A LONGITUDINAL STUDY OF THE EFFECTS OF CHANGING CLIMATE ON VEGETATION, HYDROLOGY AND BIODIVERSITY- 1972 TO 2024.

THE 31 MILE BROOK CATCHMENT, JARRAH (E. marginata) FOREST, WESTERN AUSTRALIA.

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Key words: Climate change, ecosystem health, catchment water balance, modeling.

SUMMARY

Water is a key driver for many ecosystem processes. The integration of various sets of data for a catchment now allows a holistic evaluation of an ecosytem's response to a major reduction in rainfall over the past 50 years.31 Mile Brook is considered as a suitable surrogate for forested catchments in the higher rainfall, northern jarrah forest.

From the late 1960's there was a major reduction in rainfall in the South-West of Western Australia, 17 percent at near-by Jarrahdale . Comprehensive modelling of streamflow , soil moisture storage and depth to groundwater was undertaken from 1986 to 2011. There was a good match of data and the models were able to follow the drying trend in streamflow (200mmpa to 50 mmpa), in flow days (from 350 to 170 days) and depth to groundwater(several metres) .

Between 2004 and 2010, the estimated evapotranspiration was 948 mmpa which matched the average rainfall of 949 mm. Soil moisture storage fell by 441mm. Analysis of LAI data show canopy growth of 70% from 2007-2009 (to 1.5) and then a decline of 21% from Jan-March 2011, as a result of the very dry 2010 winter. Crown scorch and some tree deaths on shallow soils were observed in autumn 2011. Basal area in 1975 averaged 25 m2/ha.

Data on aquatic biodiversity over 30 years reveal shifts in faunal assemblages, species richness and abundance. A range of terrestrial biota show little change, as the understorey vegetation is still healthy.

The data include mapping of species composition in 1972 and remapping of 480 plots in 2012. By 2024, the tree stratum was healthy and only minor changes in composition were observed, mostly adjacent to rock surfaces and in gully-heads.

INTRODUCTION

The catchment of 31 mile brook is located in the northern jarrah (E.marginata) forest, some 50 kms south-east of Perth. This brook feeds into the Canning river and a short distance downstream, at Canning dam, the rainfall average in the 1970's was 1290mmpa. Jarrah is the dominant eucalypt , interspersed with Marri (C .calophylla) on more fertile soils and Blackbutt (E.patens) and Bullich (E. megacarpa) growing on water-gaining sites. A detailed description is provided by Havel (1975b). This is a regrowth forest that has been harvested for timber and regenerated on at least three occasions.

HYDROLOGY

Data from 1880 at rainfall stations located at Perth airport and at Jarrahdale show a cyclical dry-wet-dry cycle from 1880-1914, 1915-1965 and1965 to present. Rainfall averages for these periods are as follows: Perth: 735mm, 862mm and 776mm and Jarrahdale: 1100mm, 1251mm and 1054mm(Fig 1). Very high rainfall years were: 1915, 1917, 1945, 1946, 1963, 1964 and 1967. These replenished the groundwater and filled the dams. Tree ring studies indicate that the first half of the twentieth Century was unusually wet and that a "drier climate" is probably the normal situation for these forests (O'Donnell et al 2021).

Streamflow in water supply catchments from 1975 to 2012 fell by 75 percent. In the drought year of 2010, many streams did not flow at all and the inflow of 12 GL was only 3% of the pre 1975 flow (Reed et al 2012). At 31 mile brook the flows are highly variable, ranging from 96mm in 2009 after three good years of rainfall, to only 4mm in the 2010 drought year (Silberstein et al 2011).

The forest has continued to transpire drawing on soil-water and groundwater reserves. This has led to a major decline in groundwater levels since the 1970's. Simulations by Croton etal (2012) show a fall of several meters (Fig 2) and bore data from Cobiac, a near-by catchment, fell by six meters between 1992 and 2012 (Reed et al 2012). Eventually the groundwater becomes disconnected with the stream leading to a marked reduction in both winter discharge and summer baseflow.

FOREST COVER

Trends in forest canopy cover between 1989 and 2007 were analysed by Landsat imagery (Wallace et al 2009). The western, higher rainfall zone was either a stable or increased cover. In contrast, the drier, eastern forests showed a widespread reduction in canopy cover. The cover index for the dryer zone was always lower (by about 3%) and the gap between the two rainfall zones increased with time (to 11%).

