronutrient generators of elements such as zinc, phosphorous etc and directly couple up to root hairs of plants to act as nutrient corridors. The deep black open soft soils of old forests are more a product of lignin than compost. The comparison between refined starches and sugars, and fibre rich foods is as appropriate to the soil as it is to ourselves. At least 30% woody matter will save a lot of extra feeding of nutrients and water to your Australian gardens.

Sand

The sand helps to fill cavities between the other materials and avoids air gaps. Sand also allows air to seep in and water to easily percolate through. If a white or quartz sand is used then light transmission deeper into the soil is achieved, this improves microbial activity to a greater depth.

Manure

This is not only rich in micro-organisms itself but acts to attract and accelerate existent micro-organism populations. It also helps offset the high carbon levels of the woody matter by supplying nitrogen. Dead animal bits and offal are excellent manures but watch the dogs, they may dig up a new garden looking for bones and rotting meat. We've used dead chooks, sheep, dog bits and road kill kangaroos.

Leaves and twigs

These materials provide many complex chemicals, microbial colonies and soil organism foods. They get the decomposition process under way quickly and with a good variety of organisms. Leaves and twigs are halfway between manure and woody matter in their useful lifespan being relatively exhausted within a year. Their other effect is to spread moisture sideways and more evenly through loose or sandy soils.

All of these materials together enhance the performance of all others and this gives long term fertility for minimum effort.

Close packing of plants

The close packing of plant species is a prerequisite for the survival of exotic species in the harsh summer conditions. This area has the highest daily temperatures and solar radiation levels in Australia. Summer sun angles are overhead and to the south of us in the tropics and so intense that only half sky exposure is needed for most plants. The best light period for most plants is from sunrise to 11 am then again, when it cools down from 5.30 pm to sundown. However, autumn and winter (March to September) is our main growing period for vegies and herbs and we need almost full sky exposure. This change from needing full to half sky exposure occurs within 4-6 weeks.

To build this into an ecosystem meant an involved study of sun angle and seasonal requirements for each plant. Also, growth rates and heights unique to the Pilbara needed to be factored in as well as root profile relationships between plants. This took quite a long time and is still being studied. However, we have evolved a planting arrangement that suits most plants and is functional over the full year.

We have embodied this knowledge into a 'Plant Protractor' which helps us to place our major shade and deciduous plants (see Figure 5). Once we get their angles to each other and to the sun correct we have then created a 1-3 m strip on the north side of these larger plants that is ideal for growing smaller plants. These smaller plants are also placed relative to their heights, roots and sky needs in different locations within the ideal growing strip. This general cluster of larger plants is in a boomerang shape and the self shading effects of this shape have certainly allowed very close packing of plants and extended yield periods. We repeat this shape in a offset formation across the landscape like fish scales and find this modular approach to plant positioning is very practical for large exposed sites.

We have also incorporated this design strategy into 'Guild planting' when we put from 4 to 7 plants in close association (1 m) on 2-3 drippers. This economical and strategic placement gives all plants in the group mutual support which leads to quicker growth rates, higher levels of complexity and better long term survival. The guild is simply a plant from each of the very broad groups such as grass (G); herb (H); shrub (S); tree (T), creeper (C); vine (V); and legume (L). They are placed in the following general patterns and sequences and immediately work together as a Guild.

