South-West Forest Stream Biodiversity Monitoring

Forest Management Plan 2004-2013:
Key Performance Indicator 20

Interim Report

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EXECUTIVE SUMMARY

The South-west Forest Stream Biodiversity Monitoring project was initiated as part of the Forest Management Plan 2004-2013 (Conservation Commission of Western Australia, 2004). The study was designed to assess the effects of forestry activities (particularly prescribed burning and forest harvesting) on aquatic invertebrate biodiversity and stream chemistry. Monitoring commenced in 2005 and is ongoing. This report presents data and analysis for the first four years (2005 to 2008).

Aquatic invertebrates and water physico-chemistry are monitored at 51 sites throughout the south-west forests. These were selected to have a wide geographic spread (northern Jarrah forest to southern Karri) and to include streams in catchments subject to a range of existing and planned forest management practices. Generally, these sites are downstream of, rather than within, areas subject to timber harvesting and planned burns, as the aim is to monitor broader effectiveness of forest management rather than local impacts. The sampling protocol used is based on the Australian River Assessment Scheme (AUSRIVAS) and a variety of biotic measures are used to assess the degree of disturbance.

The invertebrate communities inhabiting south-west forest streams were diverse, with a total of 311 taxa recorded. Many sites showed significant variation in the biodiversity measures and the AUSRIVAS scores and bands between years. Some of the temporal variation in the biodiversity measures may be related to rainfall, as biodiversity measures were generally low in 2007, following the particularly dry year in 2006. The lower richness in 2007 may have been the result of reduced survival and reproduction in the dry 2006 season and subsequent low recruitment in 2007. Invertebrate diversity was also higher in streams with higher maximum flow and lower conductivities, which may be related to the amount of runoff entering the streams. The eastern-most streams had higher salinities and particularly low invertebrate diversity.

There was a difference in invertebrate communities between the Jarrah and Karri forests, with Karri forests generally having a higher number of mayflies, stoneflies and caddisflies (EPTs). Differences between forest types were not consistent between years. Community analysis showed that there is a latitudinal gradient in invertebrate community composition, with southern Jarrah forest sites having similar invertebrate communities to those present in Karri forest.

There was substantial variability in biodiversity measures within and between sites. Effects of fire and logging on invertebrate communities were only detected in some years and are probably related to how the disturbances have affected the amount of runoff, debris, sediments and nutrients entering the stream. The proportion of catchment burned was only correlated with change in invertebrate diversity between 2006 and 2007. Over this period there was greater reduction in EPT richness (for both Jarrah and Karri catchments) and species richness (in Jarrah catchments only) where a higher proportion of the catchment was burned. The proportion of the catchment logged was not correlated with the change in biodiversity measures in either forest type. Over the entire four year period (2005 to 2008) there were no significant correlations between changes in biodiversity measures and the proportion of Jarrah or Karri catchments logged and/or burned. Time since the last fire or logging event was also uncorrelated with biodiversity measures.

Ordination analysis suggested some divergence in composition of Jarrah forest communities between sites with a greater proportion of the catchment logged or burned and those with less

logging or burning. However, the divergence was a case of communities in more affected catchments being spread around the periphery of communities in less affected catchments, rather than a gradient of change. This pattern suggests that, while there may be changes in community composition as a result of logging and burning, the nature of the change is not consistent across sites. There were no significant correlations between the amount of change in community composition over time (1 and 4 year intervals) and the cumulative proportion of catchment burned and/or logged in the intervening period. In factorial analyses of community composition, there was a significant difference in community composition between sites in catchments with some logging and those in catchments with no logging, but only for Jarrah Forest streams in 2005. There were no detectable differences between unburned and burned catchments in Jarrah forest sites. In Karri forest communities, there was no detectable difference in community composition between catchments with or without burning or logging.

Approximately 14% of the sites (7 sites) received an AUSRIVAS 'C' band for at least one sampling occasion and so were scored as severely impaired. All these sites occurred within the Jarrah forest and had a history of varying disturbances occurring in the catchments. At these sites, impairment did not seem to be related to any single event or disturbance, but may be due to a combination of factors occurring simultaneously or repeatedly in the catchment.

The results to date suggest that EPT taxa are the most sensitive and are proving to be a valuable measure of disturbance. However, similar disturbances may have different effects on EPT taxa depending on the site's geology, slope and amount of riparian disturbance.

There were no significant differences in biodiversity measures between the dam sites and undisturbed sites. However, low O/E family scores present at the dam sites indicate that fewer of the families included in AUSRIVAS models are found in streams below dams than one would expect to find at reference sites. Invertebrate communities downstream of the dam wall varied substantially between rivers.

Wildfires occurred at two sites (SWA24-Little Darkin and DEN26-Quickup) just prior to the first sampling occasion in 2005. Even though there was no pre-wildfire measures of invertebrate diversity, richness of species and families at these sites was well below those of undisturbed Jarrah streams for 2005. The effect was greater for SWA24 for which all biodiversity measures (except chironomid richness) were lower than the averages for undisturbed Jarrah sites in 2005, 2006 and 2007. This wildfire may have had a greater impact than the fire at DEN26 due to the fire's intensity and also the time between the fire and sampling. By 2008 (4 years after the wildfires) biodiversity measures (except EPTs) at both sites were similar to undisturbed Jarrah sites. Future sampling will track recovery of these sites, especially for EPTs.

Catchments with dieback present did not have significantly different biodiversity measures to those without dieback. However, in the Jarrah forest all measures (except for chironomid richness) were positively correlated with the proportion of the catchment affected by dieback. There was no such relationship in Karri forest communities. The dieback may be influencing stream ecosystems by increasing the amount of debris, runoff and sediment entering the streams.

Data on the aquatic fauna of south-west forest streams is spatially patchy, disparate and taxonomically inconsistent, limiting its potential use in conservation planning. This project, while not taxonomically comprehensive, does provide a large and consistent dataset on the region's aquatic invertebrate fauna, useful for analysing spatial patterns in the distribution of forest stream invertebrates. This could contribute to regional conservation planning and assessments of the conservation status for individual species. There is also very little information on the factors structuring and altering aquatic invertebrate communities in south-west streams and how these affect species' distributions.

Samples collected in 2009 have now been processed, sampling was undertaken in 2010 and will continue until 2013. Refinements to be considered include additional biodiversity measures (such as taxonomic distinctness), alternative analytical techniques (e.g. community composition modelling) and perhaps some additional approaches to sampling (e.g. longitudinal studies from within impact zones to downstream).

INTRODUCTION

Background and project description

Since the 1990s there has been considerable development in sustainable forest management at a global scale (United Nations, 1992a, United Nations, 1992b). Australia was signatory to the 1995 Santiago Declaration, under which it was committed to the development and implementation of the Montreal Process criteria and indicators (C&I) of sustainable forest management. Montreal Process C&I provide a common framework for member countries to describe, monitor, assess and report on national forest trends and progress towards sustainable forest management. In 1996, the Australian Ministerial Council on Forestry, Fisheries and Aquaculture decided that Australia would use the Montreal Process C&I as the basis for the development of a set of sub-national C&I, that would be applied on a regional scale. Western Australia's Forest Management Plan 2004-2013 (Conservation Commission of Western Australia, 2004, referred to as FMP) has adopted slightly modified Montreal Criteria of sustainability, as the framework within which to identify management actions in line with the principles of ecologically sustainable forest management. The seven criteria are: the conservation of biodiversity, the maintenance of productive capacity, the maintenance of ecosystem health and vitality, the conservation and maintenance of soil and water, the maintenance of forests contribution to the global carbon cycle, the maintenance of heritage, and the maintenance of socio-economic values. The FMP covers all land categories vested in the Conservation Commission, and freehold land that contains native vegetation held in the name of the Executive Director of the Department of Environment and Conservation, within the Department's Swan, South West and Warren Regions. However, there is a focus on the management of State forest and timber reserves because it is primarily on these land categories that disturbance activities are permitted.

Disturbances associated with forestry, such as fires and harvesting, modify landscapes and can alter stream water chemistry, hydrology, sediment processes and physical habitats, with consequences for stream biodiversity. The South-west Forest Stream Biodiversity Monitoring project was initiated to evaluate the effectiveness of the FMP in protecting aquatic invertebrate communities in forest streams (i.e. it addresses the 'conservation and maintenance of soil and water' criterion). This was formally stated as Key Performance Indicator (KPI) 20: "the percentage of water bodies (e.g. stream kilometres, lake hectares) with significant variance of biodiversity from the historic range of variability". The project involves monitoring aquatic invertebrates and measuring aspects of water physico-chemistry at >50 sites throughout the south-west forests. The sampling protocol is based on the Australian River Assessment Scheme (AUSRIVAS) and a variety of biotic measures, including AUSRIVAS models, are used to assess the degree of disturbance in the streams (Halse *et al.*, 2001b). This report is an interim analysis of the data collected during the first four years of field work (2005 to 2008).

Past research on aquatic invertebrates in the south-west forest region

Studies on the effects of fire on aquatic invertebrates have been neglected in Western Australia. Most reports and reviews on the effects of fire on aquatic ecosystems address issues associated with water quality and water resources but have not incorporated the impact of fire on aquatic invertebrates and fish, especially in streams. One study (Horwitz, 1997) has researched the effect of fire on aquatic fauna within the peatlands of the Warren region of south-western Australia. Horwitz found that the burning of peat swamps, especially under dry conditions, resulted in the substantial removal of peat and surface organic material. Since peat acts as a sponge, this meant that there was a reduction in the amount of moist habitat for invertebrates. The present research project and the Wungong Catchment Trial (being carried out by Aquatic Research Laboratory, University of Western Australia for the Water Corporation) are trying to address this lack of information and have included fire impact sites in their monitoring programs.

Research on the impacts of logging on the fauna of streams in the south-west forests has been carried out since the 1980's. Most of these studies have concentrated on the effects of water quality but a few have included aquatic invertebrates (Growns and Davis, 1991, Growns and Davis, 1994a, Horwitz *et al.*, 1997, Trayler and Davis, 1998, Armstrong *et al.*, 2005, Aquatic Research Laboratory, 2009). Growns & Davis (1991) showed invertebrate communities were different in streams running through clear-felled areas (without a buffer zone) 8 yrs after harvest to those either in buffered or undisturbed streams. However, there was no significant difference in invertebrate richness or total abundance. They found that there were changes in salinity, hydrology, debris and sedimentation in clear-felled streams which resulted in changes in the macroinvertebrate community composition. The size of the buffer zones around a clear-felled area influenced how these physico-chemical changes affected stream ecology.