CSIRO also measured Landsat derived leaf area index in 31 mile brook between 2004 and 2011 (Silberstein et al 2011). Data showed a gradual increase in cover from 2007 to 2009 (70%) after three years of good rainfall. Following the drought in 2010, cover fell by 21%, indicating a rapid capacity to adjust to prevailing conditions.

CATCHMENT MODELLING

Catchment modelling undertaken by (Croton et al 2011) show that annual streamflow was correlated (0.91) to the total inflow for all catchments that comprise the Integrated Water Supply System, indicating that it can be representative of catchments in the higher rainfall areas.

Comparisons of observed and modelled results were made between 1986 and 2011. There was a good match of data and the model was able to follow the drying trend in both streamflow (from 200mmpa to 50 mmpa) and in flow days (from 350 to 170 days). The decrease in soil water storage was calculated as 1100mm.

Depth to groundwater was also simulated and show significant reductions. In the early 1970's extensive areas of the valley floor had positive heads above the soil surface but by 2010 the groundwater contact with the surface was limited (Fig 2). The disconnection of the groundwater from the streamzone explains why small changes in rainfall lead to major changes in streamflow .

CSIRO used TOPOG and canopy data based on an Forest index derived from Landsat (Silberstein et al 2011). This model also produced a good match between observed and predicted results for streamflow, groundwater and soil storage. The model was used to estimate the proportion of reduction in flow due to lower rainfall (about 2/3) and to increased forest cover (about 1/3).

SIMULATIONS OF THINNING TREATMENTS

Thinning treatments ranging from Leaf area value of 0.4, 0.6, 0.8, 1.0 and 1.25 (the untreated control) were used to understand the management regimes required to recover groundwater and streamflow (Croton et al 2011). From 2011, the 2001-2010 annual rainfall (average 958mmpa) was applied in sequence five times, to 2060. The untreated scenario caused the groundwater to become completely disconnected from the streamzone. The resulting flows were calculated as 40mmpa to 2020, then decreasing to 28mmpa in 2060. As a comparison the catchment yielded an average of 236mm in the 1970's and 74mm from 2001-2010.

If a thinning treatment to a leaf area of 0.6 (basal area 10 m2/ha) is undertaken, and repeated every nine years (including coppice control) the estimated benefits over the control scenario are substantial- an improvement of streamflow to 110 mmpa, in flow-days by 180 days and in soil storage by 1600mm. For a leaf area of 0.8 (basal area 14) the data were: streamflow to 75mmpa (maintaining the recorded streamflow at the start point of 2010), flow-days by 90days and soil storage by 1250mm.

CATCHMENT WATER BALANCE

Macfarlane et al (2011) reported on their water balance studies from 2004-2010, though this work is also included in Silberstein et al 2011. The mean annual interception was calculated as 121mm, the mean overstorey transpiration as 427 mm and the annual evaporation from understorey and bare ground as 400mm, totaling 948mmpa. During this period, the mean annual rainfall was only 947mm, which included two drought years, 748mm in 2006 and 524mm in 2010. The catchment moisture storage decreased by 63mmpa on average, or 441mm in total.

The annual estimate of leaf area index could vary by more than 20% depending on rainfall, indicating the ability of canopy cover to respond quickly, in either direction. Mean runoff was 61mmpa, about six percent of rainfall, mostly coming out of storage.

Macfarlane also compared the water use of large trees versus smaller trees. Though sap-flow rates were similar, the water use in larger trees was about half that of smaller trees. This is due to the much larger sapwood area in the smaller trees (for a given basal area) and also a higher crown cover. In regrowth forest the evapotranspiration from the overstorey /unit Leaf Area Index (LAI) was about 310mmpa.

ENVIRONMENTAL VALUES

The observed increase and then decrease in rainfall, water tables, soil moisture storage and streamflow from 1880 to 2024 would be expected to have significant effects on forest health and biodiversity.