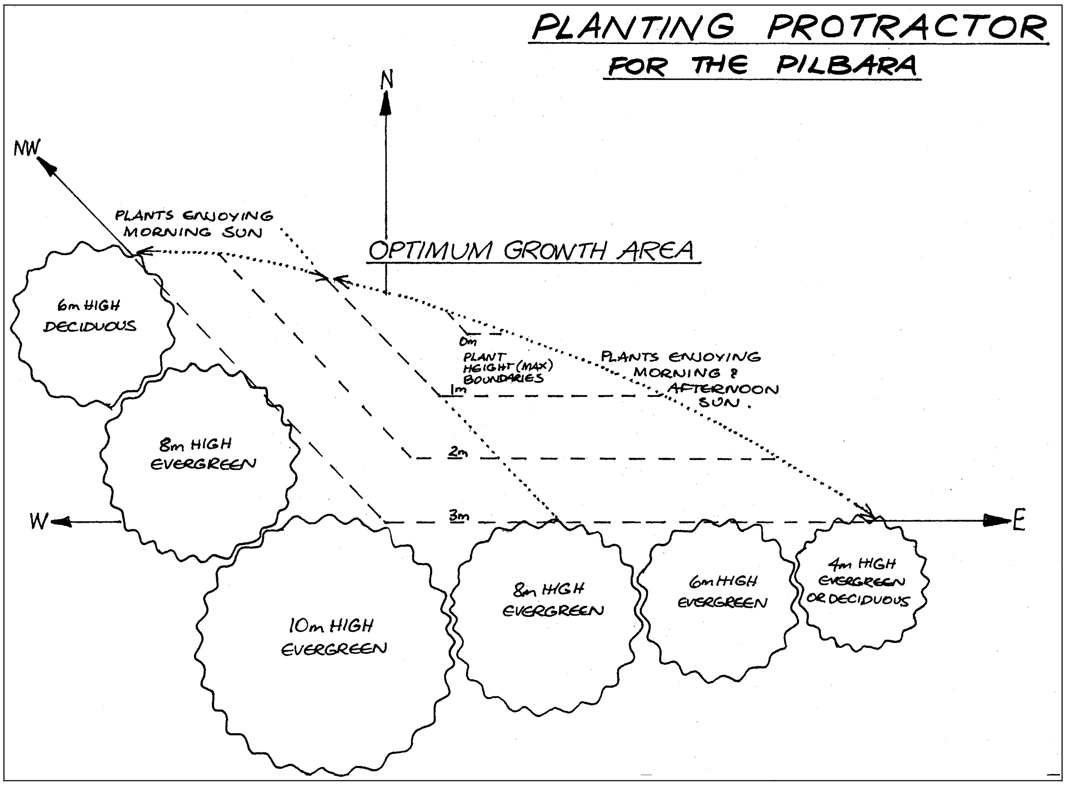

Figure 5: *Planting protractor for the Pilbara*

OUTSIDE CANOPY
(full sky conditions)

	G	
H		V
	T	
S		C
	L	

INSIDE CANOPY
(light well conditions)

	L	
C		S
	T	
V		H
	G	

It is necessary to have a good knowledge of plant characteristics, climate needs and relationships for your area to be able to select the most compatible Guild members. This planting arrangement will enhance the correct selection and can be varied slightly for other site conditions. Since developing this technique I no longer plant single plants on drip lines but always little Guilds.

Fire

Of all the great myths going around I think the one that says “The Australian bush needs fire”, is a terrible one. This lie has seen most of Australia decimated by fire to a point where it is caught in a vicious cycle of increasingly fire prone communities that burn further, hotter and more often each time around. Most native bush foods and soil improvers are *fire sensitive*. Many native plants seed well only every 2-4 years. Almost all Australian soil needs more woody matter in it to re-establish soil texture, micro organism habitat and water retention qualities.

Fire frequency has been steadily increasing from Aboriginal impact but accelerated out of control with European impact. Places that may have only seen a fire every 80 years have been exposed to one every couple of years. These places are *totally* different to what was originally there so great have been the effects.

Let us first look at seed cracking. While many seeds are cracked by fire and smoke, which are not the same thing by the way, there are numerous other events that crack seed dormancy. Weevils, birds, beetles and rodents all penetrate hard seed coats and leave *some* seeds in a condition ready for germination. One of the most powerful and gentle agents for weakening the seed coat is the opening rains which increase the salt, chemical and liquid concentration of the immediate soil. This natural soup easily invades the seed coat but often doesn't germinate the seed. If the rains continue, then germination of 20-30% of a batch of hard coated seeds will follow.

In Australia more often than not we have no immediate follow up of the opening rains. The 4-6 week dry period causes the seed coat on un-germinated seeds to shrink, fracture and fissure. Generally the second lot of rains continue a lot longer and the weathered seed coat allows easy germination of the first batch of seeds. By this time also the soil liquids are diluted and only a small percentage more seeds are weathered to the point of germination. By the end of a season 30-50% of a plant's seed stocks may have germinated leaving the rest for a later season. This hard coated seed reserve in the soil allows for sporadic ongoing germination such that up to 3 years later the last seeds from a batch can still be germinating. This is a natural insurance against poor rainfall patterns and a very practical one at that.

Now if we have a fire go through just before the first rains and have no follow up rain then we have a very big problem. First, over 80% of the soil's seed stock can be woken from dormancy. Secondly, the woody, water containing mulches are destroyed so the need for follow up rain becomes even more urgent. Thirdly, the soil chemistry is very corrosive from ash and charcoals so the next rain generally helps crack many of the remaining seed coats. Fourthly, the germination of so many seeds so close together creates an incredibly dense growth pattern such that competition is voracious for the diminishing resources of water and mulch created fertility. These features of fire are very destructive and the short term gains are often only good for one season, thereafter the stage has been set for an ongoing cycle of destruction.