In south-west Western Australia most annual rainfall (approximately 80%) falls from May to October. In the study area, there is a general increase in rainfall from north to south and a steady decline from west to east. Since the 1970s there has been a dramatic reduction (almost 10%) in the total annual rainfall across the south west. The decline in rainfall and streamflow has been well documented (Ruprecht and Rodgers, 1999, Bari *et al.*, 2005, Department of Water, 2009, CSIRO, 2009). Reduction in rainfall has been most apparent in late autumn and early winter, with a major drop in rainfall totals occurring in the 1970s and possibly another more recently in the 1990s. The abrupt drop in rainfall during the 1970s has brought much less reliable early-season rain and fewer wet years. This has strongly affected water supplies (with 40 to 50 per cent decline in dam inflows), sub-surface water and related ecosystems. It is predicted that about half of the rivers in the south west will have a 5 to 20 percent reduction in winterfill and rest-of-the-year flows if the climate trends of the recent past (1997 to 2007) continue until 2030 (CSIRO, 2009). The changes in flow in these river systems will have significant impacts on the ecological river functions that require high river flows. This includes runoff entering the system, channel scouring and inundation of the floodplain. A decrease in rainfall intensity that has accompanied the decrease in rainfall amounts in south-west Western Australia has already greatly reduced flood flows. A study in the northern Jarrah forest (Aquatic Research Laboratory, 2009) has shown that there has been historical changes in macroinvertebrate composition since 1984 and that these changes are likely reflecting transition from perennial to seasonal flows. Continued monitoring of reference sites is critical in order to separate effects of climate change from that of forest activities.

Project implementation, expenditure and reporting.

Implementation of stream biodiversity monitoring by the Department as part of the Forest Management Plan 2004-2013 is based on a project proposal dated 13 December 2005. The project proposal described the project scope and approach, expected outcomes and budget allocations for the initial few years (See Appendix 1 for Project Plan).

Due to several changes in personnel the project has consequently had delays in sample processing, data collection and analysis. In 2007 there was a complete change in team membership due to staff leaving the Department. A new team was appointed and in 2008 there was again a change in team members. Time commitments also changed slightly with changes in the team and are shown below.

Changes in Team membership and time commitments.

	Team Membership		Time commitments (FTE)
2005-2007	Principal Research Scientist Technical Officer 1 Technical officer 2	Stuart Halse Ben Smith Harley Baron	5% 60% 10%
2007-	Senior Research Scientist Technical Officer 1 Technical Officer 2	Adrian Pinder Karen Sutcliffe various	6% 50% 20%
2008-present	Senior Research Scientist Research Scientist Technical officer	Adrian Pinder Melita Pennifold Anna Leung	6% 70% 10-20%

In 2009 additional funding was requested to employ a technical officer over a longer timeframe to bring the project up to date, which has now been achieved. Budget allocations for each year were;

2005/6	$70,000
2006/7	$70,000
2007/8	$70,000
2008/9	$88,000

Two previous progress reports have being published; Smith and Halse (2006) and Smith *et al*. (2007), which summarised data from the first and second years of sampling.

METHODS

Site selection

The first round of monitoring was completed between August and October 2005, during which time 46 sites were sampled. The strategy behind the selection of those sites is outlined below and most sites are detailed in Smith and Halse (2005).

The initial basis for site selection was to examine sites previously sampled during the 1994-1999 AUSRIVAS program, for which some existing data were available. Only sites where discharge was less than 100,000 ML per annum were included. However, the program required a set of sites that are representative of forest conditions and a series of other selection criteria were imposed. These included that about 75% of sites should be in Jarrah forest, 25% in Karri; about 60% of sites should be in areas subject to logging and 40% in unlogged areas; sites should be spread across the forested area; a small number of sites should examine the impact of dams; a small number of sites should be located in areas that experienced wildfire last summer (i.e. 2004) so that the impact of intense burns could be examined; a small number of sites should be in areas to be logged the first or second year of sampling (i.e. 2005 or 2006) so that the impact of logging could be examined. In order to fulfil the above criteria, it was necessary to include a number of sites not sampled during AUSRIVAS (Smith and Halse, 2006).

Four additional sites were sampled in 2006; two downstream of Canning Reservoir (SWA34 and SWA35) plus two tributaries of the Blackwood River overlying the Yarragadee aquifer (BLA06 and BLA43). The latter were included to provide information on the potential future impacts of water extraction from the Yarragadee aquifer. BLA43 is on Milyeannup Brook, one of the perennial freshwater streams receiving discharge water from the Yarragadee aquifer. BLA06 is also a perennial stream (St John’s Brook) which is influenced by water from the Leederville aquifer and is situated in an area where it has a reasonable connection with the Yarragadee. It was intended that another Yarragadee influenced site, on Poison Gully, would be included in 2006 but this stream was dry at the time of sampling. The site on Poison Gully (BLA56) was included in the 2008 round of sampling and together with BLA54, these sites will provide some useful pre-extraction data. Figure 1 shows the location of all 51 sites now included in the program.

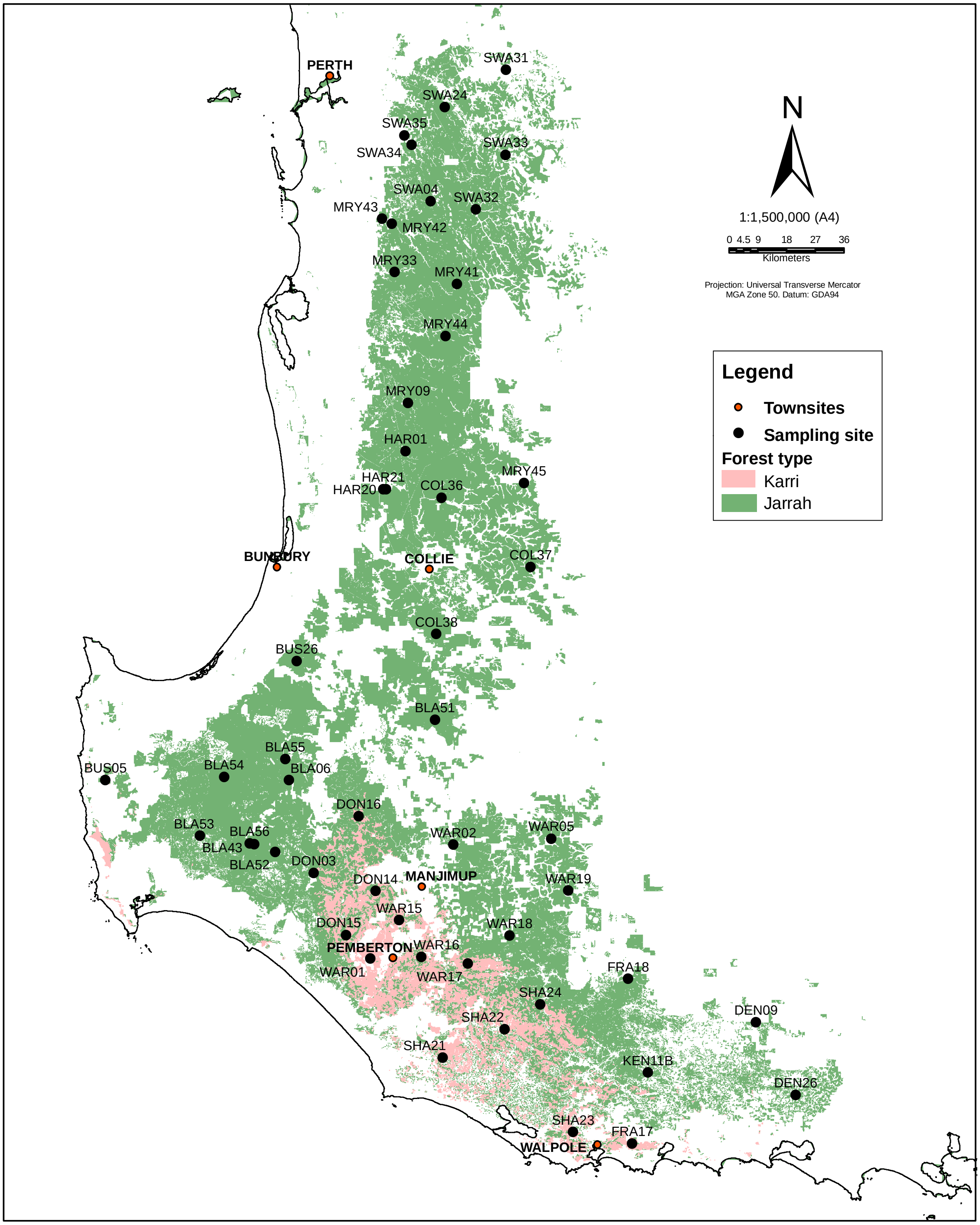


Figure 1. Site locations and forest areas.

Water Chemistry

Water chemistry was monitored to assess river condition and to identify whether forestry activities have resulted in changes in water quality. The physico-chemical variables measured at each site were: pH, temperature (°C), conductivity ($\mu S.cm^{-1}$), dissolved oxygen (% and ppM) and maximum and minimum flow along the reach sampled ($cm.sec^{-1}$). Two water samples were taken from each site; a 250 mL unfiltered sample and a 125 mL filtered sample that was frozen immediately after filtration. These samples were analysed by the Chemistry Centre of WA for alkalinity (acid neutralising power of equivalent $CaCO_3$; $mg.L^{-1}$), colour (TCU), NH_3 ($mg.L^{-1}$), NO_3 ($mg.L^{-1}$), total N ($mg.L^{-1}$), soluble reactive P ($mg.L^{-1}$), total P ($mg.L^{-1}$) and turbidity (NTU).

Other habitat variables

At each sampling site additional data were collected to describe the habitat and surrounding area.
Habitats present within the reach area sampled - percentage cover for each habitat (channel, macrophytes, riffle, and rock pools).
Mineral substrate – visual estimate of the percentage of the riverbed covered by each category (bedrock, sand etc.)
Habitat surface area - visual estimate of the percentage areal cover of each category and its density [e.g. algae may cover 10% of substrate very densely (5) or sparsely (1)].
Depth - this is the average depth where the macroinvertebrate sample was collected.
Flow - both maximum and minimum flow were measured with a flow meter (Hydrological Services, model OSS PC1).
Taxa collected - after picking invertebrates, all groups collected were recorded (as best can be identified in the field) and their 'log' abundance in the whole sample was estimated.
Site photographs – photographs of the reach sampled and surrounding areas, especially if a disturbance had occurred near the sampling site.
General comments – any additional comments about the site (e.g. any recent fire or logging disturbances within the catchment area).

Invertebrates

Invertebrates were sampled primarily from channel habitat, which generally consists of shallow areas of the stream channel without aquatic vegetation. This follows the protocol used for the AUSRIVAS model, however if large areas of aquatic vegetation were present at a site, some of the vegetated area was sampled to ensure the biodiversity at the site was represented. Invertebrates were collected with a pond net with mesh size 250µm. The sample was then washed, elutriated and sub-sampled using a box sub-sampler. Invertebrates were live-picked from the sample until 200 animals had been randomly encountered. All sampled invertebrates were identified to family level, except for the insect orders Ephemeroptera, Plecoptera, Trichoptera, Hemiptera, Coleoptera, Odonata and the dipteran family Chironomidae which were identified to species level. These groups are either species-rich and/or known to be sensitive to physical and chemical habitat change. These groups are also amenable to species identification because keys exist. Family level identifications were used in AUSRIVAS models and the species data were used to examine biodiversity trends in more detail. Overall, methodology followed that of Halse *et al.* (2001).