Drought In May 2011 the author flew in a helicopter for two hours over the Wungong catchment, located just to the West of 31 Mile brook, photographing dead trees and scorched crowns. There was a follow-up field inspection of several sites (Davison 2011). Most of the deaths or loss of crown in native forest were clearly associated with shallow soils adjacent to exposures of country rock. Some affected trees were measured at up to 90 cms at breast height, indicating that they were more than 200 years old. There was abundant excision of leaves and even large branches, up to 3cm in diameter. Marri (C. calophylla) appeared to be more resistant to drought than jarrah. There were minimal effects on understorey species.

A number of deaths were observed in areas that had been rehabilitated after mining for bauxite and had high leaf area, often above 2, sometimes as high as 3. Adjacent to White gum road (Chandler catchment) a patch of bullich (E. megacarpa) of about one hectare had died at the head of a gully of a small stream (Havel type D), but the understorey was unaffected. This was the only significant mortality observed in a water-gaining site.

It was estimated that 5% (600 ha) of the 12000 ha catchment had been affected. No deaths were observed on sites that had been thinned in 2008 to a leaf area index of less than one. Eventually, most of affected trees recovered, either by sprouting epicormic shoots on the trunk and branches, or by coppicing from the collar region.

Other observations were made and reported by Brouwers et al (2013) and Matusick et al (2013). Brouwers reported that sites in elevated landscape positions, close to rock outcrops and those with poor water-holding capacity were more likely to be affected. Matusick carried out a much more extensive aerial survey and subsequent field investigation. Canopy mortality was found to be concentrated in distinct patches, representing 1.5 % of the aerial sample, totaling 1350 ha of native forest. Within these severely affected patches, 74% of all stems >1cm at breast height had dying or recently dead crowns, leading to 26% stem mortality six months after the initial collapse. Marri was more resistant to crown dieback than was jarrah.

Waterlogging Excessive rainfall (between 1915 and 1965, Fig 1), the associated waterlogging (Fig 2), combined with Phytophthora disease impacted about 12 percent of the catchment area (Havel 1975 b) and had a much greater environmental impact than the drought deaths observed since 2011. The current drier phase is not atypical, but is considered as the more "natural" condition for this ecosystem.

Vegetation Comprehensive mapping of the tree statum, of shrub species in the understorey, of site-vegetation complexes, soils, dieback, altitude, slope and rock surfaces was published in 1975 by Havel, with field work carried out some years earlier. Five hundred vegetation plots were set up on a 400m x 100m grid and on each plot of 40m x 40 m all trees greater than 7.5 cm at breast height were measured. Within each larger plot, sixteen quadrats each of one square meter were selected and the cover contribution of each perennial species was estimated. Based on previous studies, 55 species were selected as good indicators of site. For field mapping the vegetation continuum was split into 14 segments, based on the indicator species and the underlying environmental conditions. These were then mapped using both the field data and aerial photos. This extensive study provides an excellent baseline.

Forty years later, 480 of the sites were used to re-measure the tree stratum, the shrub cover and to re-map the site-vegetation complexes (Mattiske 2012). Recorded in this survey were 242 vascular plant taxa, from 124 genera and 48 families.

When the two maps were overlaid, some localised shifts in classification were noted in heads of gullies and adjacent to rock surfaces. Overall there was excellent agreement between the two maps:

S and P	Crests/slopes	Havel 1210 ha	Mattiske 1203 ha	64 percent
Variants of S, P		Havel 267 ha	Mattiske 287 ha	15 percent
C,D,W,Q	Water-gaining	Havel 350 ha	Mattiske 343 ha	18 percent
R and G	Exposed rock	Havel 58 ha	Mattiske 56 ha	3 percent

A comparison was also made on abundance for both tree and understorey species. Some species that prefer moister soil conditions, for example E patens (blackbutt), bullich (E megacarpa) and Hypocalymna angustifolium, were less abundant in 2012, indicating a slight xeric shift . Tree deaths were recorded on shallow soils, especially near exposures of rock. There was no collapse of streamside vegetation. A road reconnaissance in 2024 confirmed that the forest ecosystem in 31 Mile brook is still healthy.