Fire and forest roads

Apart from spreading disease, feral plants and human impact, roads often create fire. Cutting through a forest canopy for a road allows wind and air circulation to reach the forest floor. The increased air and wind access has an incredibly drying effect on all the mulch and leaf litter. This tangle of branches and leaves normally holds much moisture over the dry period so as to help to forest through drought, and is relatively fire proof. Once it is aired and dried it becomes a fire bomb.

Many large wildfires have occurred in forests within 2-3 years of a road going through *tall* timber stands. The *tall* forest is most vulnerable because it takes so much longer for its canopy to reunite with the ground. Also, the *tall* forest occurs at the 'heart' of the forest that may be well over 100 km across. It has been sealed up against light and dry air and has a huge mulch content on the floor. Because it has been heavily mulched and sealed up for so long there is often little or no pioneer seed stock in the soil of the heart of a *tall* forest. These pioneer plants are the quick growing, short lived plants that would be needed to quickly seal the canopy back to the ground. They are often only found around the edges of an old growth forest many kilometres from it heart.

One useful strategy for remediation is to select local pioneer species from the edge of the old growth forest. The species need to be fire retardant, quick growing pioneers that get from 4-10 m high in a couple of years and vines that reach at least 6 m high to help bind together a substantial wind break. These pioneers need to be planted/seeded along the edge that has become exposed and encouraged to seal up the canopy again. In Queensland tall timber forests seal up quickly quite naturally because it is warm and wet, however NSW and WA are too dry and Victoria is too cold for rapid regrowth.

This general strategy is quite applicable to other types of ecosystems with local species choice, canopy height and shade being more relevant in open canopy systems. Grass suppression through shade and displacement by herbs is the general technique used in open canopy systems, although getting a canopy around a water way is still aimed for.

Fire and species composition

The advent of a fire tends to create a significant shift from one species composition to another. In earlier times Callitris (pine) and Eucalyptus were co-dominant. However, fire has altered this. If fire is more frequent than 15 year intervals then Eucalyptus wins and Callitris loses. If an evenly mixed stand only gets fired a intervals greater than 15 years then it will still take 100-500 years for the Callitris to win. One can easily see the repercussions of regular burns. Callitris tend to inhabit ridge and mid slopes and so if they burn, the fire is not opening up the water ways. However, Eucalyptus have (due to increasing fertility) moved into the waterways and now bring fire into them also. Callitris is a great creator of soil fertility and feeder of fungi. While they can suppress growth around themselves, their removal exposes a useful soil which will support healthy growth of most plants. The Eucalyptus after 40 years of dominance of an area often leaves behind a chalky, collapsed soil that is in sharp contrast to what the whole pine family achieves. (Pinus, Callitris, Casuarina etc.)

The increased fire incidence that Eucalyptus introduce lowers fertility, destroys many food and soil improvers and hosts more of the fire prone hot burning plants. These plants such as banksia tend to bring more ants (which help open collapsed low mulch soil) which predate more soil organisms and also the downward spiral of soil fertility is formed by the increasing incidence of fire and fire promoters.

There are species that are very quick to disappear after fire and I always look for them to get an indication of ecosystem health.

First are the ferns which live mainly on decomposing woody material. Once fire removes the woody material stocks they disappear quickly.

Second are the fungi which also live on woody material although are not as sensitive as the fern because they can live on living plants and underground. The level that they occur above ground and variety does indicate how intact the canopy is. The higher humidity that comes with a good canopy also allows fungi to be successful higher up the trunks of trees. Lower humidity from damaged canopies sees most fungi only at ground level and very little humidity.

Third are the vines which help bind a canopy together against wind invasion. They are often found densely along water courses and the edge areas of larger trees. They are often shallow rooted, use old sticks and low branches to access the canopy and are easily killed by fire. The seeds and roots often don't survive fire and without their binding effect, very few canopies are very wind proof. Once fire invades the waterways there is a rapid loss of vines from an ecosystem.

More remediation of edge areas at risk from wind invasion and protection of high mulch areas from fire and drying out needs to occur at least on private owned forest.

Selective removal of Eucalyptus and fire promoters and replacement with local pine types, fire retardant pioneers to 10 m and vines to 6 m would see a giant leap forward in fire protection.

A plan of a forest block showing high mulch areas, dry wind directions, unsealed canopy and problematic plant areas would help make a holistic strategy possible. Long term privately owned land with sensitive stewardship could create forest that wouldn't burn at all if done correctly.

The use of strategic logging and fire should not be ruled out as a management plan if they are followed up by careful seed and plant selection for replacement. It is the lack of astute seed/plant and rain follow up planning that makes the whole process fail severely. Because the demise of the forest has been under way now for quite a long time, only correct management can interrupt this destructive spiral, not standing back and doing nothing.