Table 1 explains all the biodiversity measures calculated for each site.

Table 1. Explanation of the different measures of biodiversity used in this study.

Biodiversity Measure	Explanation
Species Richness	Total number of taxa, according to the lowest level they were identified to (species-level for Ephemeroptera, Plecoptera, Trichoptera, Hemiptera, Coleoptera, Odonata and Chironomidae and family-level for all other groups). Note that all earthworms were grouped into one "family", and all trombidioid and oribatid mites were counted as one "family".
Chironomid Richness	Number of species from within the family Chironomidae.
EPT Richness	Number of species from within Ephemeroptera, Plecoptera and Trichoptera.
Family Richness	Total number of families. Note that all earthworms were grouped into one "family", all trombidioid and oribatid mites were counted as one "family", and chironomid sub-families were treated as separate "families".
O/E Family Score	Number of invertebrate families observed (O) divided by the number of invertebrate families expected if the stream were in pristine condition (E). Calculated by the AUSRIVAS model.
O/E SIGNAL score	Observed SIGNAL score (O) for a site divided by the expected SIGNAL score (E). Calculated by the AUSRIVAS model.

In the AUSRIVAS models invertebrates used are identified to family level with the exception of Oligochaeta (Class), Acarina (Order), Collembola (Order), Turbellaria (Order), and Chironomidae (sub-family). The AUSRIVAS model only considers taxa that were calculated to have a probability of 50% or greater of occurring at a test site. The model used for this project is for Western Australia (spring sampling, channel habitat) based on stream discharge category, maximum flow, latitude and longitude. The O/E family score represents the number of invertebrate taxa observed (O) divided by the number of invertebrate taxa expected if the stream were in pristine condition (E). These O/E family scores were then allocated to bandings based on the 10th percentiles of mean O/E values recorded during model development (Table 2).

Table 2. O/E Scores and their corresponding bandings, as used by Halse *et al* (2001b).

O/E Score	Band	Ecological Significance
>1.15	X	Enriched (slightly disturbed or ecological hotspot)
0.85 – 1.15	A	Undisturbed
0.55 – 0.84	B	Significantly impaired
0.25 – 0.54	C	Severely impaired
0.00 – 0.24	D	Extremely impaired

In addition to calculating the expected number of taxa at a test site, AUSRIVAS also calculates the expected SIGNAL (Stream Invertebrate Grade Number Average Level) score for a site. Calculation for the SIGNAL scores uses SIGNAL grades (Chessman, 1995), a system that assigns a value to each invertebrate family based on sensitivity to pollution. A grade of 10 represents high sensitivity to pollution, while a grade of 1 represents high tolerance to pollution.

Determination of disturbance categories and areas.

A geographic information system (ArcGIS, ESRI) was used to determine and measure the area of the catchments affected by timber harvesting, prescribed burning or unplanned bushfire. GIS data on fire and harvest areas were provided by the Fire Management Services (FMS) and the Forest Management Branch (FMB) within the Department of Environment and Conservation. Data were clipped to the catchment area upstream of the sampling location and used to calculate the area (ha) of disturbance ("Fire" or "Logging") which had occurred in the catchment area. Categories included "Fire" for areas burned, "Logged" for areas harvested, "F+L" for areas both burned and harvested, 'Nil', for sites where no disturbance had been recorded for the previous 12 months in the catchment or observed at the time of sampling, 'Dam', for sites located immediately downstream of a dam wall and "reset" for the sites situated downstream of the "Dam" sites after several tributaries had entered the river.

Fire data from FMS is reported in "fire seasons" from July to June inclusive. As sampling for this project occurs in spring fire data is allocated from the previous fire season records. For example; a sample taken in spring 2005 will be allocated the fire data from the 2004/2005 season. No fires have been reported as "winter" since 2004 in the FMB data set suggesting minimal fire activity occurs between June and the sampling occasion. Recent fire activity at a site was recorded while in the field, so any fire disturbance occurring between end of June and the sampling time should be identified in the dataset.

Logging data from FMB is reported in calendar years. Logging data for a sampling occasion is allocated the previous year's logging data For example; a sample taken in spring 2005 will be allocated the 2004 harvest data. This may mean that harvest activities that occur from the beginning of the year which would impact the site may not be included. It is noted at the sampling occasion whether logging activity has occurred at the site, however logging further away in the upper catchment area may not be detected.

Calculation of disturbance areas within the catchment have been measured over three time periods:
1) Previous 1 year; areas burned or logged for previous year only (i.e. 2008 samples are allocated 2007/2008 season for fires and 2007 for logging),
2) Previous five years; the accumulation of all areas burned or logged over five years (i.e. 2008 samples are allocated fire data from 2003/2004 season to 2007/2008 season and logging from 2003 to 2007)
3) Previous ten years; the accumulation of all areas burned or logged over ten years (i.e. 2008 samples are allocated fire data from 1998/1999 season to 2007/2008 season and logging from 1998 to 2007)

Catchment characteristics

Additional information about the catchment areas was provided from Forest Management Branch or calculated from GIS data. Site locations were provided to the FMB and using the Forest Management Information system (FMIS) data was provided on tenures, dieback, harvest activities (intensity and frequency) and fuel age groups within the catchment area. Discharge categories were calculated using catchment area, percentage of area cleared within the catchment and rainfall data. The percentage of cleared area was determined by clipping the DEC remnant vegetation dataset to the catchment area. The average annual rainfall for sites was calculated by overlaying rainfall isohyets (rounded to the nearest 25mm) onto site locations.

Data Management

All data were entered into an Access database maintained by the wetland fauna group within DEC's Science Division. The biological data will be made available on the DEC/WA Museum's NatureMap online database as time and resources permit.

Data Analysis

Species richness within a sample was calculated from the whole dataset (i.e. including juveniles where there were no adults of the taxon present). For multivariate analyses partly identified specimens (juveniles and females of some groups) were removed where they would have tended to inflate similarity between samples.

Assumptions of normality and homogeneity of variance were generally met for biodiversity measures but some environmental variables (alkalinity, colour, NH3, NO3, Total N, turbidity and conductivity) were transformed (log10) to meet assumptions. It should be noted that all soluble reactive phosphorus (SRP) concentrations were $0.05mg.L^{-1}$ or less and most measurements were below detectable concentrations ($<0.01mg.L^{-1}$). Total P was only found above detectable levels ($>0.01mg.L^{-1}$) at 6 sites. Minimum flow was mostly zero. Therefore, these data were only assessed visually. Correlations between environmental variables and a) biodiversity measures and b) catchment history variables (amount of burning and/or logging over a given time period) were assessed using Spearman's rank co-efficient (alpha 0.05).

Differences in biodiversity measures (species richness, chironomid richness, EPT richness, family richness, O/E scores) between forest types (Jarrah and Karri) and dieback presence were analysed using repeated measures ANOVAs', with site being the within repeated measure. Since not all sites were sampled for invertebrates each year only those sites with a complete set of data (that is sampled in 2005, 2006, 2007 and 2008) were used in the analysis (n=33). The repeated measures ANOVA analysis does not take into account the disturbances occurring within the catchment areas, as there would have been insufficient replication to carry out this analysis.

Repeated measures ANOVA's could not be used to test for differences in the biodiversity measures between disturbance categories (fire and/or logging) as the disturbance category changes annually at each site. Therefore, ANOVA's were used to test for differences in the biodiversity measures between the disturbance categories ("F", "F+L", "L" and "nil") for each year separately (2005, 2006, 2007 and 2008). Where there was a significant main effect, Tukey's HSD multiple range tests were applied *a posterior* to detect treatment differences in the biodiversity measures. Separate ANOVA's were performed using 1) fire ("F" and "F+L") and "nil" and 2) logging ("L" and "F+L") and "nil" to examine differences in biodiversity measures in burned or logged sites.

The relationship between the proportion of the catchment disturbed (% area) and biodiversity measures was analyzed using correlations. Data were analyzed by looking for associations between change in response variables between sampling times and values of the catchment history variables during the intervening period. This eliminated the statistical problem of non-independence between samples from the same site. This approach was used to look for relationships between the amount of change in the biodiversity measures between samples collected one year apart and four years apart and catchment history (amount of burning and/or logging) during the intervening periods. If burning or logging in the catchment causes changes in the biodiversity measures, then there should be a correlation between proportion of catchment disturbed and the degree of change in biodiversity measures. These analyses were performed for two interval classes: all consecutive years (2005-2006, 2006-2007 and 2007-2008) and across the four years of sampling (change between 2005 and 2008). For the analyses of all consecutive years, catchment history was the proportion of each catchment burned in the intervening year. For the four year analysis, catchment history was the sum of burning and logging in the intervening three years.

The effect of wildfires (sites DEN26 and SWA24) were explored by comparing biodiversity measures at these sites to the average values of Jarrah sites not subject to harvesting or prescribed burns (undisturbed).

The effect of dams (sites HAR20, MRY42 and SWA34) were explored by comparing the biodiversity measures at these sites to the reset sites (HAR21, MRY43 and SWA35 respectively) and average values of undisturbed Jarrah sites. Biodiversity measures for streams affected by dams were compared by t-test (alpha 0.05), using groupings ‘dam versus undisturbed’, ‘dam versus reset’ and ‘reset versus undisturbed’.

All of the above analyses were performed in Statistica 7.1 (Statsoft Inc., 2005).

Analyses of community composition

Four types of analysis were used to assess relationships between community composition and catchment history, as follows:

1. *Non-metric multidimensional scaling (nMDS)*. nMDS ordinations in Primer (v6.1.11 with Permanova+ v1.0.1, Primer-E Ltd 2008) was used to visually assess patterns in community composition among samples. The Bray-Curtis similarity measure and 25 restarts were used for nMDS analyses.

2. *Permanova analysis*. Permanova analyses in Primer were used to test for differences in community composition between samples from different forest types and from catchments with or without logging or burning. This test is an equivalent of traditional analysis of variance for multivariate response data (whole invertebrate communities). Where there were insufficient samples (<4) from unburned/unlogged catchments, a contrast was made between lower versus higher proportions of catchment affected. The combination of repeated measures and changing treatment between years meant that permanova analyses had to be performed for each year separately. For these analyses an alpha value of 0.05 was used.

3. *Distance-based linear modeling (DistLM).* DistLM explores relationships between environmental variables and community composition: the latter represented by position of samples along axes from a principal coordinates analysis (PCoA, an unconstrained metric ordination technique). The Bray-Curtis index of similarity was used for the PCoA. Although DistLM analyses do not assume normally distributed explanatory variables, variables should not be heavily skewed or contain strong outliers, so transformations were applied as appropriate.