Terrestrial biodiversity The dense streamside vegetation provides excellent cover, protection from predation and food sources for a range of native marsupials, mammals and birds, including the endangered red-eared firetail (Emblema oculata), golden whistler(Pachycephala pectoralis fuliginosa) and white-breasted robin(Eopsaltria georgiana) (Johnstone and Kirkby (2009) and also the quokka (Setonyx brachyurus), quenda(Isoodon obesulus), chuditch (Dasyurus geoffroii) and rakali(Hydromys chrysogaster) (Dundas et al 2011). In addition seed-eating birds such as the forest red-tailed black cockatoo and the brush bronzewing require regular access to water.

Swamp systems at the terminal end of tributaries (gully heads) are the most likely places where changes in occupancy by native species may occur as the result of loss of habitat. A key feature is the maintenance of the quality of this habitat, with a mosaic of fire ages preferred, so as to provide both adequate cover and food source. As the observed shifts in streamside understorey vegetation have been minor, the impact on key terrestrial fauna and birds to date is considered as minimal.

Aquatic biodiversity Comparisons between 1984 and 2010 show that similarity in assemblages has recently shifted by up to 10% as the stream has become increasingly seasonal and longer lifecycles cannot be completed. Macroinvertebrates play a vital role in freshwater food webs (Davies and Storey 2012).

The distribution of freshwater species will become increasingly restricted, including species such as Gondwanic dragonflies, stoneflies, freshwater snail, marron, gilgies and mussels. Breeding habitat for frogs and native fish will also be reduced.

DISCUSSION

Water is a key driver for many ecosystem processes. The integration of various sets of discrete data for a catchment allows an holistic evaluation of an ecosystem response to changes in forest structure and a major reduction in rainfall over the past 50 years. As a consequence of this groundwater levels have fallen, the soil storage has decreased and streamflow is markedly lower. It is estimated that about 65 percent of the changes observed is due to reduced rainfall and that 35 percent is due to higher transpiration rates in smaller trees.

Crown cover has shown an ability to respond quickly and substantially to annual rainfall, increasing in wet years and shedding leaves and larger branches during drought. Despite the overall reduction in rainfall, the long-term trend in this catchment has been to increase its crown cover, the opposite of what was expected.

The forest is transpiring or evaporating all of each year's rainfall, drawing down on its moisture store, and it is unclear for how long this can continue. The water loss from understorey and bare ground is a significant component of the total loss.

The observed changes to rainfall, water tables, soil moisture storage and streamflow over such a long period of time would be expected to have significant effects on forest health and biodiversity. Some deaths have been observed on shallower soils and occasionally on moister sites. Vegetation adjacent to stream lines has not collapsed, but has shown a small xeric shift, especially in gully-head sites.

The only exception observed was in an almost pure stands of bullich, in 2011 at White Gum road (on an adjacent catchment) where about one hectare died suddenly. The site was resurveyed in 2020. Few of the original large trees were alive but many stems had coppiced from the base. There was also considerable regeneration from seed.

Regular drought events are now more common. Adjacent to Chandler road, drought deaths on shallow soil over rock were observed in 2001, 2007, 2011 and 2020. Each time the trees recovered with epicormic shoots or by coppicing from the base, grew to 4-5m and then died back again. Despite some tree deaths, predominantly on shallow soils or in rehabilitated areas, the vegetation's response over the past 50 years has been resilient.

While the death of some trees is regrettable, it is the dense understorey in the streamzones that fauna are so dependent on for food and shelter. Because this vegetation has only been slightly affected, the impacts on terrestrial fauna to date are considered as minor. In contrast aquatic fauna with longer lifecycles have been affected to some degree.

A single wildfire would have a much greater negative impact on vegetation, water quality and fauna (Figure 3). Appropriate fire management that results in patchy burns of varying intensity, followed up by baiting for predator control is required.

The modelling carried out by Croton Consulting matched observed data well and gives confidence that the predictions made about management options would be reasonably accurate. These showed that regular thinning to a leaf area of 0.8 (basal area of 14) could maintain streamflows at the 2000-2010 levels, which is encouraging. However it would be better to keep 31 mile brook as an untreated control catchment so as to build on this long-term study.

This forest has recently been listed at a "High risk of transition or collapse from drought (with a high level of confidence)" (IPCC 2022). The data show that this listing is based on incomplete or biased advice, without the benefit of visiting the site or talking to foresters.