However, the %1yrLog and %1yrBurn variables had a large proportion of their values = zero, so right skew could not be entirely alleviated by transformation. For these variables, null hypotheses accepted or rejected with marginal p values should be viewed with caution.

4. *Regression of community composition change and catchment history*. The DistLM analyses were performed separately for each year because of the repeated measures issue in the study design. One way of analyzing data across years is to look for associations between change in response variables between sampling times and values for the independent data during the intervening period. This eliminates the problem of non-independence between samples from the same site. This approach was used to look for relationships between the amount of change in invertebrate communities over one year and four year periods and catchment history (amount of burning and/or logging) during the intervening periods. If burning or logging in the catchment causes changes in community composition, then there should be a correlation between proportion of catchment affected and the degree of change in community composition. The Bray-Curtis index of community similarity was used as a measure of community change between samples collected from the same site at different times, so lower values of the index indicate a larger change in composition. These analyses were performed for two interval classes: all consecutive years (2005-2006, 2006-2007 and 2007-2008) and across the four years of sampling (change between 2005 and 2008). For the analyses of all consecutive years, catchment history was the proportion of each catchment burned in the intervening year. For the four year analysis, catchment history was the sum of burning and logging in the intervening three years. These analyses are presented graphically and two types of correlation were performed: 1) Spearman Rank correlation of untransformed catchment history variables and 2) Linear regression of $\log_{10}$ transformed catchment history variables.

Community analyses were performed separately for 1) all taxa identified to family, genus or species level and 2) species level identifications only (insects). Taxa identified to order level or higher were excluded.

RESULTS AND DISCUSSION

Invertebrates samples

Monitoring occurred at 51 sites located in the south-west forest (Swan, South West and Warren regions) between 2005 and 2008. Over the monitoring period several sites were not sampled every year for varying reasons. Some sites were dry or had only small puddles as a result of low winter rainfall, especially in 2006 when 10 sites were dry. Several sites were not accessible due to either fallen trees or roads being flooded and site HAR20 (Stirling Dam 1) was highly disturbed due to the progress of Dam works between 2007 and 2009. Table 3 shows the sampling occurrences for each site. In total 177 invertebrate samples were taken over the 4 years of monitoring. Table 4 presents the forest type, catchment area for the stream above the sampling location, average annual rainfall for the area and tenure at each sampling location.

Table 3. Sampling occurrence for 51 monitoring sites.

Site	2005	2006	2007	2008	Comments
BLA06	NS	S	S	S	site added 2006
BLA43	NS	S	S	S	site added 2006
BLA51	S	S	S	S	
BLA52	S	Dry	S	S	
BLA53	S	S	S	S	
BLA54	S	S	S	S	
BLA55	S	S	S	S	
BLA56	NS	NS	NS	S	site added 2008
BUS05	S	S	S	S	
BUS26	S	Dry	S	S	
COL36	S	S	S	S	
COL37	S	Dry	Dry	WO	
COL38	S	S	S	S	
DEN09	S	Dry	Dry	S	
DEN26	S	S	S	S	
DON03	S	S	S	S	
DON14	S	S	S	S	
DON15	S	S	S	S	
DON16	S	S	S	S	
FRA17	S	S	S	S	
FRA18	S	Dry	S	S	
HAR01	S	S	S	S	
HAR20	S	S	S	S	Dams works 2007 (major disturbance), 2008,
HAR21	S	S	S	NS	2008 no access
KEN11	S	S	NS	S	2007 dry? could not locate site
MRY09	S	S	S	S	
MRY33	S	S	S	S	
MRY41	S	S	S	S	
MRY42	S	S	S	S	
MRY43	S	S	S	S	
MRY44	S	S	S	S	
MRY45	S	Dry	WO	WO	
SHA21	S	S	S	S	
SHA22	S	S	S	S	
SHA23	S	S	S	NS	2008 no access
SHA24	S	S	S	S	
SWA04	S	S	S	S	
SWA24	S	S	S	S	
SWA31	S	S	S	S	
SWA32	S	Dry	S	S	
SWA33	S	Dry	S	S	
SWA34	NS	S	S	S	site added 2006
SWA35	NS	S	S	S	site added 2006
WAR01	S	S	S	S	
WAR02	S	S	S	S	
WAR05	S	S	S	S	
WAR15	S	S	S	S	
WAR16	S	S	S	S	
WAR17	S	Dry	S	S	
WAR18	S	S	S	S	
WAR19	S	Dry	Dry	Dry	
Total of sites sampled	**46**	**40**	**46**	**48**	

S – site sampled; NS – no sample; Dry – site dry; WO - water sample only, no invertebrates collected as only a small puddle present.

Table 4. Characteristics for each site sampled. Discharge category is the mean annual discharge in megalitres per annum (1=10-100ML/a; 2=100-1000; 3= 1000-10,000; 4= 10^4-10^5; 5= 10^5-10^6)

Region	Site Code	Site Name	Tenure at sampling point	Forest Type	Catchment Area (Ha)	Average Annual Rainfall (mm)	Discharge Category
Southwest	BLA06	ST JOHN BROOK	Conservation park	Jarrah	55,244 *	975	4
	BLA43	BLACKWOOD RD MILY	State forest	Jarrah	10,011	1000	3
	BLA51	BALINGUP BROOK	State forest	Jarrah	6,433	825	3
	BLA52	DARRADUP ROAD	National park	Jarrah	401	1025	2
	BLA53	BLACKWOOD RD WEST	State forest	Jarrah	1,525	1050	3
	BLA54	ROSA BK LAWSON RD	State forest	Jarrah	2,409	975	3
	BLA55	ROCKY GULLY	Other crown reserves/freehold	Jarrah	4,741	975	3
	BLA56	POISON GULLY	State forest	Jarrah	4,731	975	3
	BUS05	BRAMLEY BROOK	National park	Jarrah	4,689	1100	3
	BUS26	CAMP GULLY ROAD	State forest	Jarrah	550	950	2
	COL36	TREES ROAD	State forest	Jarrah	425	975	2
	COL37	ERNIE ROAD	State forest	Jarrah	420	675	2
	COL38	ROSEWOOD ROAD	State forest	Jarrah	81	850	1
	DEN09	UPPER DENMARK	National park	Jarrah	3,832	750	3
	DON16	GOLD GULLY ROAD	State forest	Karri	3,307	1100	3
	HAR01	NEAR HOFFMAN'S MILL	State forest	Jarrah	2,802	1200	3
	HAR20	STIRLING DAM 1	State forest	Jarrah	dam	1200	4
	HAR21	STIRLING DAM 2	Other land ;adjacent to other Crown reserve; 450m from State forest	Jarrah	185	1200	4
	MRY45	OLD STOCKYARD BK	National park	Jarrah	2,465	700	2
Swan	MRY09	BIG BROOK	Conservation park	Jarrah	1,697	1200	3
	MRY33	FINLAY BROOK NORTH RD	State forest	Jarrah	1,756	1300	3
	MRY41	O'NEILL BROOK	State forest	Jarrah	3,510	975	3
	MRY42	SERPENTINE DAM 1	Other crown reserves/freehold	Jarrah	dam	1250	5
	MRY43	SERPENTINE DAM 2	Other crown reserves/freehold	Jarrah	6,783	1100	4
	MRY44	SCENIC RD	State forest	Jarrah	2,574	1000	3
	SWA04	WUNGONG BROOK	State forest	Jarrah	1,395	1150	3
	SWA24	LITTLE DARKIN RIVER	State forest	Jarrah	2,984	950	3
	SWA31	HELENA RIVER	State forest	Jarrah	24,566	675	3
	SWA32	CANNING R, RANDALL RD	State forest	Jarrah	28,331	875	4
	SWA33	WILLIES RD	Conservation park	Jarrah	14,110	725	3
	SWA34	CANNING RESERVOIR 1	Other land; 300m from national park; 1km from State forest	Jarrah	dam	1250	5
	SWA35	CANNING RESERVOIR 2	5 (1) (g), (h) reserve - conservation	Jarrah	7,555	1275	5
Warren	DEN26	QUICKUP FIRE	National park	Jarrah	718	850	2
	DON03	BARLEE BK DICKSON RD	National park	Jarrah	15,681	1150	4
	DON14	RECORD BK	State forest	Karri	1,400	1225	3
	DON15	STIRLING TRACK	National park	Karri	2,420	1400	3
	FRA17	BOXHALL CREEK	National park	Karri	221	1250	2
	FRA18	CHITELUP RD NTH	National park	Jarrah	2,347	800	2
	KEN11	NILE CREEK	National park	Jarrah	2,867	1125	3
	SHA21	UNA BK	State forest	Karri	768	1400	3
	SHA22	FISH CK	National park	Karri	2,242	1275	3
	SHA23	COMPASS ROAD	National park	Karri	150	1400	2
	SHA24	ARTHUR RD	State forest	Karri	1,768	1000	3
	WAR01	TRACK OFF EAST BREAK RD	State forest	Karri	1,130	1400	3
	WAR02	WHIM LANDING RD	State forest	Jarrah	2,707	900	3
	WAR05	EAST BOUNDARY BLOCK 1661	Nature reserve	Jarrah	5,793	725	3
	WAR15	CHANNYBEARUP RD	State forest	Karri	9,203	1175	4
	WAR16	BANNISTER RD	State forest	Karri	498	1150	2
	WAR17	SIX MILE BK	State forest	Karri	3,441	1050	3
	WAR18	MUIRS HWY	Other land adjacent to State forest	Jarrah	37	800	3
	WAR19	DE LANDGRAFFT RD	Nature reserve	Jarrah	9	675	2

* BLA06 (St John Brook) has a large stream network upstream from the sampling point and therefore has a large catchment area.

Sampling revealed the presence of 311 taxa (lowest identified level) in 84 families (an additional 10 orders not identified to family) (Table 5). The most diverse group was the family Chironomidae from which 84 taxa were identified. Chironomidae were collected at every sampling occasion, with sub-families Chironominae, Tanypodinae and Orthocladinae, collected at 99%, 88% and 85% of the sampling occasions retrospectively. The families Leptoceridae, Perthidae and Dytisicidae were also collected in over 70% of samples (75%, 72% and 71% retrospectively). Other taxa that occurred in over 50% of samples were; *Paramerina levidensis* (68%), Ceratopogonidae (68%), Simulidae (61%), Naididae (54%), Tipulidae (53%) and *Cricotopus annuliventris* (51%).

No exotic species were collected. A taxon of scientific interest is the paramelitid amphipods. These are primarily groundwater fauna (stygofauna) and they were recorded from 24 samples collected from 12 sites; SHA24 (2005, 2006), MRY43 (2006, 2007, 2008), KEN11 (2005, 2006), FRA17 (2005), FRA18 (2007), COL38 (2005, 2006, 2007), COL36 (2006), BLA55 (2005, 2006), BLA54 (2005, 2006, 2007), BLA53 (2005, 2006), BLA51 (2006), BLA43 (2006). Their presence suggests ground and surface water intersect at these sites. The conservation significance of these amphipods is difficult to determine owing to the limited information on their biology and distribution. A study examining the Wungong catchment area (Aquatic Research Laboratory, 2009) recorded Paramelitidae from most sites in that area.

The conservation significance of many of the taxa collected is difficult to determine owing to the limited information on their biology and distribution. Thirty eight aquatic arthropods are listed as threatened, vunerable or endangered in the International Union for Conservation of Nature (IUCN) red list (2009), five of which occur in Western Australia. Only two of these are found in the south-west; an odonate: *Argiolestes pusillissimus* and a copepod; *Hemiboeckella powellensis*. It is indeterminate whether these species were collected during this survey as the copepods were only identified to the family level and the larvae in the *Argiolestes pusillus* complex (comprised of three species) are unable to be distinguished from each other. However, *Argiolestes* specimens were found within the presumed ranges for each of the three species within the complex (Figure 2). Sutcliffe (2003) looked at the conservation status of aquatic insects in south-western Australia from three orders; Odonata, Plecoptera and Tricoptera, comparing data to the IUCN red list (2000) criteria. She considered 37% of the taxa were threatened and the high rainfall forested region was found to be important for a large number of species, including the majority of those found to be rare and/or restricted. Trayler *et al* (1996) also supported this suggestion finding approximately 17% of the invertebrate taxa in the Warren region to be locally restricted. Several specimens collected in this project (e.g. *Kaninga sp*.) have very few collection records and so their conservation status is not known, but seems to have a very limited distribution. For example *Kaninga sp.* has fewer than ten collection records and has only been found in small to medium sized Karri forest streams within 30km radius of Pemberton. During this monitoring project it was only collected several times from one site (DON15).

Knowledge about the aquatic fauna in the south-west forest area is low and therefore minimal information is available to inform management decisions. While this project is not taxonomically comprehensive, it does provide a large and consistent dataset on the region’s aquatic invertebrate fauna, useful for analysing spatial patterns in the distribution of forest stream invertebrates. This could contribute to regional conservation planning and assessments of the conservation status for individual species.

Table 5: Overall taxonomic composition of all live-picked samples.

Class	Order	Family	Lowest identified taxon level
Nematoda	-	-	Nematoda
Nemertini	-	-	Nemertini
Oligochaeta	-	-	Oligochaeta
	Opisthopora	-	Opisthopora
	Tubificida	Enchytraeidae	Enchytraeidae
			Fridericia sp.
		Naididae	*Ainudrilus nharna*
			Naididae
		Phreodrilidae	*Insulodrilus bifidus*
			Phreodrilidae
			Phreodrilidae WA37 (SFM)
Turbellaria	-	-	Turbellaria
	Temnocephalidea	-	Temnocephalidea
	Tricladida	Dugesiidae	Dugesiidae
Hirudinea	-	-	Hirudinea sp.
Bivalvia	Veneroida	Sphaeriidae	Sphaeriidae
Gastropoda	Basommatophora	Ancylidae	Ancylidae
		Lymnaeidae	Lymnaeidae
		Physidae	Physidae
		Planorbidae	Planorbidae
Arachnida	Acariformes	-	Oribatida
		-	Trombidioidea
		Arrenuridae	Arrenuridae
		Arrenuridae	Arrenurus sp.
		Aturidae	Aturidae
		Eylaidae	Eylaidae
		Halacaridae	Halacaridae
		Hydrachnidae	Hydrachnidae
		Hydrodromidae	Hydrodromidae
		Hydryphantidae	Hydryphantidae
		Limnesiidae	Limnesiidae
		Oxidae	Oxidae
		Pionidae	Pionidae
		Unionicolidae	Unionicolidae
	Parasitiformes	-	Mesostigmata
Crustacea	Amphipoda	Ceinidae	Ceinidae
		Eusiridae	Eusiridae
		Paramelitidae	Paramelitidae
		Perthidae	Perthiidae
	Cladocera	-	Cladocera (Unident.)
	Copepoda	-	Calanoida
		-	Copepoda
		-	Cyclopoida
		-	Harpacticoida sp
	Decapoda	Palaemonidae	Palaemonidae
		Parastacidae	Parastacidae
	Isopoda	Amphisopodidae	Amphisopodidae
		Hypsimetopodidae	Hypsimetopodidae
		Oniscidae	Oniscidae
		Phreatoicidae	Phreatoicidae
	Ostracoda	-	Ostracoda (Unident.)
Insecta	Coleoptera	Brentidae	Brentidae
		Carabidae	Carabidae
		Chrysomelidae	Chrysomelidae
		Curculionidae	Curculionidae
		Dytiscidae	*Allodessus bistrigatus*
			Allomatus nannup
			Antiporus femoralis
			Antiporus gilberti
			Bidessini
			Copelatus sp.
			Exocelina ater
			Hyderodes sp.
			Hyphydrus elegans
			Lancetes lanceolatus
			Liodessus dispar

Class	Order	Family	Lowest identified taxon level
Insecta	Coleoptera		*Liodessus inornatus*
			Megaporus solidus
			Necterosoma darwini
			Necterosoma penicillatus
			Necterosoma regulare
			Onychohydrus sp.
			Paroster couragei
			Platynectes aenescens
			Platynectes decempuntatus var polygrammus
			Platynectes sp.
			Rhantus suturalis
			Sternopriscus browni
			Sternopriscus marginatus
			Sternopriscus minimus
			Uvarus pictipes
		Gyrinidae	Gyrinidae
			Macrogyrus angustatus
			Macrogyrus australis
		Haliplidae	*Haliplus fuscatus*
			Haliplus gibbus
		Heteroceridae	Heteroceridae
		Hydraenidae	*Hydraena sp.*
			Ochthebius sp.
		Hydrochidae	*Hydrochus australis*
		Hydrophilidae	*Amphiops sp.*
			Berosus approximans
			Berosus discolor
			Berosus munitipennis
			Chaetarthria sp.
			Coelostoma fabricii
			Crenitis sp.
			Enochrus sp.
			Helochares sp.
			Hydrophilidae
			Limnoxenus sp.
			Limnoxenus zelandicus
			Paracymus pygmaeus
			Paracymus spenceri
		Scirtidae	*Scirtidae sp.*
		Staphylinidae	Staphylinidae
	Diptera	Athericidae	Athericidae
		Ceratopogonidae	Ceratopogonidae
			Dasyheleinae
		Chaoboridae	Chaoboridae
		Chironomidae	*Ablabesmyia notabilis*
			Aphroteniella filicornis
			Apsectrotanypus sp. 1 (SFM)
			Botryocladius bibulmun
			Botryocladius freemani
			Botryocladius petrophilus
			Chironomus aff. alternans (V24) (CB)
			Chironomus australis
			Chironomus occidentalis
			Chironomus sp.
			Chironomus sp. A
			Chironomus tepperi
			Cladopelma curtivalva
			Cladotanytarsus sp. A (SAP)
			Compterosmittia sp.
			Corynoneura sp. (V49) (SAP)
			Cricotopus annuliventris
			Cryptochironomus griseidorsum
			Demicryptochironomus sp.
			Dicrotendipes conjunctus
			Dicrotendipes jobetus
			Dicrotendipes sp.
			Dicrotendipes sp. A (V47) (SAP)
			Eukiefferiella sp.

Class	Order	Family	Lowest identified taxon level
Insecta	Diptera	Chironomidae	*Gymnometriocnemus sp. A (SAP)*
			Gymnometriocnemus sp. C (SFM)
			Harrisius sp. A (SAP)
			Harrisius sp. B (SFM)
			Kiefferulus intertinctus
			Kiefferulus martini
			Larsia albiceps
			Microchironomus sp. 1 (SFM)
			Orthoclad sp. 2 (SFM)
			Orthoclad sp. 3 (SFM)
			Orthoclad sp. 4 (SFM)
			Orthoclad sp. 5 (SFM)
			Orthocladiinae
			Orthocladiinae S03 sp. A (SAP)
			Orthocladiinae S03 sp. D (SAP)
			Orthocladiinae sp. P (SAP)
			Orthocladiinae 'woodminer' (SAP)
			Paraborniella tonnoiri
			Parachironomus sp.
			Paracladopelma M1 [SFM)
			Parakiefferiella sp. A (SAP)
			Parakiefferiella sp. C (SFM)
			Parakiefferiella? sp. B (SAP)
			Paralimnophyes pullulus
			Paramerina levidensis
			Paramerina sp.
			Paramerina sp.A (parva?) (SAP)
			Pentaneurini genus C sp. 1 (SFM)
			Pentaneurini genus SW1 (SFM)
			Polypedilum nr. convexum (SAP)
			Polypedilum sp.
			Polypedilum watsoni
			Procladius paludicola
			Procladius villosimanus
			Rheotanytarsus flabellatus
			Rheotanytarsus juliae
			Rheotanytarsus trivittatus
			Rheotanytarsus underwoodi
			Riethia V4
			Riethia V5
			Skusella/"V12 ex-WA" (Cranston)
			Stempellina sp. 1 (SFM)
			Stictocladius uniserialis
			Symbiocladius sp. 1 (SFM)
			Tanypodinae
			Tanypodinae genus nr. Apsectrotanypus sp. SW1
			Tanytarsus aff manleyensis
			Tanytarsus B1
			Tanytarsus fuscithorax/semibarbitarsus
			Tanytarsus 'K12' (PSW)
			Tanytarsus K5
			Tanytarsus manleyensis
			Tanytarsus nr K5
			Tanytarsus palmatus
			Tanytarsus sp.
			Tanytarsus sp. E (SAP)
			Tanytarsus sp. F (SAP)
			Tanytarsus sp. I (SAP)
			Thienemanniella sp. (V19) (SAP)
			Thienemannimyia sp. SW1 (SFM)
		Culicidae	Culicidae
		Dolichopodidae	Dolichopodidae
		Empididae	Empididae
		Ephydridae	Ephydridae
		Muscidae	Muscidae
		Psychodidae	Psychodidae
		Simuliidae	Simuliidae
		Stratiomyidae	Stratiomyidae