ACKNOWLEGEMENTS

The Water Corporation, Forest Products Commission, Forests Department, Bauxite Hydrology Committee and Premier's Water Research Foundation have all provided support, funding and access to their studies. Mr Keith Barrett, formerly a Senior Manager at the Water Corporation instigated the re-opening of the gauging station and encouraged this research and Dr J J Havel and Mr R Edmiston established the original baseline vegetation plots in the 1970's.

AUTHOR'S NOTE

Most of the reports about research work in 31 Mile brook have not been published in peer-reviewed journals these valuable data may be lost or forgotten. Until now, no other document has examined the effects of climate change since 1973 on catchment hydrology, streamflow, biodiversity and ecosystem health.

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Fig 1 Jarrahdale rainfall

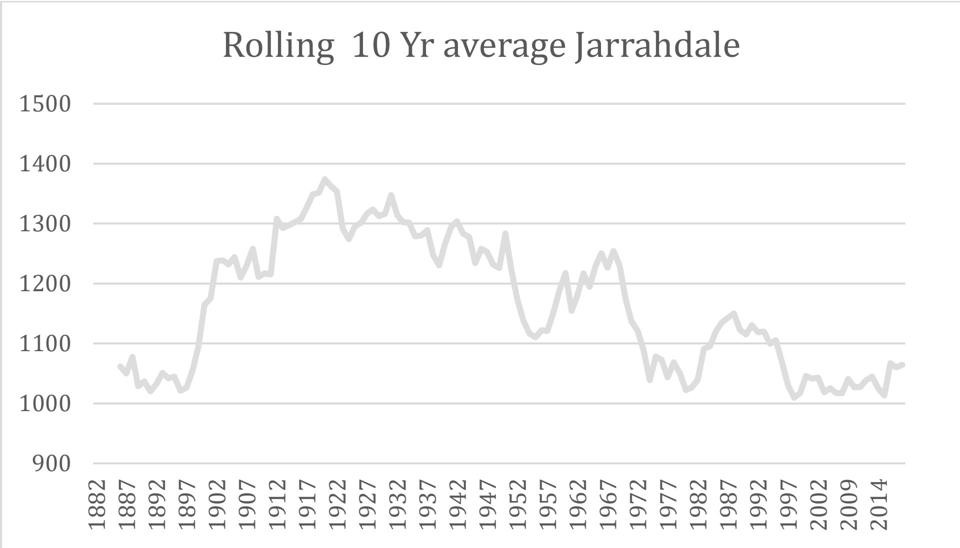

Figure 2 Simulated depth to groundwater (Croton et al 2011)

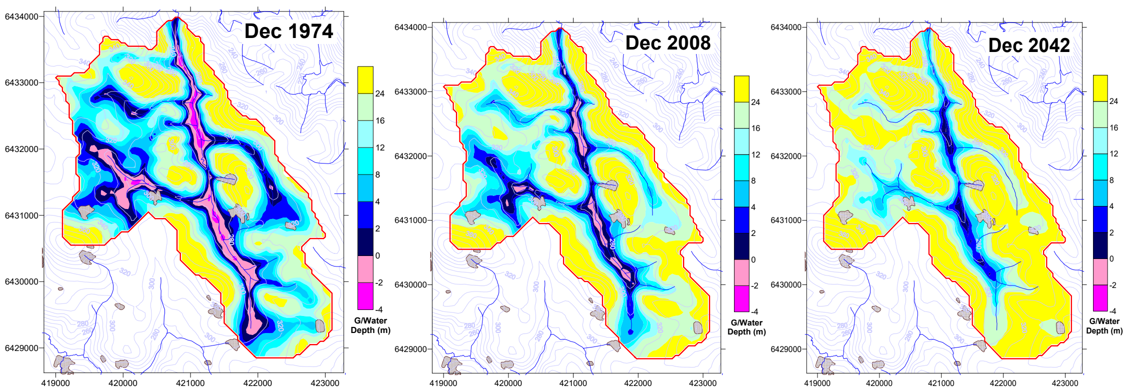

Figure 3 A Bullich wetland near Willowdale devastated by the Yarloop wild fire. Both over and understorey species killed over a large area. (F Batini, March 2016)