Class	Order	Family	Lowest identified taxon level
Insecta	Diptera	Tabanidae	Tabanidae
		Tipulidae	Tipulidae
	Ephemeroptera	Baetidae	*Baetid genus 1 sp. SW1 (SFM)*
			Cloeon sp.
			Cloeon sp. 2 (SFM)
			Offadens (ex genus 1) soror (ex WA sp. 1) (PSW)
		Caenidae	*Tasmanocoenis tillyardi*
		Leptophlebiidae	*Bibulmena kadjina*
			Kaniga sp. AV1
			Leptophlebiid genus S sp. AV1
			Neboissophlebia occidentalis
			Nousia sp. AV16
			Nyungara bunni
	Hemiptera	Corixidae	*Agraptocorixa parvipunctata*
			Agraptocorixa sp.
			Diaprepocoris barycephala
			Micronecta gracilis
			Micronecta robusta
			Sigara sp.
		Mesoveliidae	Mesoveliidae
		Notonectidae	*Anisops hackeri*
			Anisops thienemanni
		Ochteridae	*Ochterus occidentalis*
		Veliidae	*Microvelia (Austromicrovelia) australiensis*
			Microvelia (Pacificovelia) oceanica
			Microvelia sp.
			Veliidae
	Lepidoptera	-	Lepidoptera (non-pyralid)
		-	Lepidoptera (non-pyralid) sp. 3 (SAP)
		Pyralidae	Pyralidae
	Megaloptera	Corydalidae	*Archichauliodes sp.*
	Odonata	Aeshnidae	*Aeshna brevistyla*
			Aeshnidae
			Hemianax papuensis
		Austrocorduliidae	*Lathrocordulia metallica*
		Coenagrionidae	*Ischnura aurora aurora*
			Xanthagrion erythroneurum
		Gomphidae	*Austroepigomphus (Xerogomphus) gordoni*
			Austrogomphus (Zephyrogomphus) lateralis
			Hemigomphus armiger
			Zephyrogomphus lateralis
		Hemicorduliidae	*Hemicordulia australiae*
			Hemicordulia tau
			Procordulia affinis
		Lestidae	*Austrolestes analis*
		Libellulidae	*Diplacodes bipunctata*
			Nannophya occidentalis
			Orthetrum caledonicum
		Megapodagrionidae	*Archiargiolestes pusillus*
			Archiargiolestes sp.
			Megapodagrionidae
			Miniargiolestes minimus
		Oxygastridae	*Hesperocordulia berthoudi*
		Synthemistidae	*Archaeosynthemis occidentalis*
			Archaeosynthemis spiniger
			Austrosynthemis cyanitincta
		Telephlebiidae	*Austroaeschna anacantha*
	Plecoptera	Gripopterygidae	*Leptoperla australica*
			Newmanoperla exigua
			Riekoperla occidentalis
	Trichoptera	Atriplectididae	*Atriplectides dubius*
		Ecnomidae	*Ecnomina D group*
			Ecnomina E group sp. 4
			Ecnomina E group sp. 5
			Ecnomina E group sp. 7
			Ecnomina F group
			Ecnomina F group sp. 8 (SFM)
			Ecnomina F group sp. AV20 (SAP)

Class	Order	Family	Lowest identified taxon level
Insecta			*Ecnomus sp.*
			Ecnomus turgidus
		Hydrobiosidae	*Apsilochorema sp.*
			Apsilochorema urdalum
			Taschorema pallescens
		Hydropsychidae	*Cheumatopsyche sp. AV2 (SAP)*
			Diplectrona sp.
			Diplectrona sp. AV9 (SFM)
			Smicrophylax australis
		Hydroptilidae	*Acritoptila globosa*
			Acritoptila sp.
			Hellyethira litua
			Hellyethira malleoforma
	Trichoptera	Hydroptilidae	*Hellyethira sp.*
			Hydroptila losida
			Maydenoptila baynesi
			Maydenoptila sp.
			Oxyethira sp.
		Leptoceridae	*Condocerus aptus*
			Lectrides parilis
			Lectrides sp. AV1
			Leptoc Genus A sp. AV1
			Notalina nr. sp. AV14
			Notalina sp. AV14
			Notalina sp. AV15 (PSW)
			Notalina sp. AV16 (SFM)
			Notoperata sp. AV1 (SFM)
			Notoperata sp. AV4 (SFM)
			Notoperata tenax
			Oecetis sp.
			Triaenodes sp.
			Triplectides australicus
			Triplectides australis
			Triplectides sp.
			Triplectides sp. AV1 (SFM)
			Triplectides sp. AV21 (SFM)
		Philopotamidae	*Hydrobiosella michaelseni*
			Hydrobiosella sp.
			Hydrobiosella sp. AV16
		Philorheithridae	*Kosrheithrus boorarus*

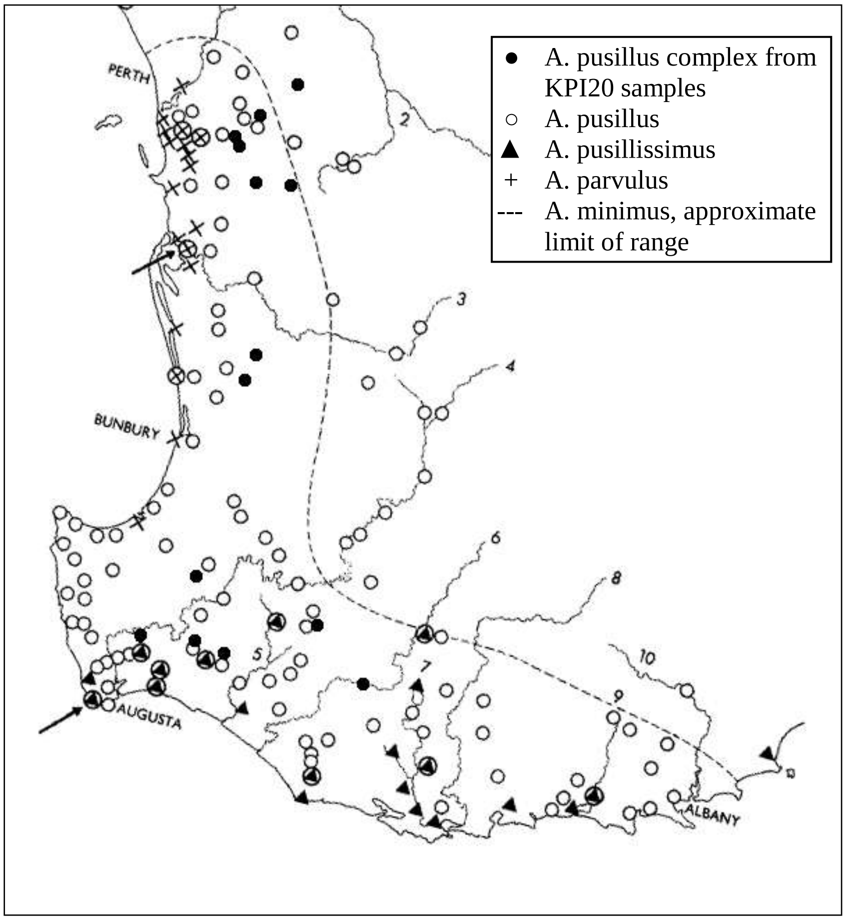


Figure 2. Distribution of the three species of the *Argiolestes pusillus* complex in Western Australia (from Watson, 1977). Concentric symbols indicate localities where species were found together, arrows mark sites where hybridization may have occurred. River systems: (1) Brockman; (2) Avon/Dale; (3) Murray/William; (4) Blackwood/Arthur; (5) Donnelly; (6) Warren/Tone); 7) Deep; (8) Frankland (9) Hay; (10) Kalgan.

Biodiversity measures

Table 6 shows the invertebrate biodiversity measures for each sample. The mean and standard deviation of each measure for each site is shown in Table 7.

Species richness was highest at HAR21 in 2005 (41) and lowest at SWA34 (6) in 2007. Across the four years of sampling, the highest mean species richness was recorded at MRY09 (36±4) and the largest standard deviation was calculated for HAR21 (28±13, minimum 15 and maximum 41).

The number of EPT (Ephemeroptera, Plecoptera, Tricoptera) taxa was highest at DON15 (15) in 2005 and no EPTs were recorded in 15 samples. The highest mean (12±2) was recorded at DON15 and MRY09 and the largest standard deviation was calculated for BLA52 (3±4, minimum 0 and maximum 8).

The number of chironomid taxa was highest at DON15 (19) in 2005 and the lowest at SWA34 (2) in 2006. The highest mean was recorded at MRY42 (12±1) and the largest variation was calculated for DON15 (9±6, minimum 6 and maximum 19).

Family richness was highest at HAR21 (26) in 2005 and lowest at WAR05 (5) in 2007. The highest mean was recorded at BLA06 (21±2) and the largest variation was calculated for HAR21 (18±8, minimum 11 and maximum 26).

Greatest variation in biodiversity measures was observed in HAR21, DON15 and BLA52 (Figure 3.). Timing of disturbance events (such as fire, logging, site dry) within each catchment since the year 2000 is shown.

HAR 21 is the reset site for Stirling Dam. This site is discussed in more detail below in the AUSRIVAS scores and banding section and later in the report in the Dams section.

BLA52 is a Jarrah site which has had two fires in the catchment since 2000; in the fire seasons 2002/2003 which burned 12% of the catchment and 2003/2004 which burned 68% of the catchment. This site was also dry in 2006. The largest variation in biodiversity measures occurred between 2005 and 2007, before and after a year (2006) in which the site was dry in spring 2007. Ten sites were dry when visited in 2006 and many had decreased numbers of invertebrates in 2007. This decrease in the year after being dry may be due to the very short hydro-period in 2006 and the invertebrates either not surviving or maturing to breed in 2006 and therefore there was lower recruitment in 2007. This may be especially the case for EPTs as they prefer flowing water.

DON15 is a Karri site which has had three fires in the catchment since 2000; 2000/2001, 2004/2005 and 2005/2006 fire seasons. The percentage of the catchment burned was 2%, 85% and 10% respectively. Even though the total number of species and families did not vary significantly between 2005 and 2008 (35±3 and 20±2 respectively) the composition of the community did change; with chironomid species richness changing from 19 to 6 to 4 to 8 and EPT richness changing from 9 to 12 to 12 to 15 from 2005 to 2008 respectively. The higher chironomid richness and lower EPT richness in 2005 compared to subsequent years may have been caused by effects of the large burn in 2004/5. High levels of sedimentation and organic matter were measured at this site in 2005 which could be due to the large fire disturbance in the summer of 2004, although lack of pre-2005 data prevents comparisons to pre-fire conditions. It is interesting to note that in 2006 water chemistry readings for alkalinity, colour, NH_3, Total N, turbidity and pH were high at this site compared to the other years. Some of these readings were the highest recorded for the project to date; pH (7.64) was the highest record, Total P (30µg.L^{-1}) was the 4^{th} highest and Total N (1.6mg.L^{-1}) and turbidity (24NTU) were the 5^{th} highest records. The increase in water chemistry in 2006 may explain the decrease in species, chironomid and family richness at the site for this year. The only disturbance recorded prior to 2006 sampling was a fire (approximately 7km upstream from the sampling point) but whether these increased levels are a result of the burn is uncertain.

Table 6. Biodiversity measure for each site for each year sampled. Shading denotes the highest or lowest measure for each measure.

SITE	2005							2006							2007							2008						
	Species rich	Chiron rich	EPT rich	Family rich	O/E50 Signal	O/E50 family	Band	Species rich	Chiron rich	EPT rich	Family rich	O/E50 Signal	O/E50 family	Band	Species rich	Chiron rich	EPT rich	Family rich	O/E50 Signal	O/E50 family	Band	Species rich	Chiron rich	EPT rich	Family rich	O/E50 Signal	O/E50 family	Band
BLA06								33	6	9	21	0.98	0.9	A	37	14	6	19	0.8	0.78	B	32	9	7	22	1	1.1	A
BLA43								23	7	4	16	0.94	1.09	A	23	10	1	13	0.92	0.79	B	25	9	4	14	0.93	0.91	A
BLA51	21	7	1	16	0.88	0.72	B	18	6	2	14	0.89	0.9	A	15	9	0	9	0.82	0.64	B	16	6	1	10	1.14	0.81	B
BLA52	33	12	8	18	0.95	1.04	A								20	8	1	10	0.91	0.85	A	18	8	1	10	0.91	0.64	B
BLA53	32	8	10	19	1.03	1.03	A	26	9	3	17	1.03	0.99	A	18	4	5	14	1.05	0.91	A	26	9	5	15	0.94	0.89	A
BLA54	26	5	8	18	0.99	1.1	A	21	3	6	16	1.08	0.9	A	26	8	5	18	1.06	1.08	A	24	7	5	16	1.05	1.1	A
BLA55	37	14	7	19	1.01	1.11	A	24	8	3	16	0.96	0.86	A	33	14	5	15	0.99	1	A	25	6	4	18	1	0.99	A
BLA56																						22	5	5	15	1.04	0.95	A
BUS05	25	8	7	14	1.12	1.07	A	26	9	6	16	1.05	1.11	A	24	7	4	16	1.05	0.96	A	27	7	7	16	1.08	0.95	A
BUS26	21	11	4	10	0.98	0.75	B								18	8	1	9	0.82	0.6	B	20	6	3	15	1	0.96	A
COL36	18	9	1	12	0.93	0.82	B	21	4	4	16	1.04	1.13	A	15	5	0	11	0.81	0.63	B	20	6	2	14	0.94	0.91	A
COL37	21	11	1	10	0.84	0.78	B																					
COL38	18	7	1	12	0.82	0.64	B	21	5	3	14	0.95	0.83	B	18	7	0	10	0.79	0.38	C	17	0	0	9	0.71	0.25	C
DEN09	16	7	1	11	0.85	0.72	B															11	3	0	7	0.69	0.36	C
DEN26	18	10	0	11	0.87	0.77	B	19	3	2	14	0.91	0.85	A	24	6	1	16	1.08	0.8	B	23	6	2	16	0.97	0.95	A
DON03	22	5	9	13	1.04	0.91	A	34	10	8	19	0.94	0.96	A	33	7	7	21	1	1.19	X	24	7	2	18	0.98	1.1	A
DON14	29	10	7	15	1.03	0.91	A	30	9	9	20	1.06	1	A	28	9	10	15	1.07	0.83	B	23	6	10	11	1.26	0.8	B
DON15	39	19	9	17	1.04	1.08	A	32	6	12	22	1.02	1.14	A	34	7	12	21	1.05	1.05	A	35	8	15	20	1.03	0.96	A
DON16	16	8	4	8	0.99	0.69	B	13	3	5	9	1.09	0.58	B	24	6	4	19	1	0.94	A	24	2	8	18	1.03	0.94	A
FRA17	19	4	6	16	1.02	1.02	A	23	3	9	18	1.03	1.07	A	24	6	9	15	1.03	0.95	A	22	4	6	17	1.02	0.83	B
FRA18	15	6	0	11	0.81	0.79	B								23	7	1	13	0.89	0.53	C	22	5	0	12	0.8	0.65	B
HAR01	31	9	8	21	1.06	0.9	A	19	4	8	13	1.06	0.82	B	35	13	11	20	1.04	0.96	A	20	4	7	14	1.03	0.95	A
HAR20	24	11	6	14	0.86	0.66	B	24	9	6	16	0.95	0.87	A	15	5	1	13	0.94	0.91	A	28	9	5	21	0.9	0.87	A
HAR21	41	13	7	26	0.98	1.18	X	27	8	7	17	1.01	1.2	X	15	5	1	11	0.89	0.67	B							
KEN11	17	4	5	13	1.12	0.81	B	26	8	6	20	1.14	0.95	A								26	7	6	17	0.98	1.11	A
MRY09	38	11	10	23	0.95	0.78	B	34	11	11	19	1	0.91	A	40	14	14	20	1.07	1	A	32	7	14	19	1.07	0.93	A
MRY33	19	5	3	15	0.93	0.91	A	23	7	7	15	1.06	0.91	A	25	6	5	19	0.91	0.95	A	36	12	11	17	0.98	0.99	A
MRY41	22	9	6	12	1.02	0.82	B	17	7	2	11	0.99	0.91	A	21	10	2	12	0.92	0.82	B	21	7	3	13	1.07	0.78	B
MRY42	29	14	4	15	0.95	0.94	A	20	12	1	9	0.83	0.75	B	24	10	1	14	0.86	0.62	B	33	11	4	17	0.88	1.03	A
MRY43	34	9	8	23	1.05	1.21	X	29	11	6	17	0.9	0.79	B	31	10	5	20	1	0.69	B	26	6	8	13	0.99	0.87	A
MRY44	20	7	4	12	1.02	0.72	B	11	5	1	8	0.88	0.62	B	22	8	1	10	0.86	0.55	B	17	5	2	10	0.99	0.6	B
MRY45	21	6	0	15	0.8	0.74	B																					
SHA21	23	9	3	14	0.88	0.83	B	20	6	4	15	0.96	0.68	B	13	6	1	9	0.83	0.79	B	17	6	2	10	0.91	0.74	B
SHA22	18	9	3	10	0.96	0.87	A	15	4	2	13	1.03	0.91	A	26	11	0	13	0.81	0.82	B	17	6	2	12	0.92	0.96	A
SHA23	30	11	7	17	1.06	1.17	X	23	5	7	19	1.07	1.01	A	24	7	6	16	1.18	0.93	A							
SHA24	19	8	3	12	1	0.66	B	24	7	6	17	1.01	0.94	A	26	9	3	18	1	0.87	A	18	4	4	14	1.03	0.9	A
SWA04	26	8	8	17	1.06	0.89	A	25	9	3	17	1.07	1.08	A	24	7	3	16	0.93	1	A	22	9	3	14	0.96	0.77	B
SWA24	22	13	2	11	1.08	0.75	B	20	8	1	12	0.76	0.61	B	15	7	0	9	0.7	0.62	B	24	7	3	14	0.94	0.87	A
SWA31	27	8	3	16	0.85	0.81	B	34	9	4	18	0.83	0.78	B	21	9	1	13	0.76	0.65	B	32	9	2	23	0.87	0.91	A
SWA32	22	10	2	13	0.85	0.83	B								33	14	2	18	0.91	1	A	27	8	5	18	1.07	0.87	A
SWA33	22	7	0	15	0.8	0.72	B								15	7	0	10	0.74	0.54	C	18	4	0	10	0.86	0.57	B
SWA34								13	2	1	10	1.1	0.81	B	6	4	0	4	0.65	0.28	C	17	2	2	12	1.07	0.52	C
SWA35								25	10	2	11	0.85	0.53	C	29	13	2	14	0.83	0.74	B	27	11	4	12	0.83	0.58	B
WAR01	37	13	10	19	0.99	1.15	X	28	7	6	19	1.14	0.94	A	33	10	11	18	1.03	1.13	A	40	10	13	24	1	1.18	X
WAR02	22	7	4	17	1	1.07	A	22	10	1	12	0.88	0.87	A	25	12	2	13	0.88	1.02	A	22	5	3	16	0.95	0.94	A
WAR05	15	7	0	11	0.85	0.64	B	7	3	0	6	0.82	0.34	C	9	5	0	5	0.74	0.29	C	8	3	0	6	0.79	0.28	C
WAR15	28	8	6	19	0.96	1.12	A	28	6	9	19	1.01	1.03	A	29	10	3	20	0.99	1.12	A	23	6	6	16	1	0.79	B
WAR16	36	10	8	20	1	1.01	A	29	7	7	17	1	1.08	A	26	12	4	15	0.98	0.67	B	27	6	8	16	0.99	0.8	B
WAR17	26	7	8	15	0.98	0.68	B								19	4	4	13	1	0.91	A	18	5	5	12	1.01	0.88	A
WAR18	15	5	2	13	1.03	0.81	B	11	3	1	10	0.99	0.95	A	18	3	0	11	0.82	0.6	B	26	3	5	16	1.08	0.72	B
WAR19	20	8	0	10	0.82	0.73	B																					
mean	24.6	8.8	4.7	15.0	1.0	0.9		23.0	6.7	4.9	15.2	1.0	0.9		23.5	8.3	3.4	14.2	0.9	0.8		23.4	6.3	4.7	14.8	1.0	0.8	
SD	7.2	3.0	3.2	4.0	0.1	0.2		6.6	2.7	3.1	3.8	0.1	0.2		7.5	3.0	3.7	4.2	0.1	0.2		6.3	2.5	3.6	4.0	0.1	0.2	

Table 7. The mean and standard deviation for each biodiversity measure for the 4 year sampling period (2005-2008). Shading denotes the largest variation for each measure.

SITE	Species richness			Chironomid richness			EPT richness			Family richness			O/E50Signal			O/E50 family			AUSRIVAS Bands
	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD	2005-2008
BLA06	34	±	3	9	±	4	8	±	2	21	±	2	0.94	±	0.1	0.92	±	0.2	-A-B-A
BLA43	24	±	1	8	±	2	3	±	2	15	±	2	0.93	±	0.0	0.97	±	0.2	-A-B-A
BLA51	18	±	3	7	±	1	1	±	1	13	±	3	0.92	±	0.1	0.79	±	0.1	B-A-B-B
BLA52	24	±	8	9	±	2	3	±	4	13	±	5	0.92	±	0.0	0.84	±	0.2	A--A-B
BLA53	26	±	6	8	±	2	5	±	3	16	±	2	1.02	±	0.0	0.96	±	0.1	A-A-A-A
BLA54	24	±	2	5	±	2	6	±	1	17	±	1	1.05	±	0.0	1.02	±	0.1	A-A-A-A
BLA55	30	±	6	10	±	4	4	±	2	17	±	2	0.98	±	0.0	0.96	±	0.1	A-A-A-A
BLA56	22	±		5	±		5	±		15	±		1.04	±		0.95	±		---A
BUS05	26	±	1	8	±	1	6	±	1	16	±	1	1.07	±	0.0	1.04	±	0.1	A-A-A-A
BUS26	20	±	2	8	±	3	3	±	2	11	±	3	0.93	±	0.1	0.77	±	0.2	B--B-A
COL36	19	±	3	6	±	2	2	±	2	14	±	2	0.95	±	0.1	0.92	±	0.2	B-A-B-A
COL37	21	±		11	±		1	±		10	±		0.84	±		0.78	±		B---
COL38	19	±	2	5	±	3	1	±	1	12	±	2	0.84	±	0.1	0.59	±	0.3	B-B-C-C
DEN09	14	±	4	5	±	3	1	±	1	9	±	3	0.77	±	0.1	0.54	±	0.3	B---C
DEN26	21	±	3	6	±	3	1	±	1	14	±	2	0.95	±	0.1	0.84	±	0.1	B-A-B-A
DON03	28	±	6	8	±	2	7	±	3	18	±	3	0.98	±	0.0	1.02	±	0.1	A-A-X-A
DON14	28	±	3	9	±	2	9	±	1	16	±	4	1.10	±	0.1	0.91	±	0.1	A-A-B-B
DON15	35	±	3	9	±	6	12	±	2	20	±	2	1.03	±	0.0	1.07	±	0.1	A-A-A-A
DON16	19	±	6	4	±	3	5	±	2	13	±	6	1.04	±	0.0	0.75	±	0.2	B-B-A-A
FRA17	22	±	2	4	±	1	8	±	2	17	±	1	1.03	±	0.0	0.99	±	0.1	A-A-A-B
FRA18	20	±	4	6	±	1	0	±	1	12	±	1	0.83	±	0.0	0.66	±	0.1	B--C-B
HAR01	26	±	8	7	±	4	8	±	2	16	±	4	1.05	±	0.0	0.89	±	0.1	A-B-A-A
HAR20	23	±	6	9	±	2	5	±	2	16	±	4	0.92	±	0.0	0.84	±	0.1	B-A-A-A
HAR21	28	±	13	9	±	3	6	±	3	18	±	8	0.97	±	0.1	1.06	±	0.3	X-X-B-
KEN11	23	±	5	7	±	2	6	±	1	18	±	4	1.10	±	0.1	0.96	±	0.2	B-A--A
MRY09	36	±	4	11	±	2	12	±	2	20	±	2	1.02	±	0.1	0.91	±	0.1	B-A-A-A
MRY33	26	±	7	7	±	3	7	±	3	16	±	2	0.99	±	0.1	0.93	±	0.0	A-A-A-A
MRY41	20	±	2	8	±	1	3	±	2	12	±	1	1.00	±	0.1	0.85	±	0.1	B-A-B-B
MRY42	27	±	6	12	±	1	2	±	2	13	±	3	0.87	±	0.1	0.82	±	0.2	A-B-B-A
MRY43	30	±	3	9	±	2	7	±	2	18	±	4	0.97	±	0.1	0.87	±	0.2	X-B-B-A
MRY44	18	±	5	6	±	1	2	±	1	10	±	2	0.93	±	0.1	0.62	±	0.1	B-B-B-B
MRY45	21	±		6	±		0	±		15	±		0.80	±		0.74	±		B---
SHA21	18	±	4	7	±	1	3	±	1	13	±	3	0.91	±	0.1	0.74	±	0.1	B-B-B-B
SHA22	19	±	5	7	±	3	2	±	1	12	±	1	0.95	±	0.1	0.89	±	0.1	A-A-B-A
SHA23	26	±	4	7	±	3	7	±	1	18	±	2	1.10	±	0.1	1.03	±	0.1	X-A-A-
SHA24	22	±	4	7	±	2	4	±	1	16	±	3	1.01	±	0.0	0.86	±	0.1	B-A-A-A
SWA04	24	±	2	8	±	1	4	±	3	16	±	1	1.02	±	0.1	0.96	±	0.1	A-A-A-B
SWA24	20	±	4	9	±	3	1	±	1	12	±	2	0.85	±	0.2	0.69	±	0.1	B-B-B-A
SWA31	29	±	6	9	±	0	3	±	1	18	±	4	0.83	±	0.0	0.79	±	0.1	B-B-B-A
SWA32	27	±	6	11	±	3	3	±	2	16	±	3	0.94	±	0.1	0.90	±	0.1	B--A-A
SWA33	18	±	4	6	±	2	0	±	0	12	±	3	0.80	±	0.1	0.61	±	0.1	B--C-B
SWA34	12	±	6	3	±	1	1	±	1	9	±	4	0.98	±	0.3	0.61	±	0.3	-B-C-C
SWA35	27	±	2	11	±	1	3	±	1	12	±	2	0.84	±	0.0	0.60	±	0.1	-C-B-B
WAR01	35	±	5	9	±	3	9	±	3	20	±	3	1.06	±	0.1	1.07	±	0.1	X-A-A-X
WAR02	23	±	2	9	±	3	2	±	1	14	±	2	0.92	±	0.1	0.95	±	0.1	A-A-A-A
WAR05	10	±	4	4	±	2	0	±	0	7	±	3	0.80	±	0.0	0.38	±	0.2	B-C-C-C
WAR15	27	±	3	7	±	2	7	±	2	19	±	2	0.99	±	0.0	1.02	±	0.2	A-A-A-B
WAR16	30	±	5	8	±	3	7	±	2	17	±	2	0.99	±	0.0	0.93	±	0.2	A-A-B-B
WAR17	21	±	4	5	±	2	6	±	2	13	±	2	1.00	±	0.0	0.82	±	0.1	B--A-A
WAR18	18	±	6	3	±	1	2	±	2	12	±	3	0.98	±	0.1	0.81	±	0.1	B-A-B-B
WAR19	20	±		8	±		0	±		10	±		0.82	±		0.73	±		B---

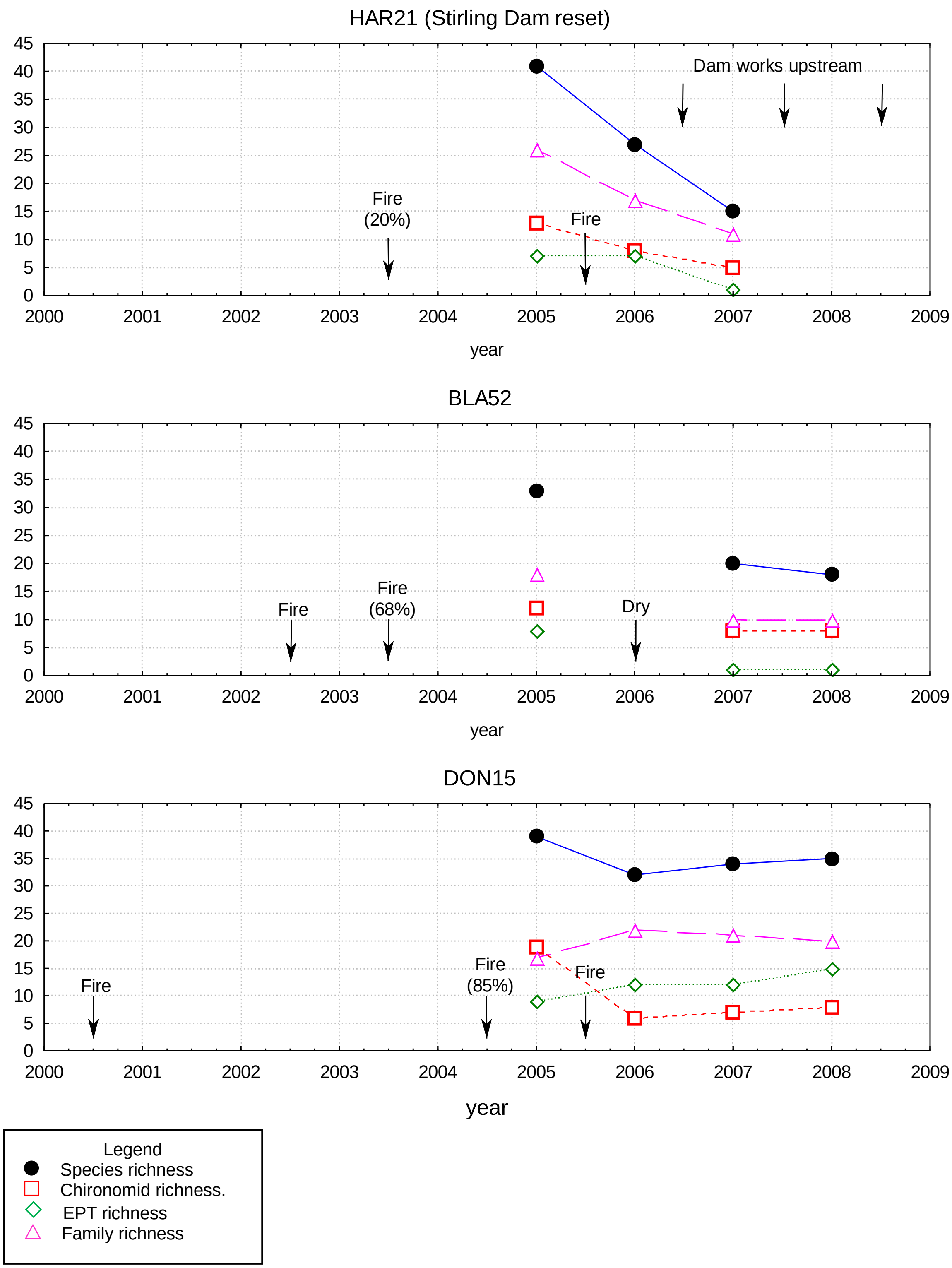


Figure 3. Sites which showed the largest variation in the biodiversity measures between 2005 and 2008. Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets

AUSRIVAS scores and banding for individual sites

Observed/Expected ratio scores and the banding classification from the AUSRIVAS models are shown in Table 6. The highest O/E SIGNAL score was recorded at DON14 in 2008 (1.26). This infers that this site has a higher number of sensitive taxa than the reference sites used in the model. However, caution should be used when interpreting the O/E SIGNAL in Western Australia, as many families are more tolerant in Western Australia and the current SIGNAL index used in the model is largely based on eastern Australian data (Halse *et al.*, 2001b). The lowest O/E SIGNAL score was calculated for SWA34 in 2007 (0.65) which is located just downstream of the Dam at the Canning Reservoir. The highest O/E families score was recorded at MRY43 in 2005 (1.21) which is the reset site for the Serpentine Dam. This infers that this site has a greater number of families than the reference sites used in the model. The lowest O/E family score calculated was at COL38 in 2008 (0.25) which had several logging disturbances (2004, 2005 and 2006) and all of the catchment area burned in 2007.

A system of bands, representing ranges of O/E family scores, is usually used to classify sites into grades of biological condition (see Table 2). The bands for each site are listed in Tables 6 and 7. Several sites have changed bands between years. This may be due to natural temporal variation, especially when a site switches back and forth between two bands. For example WAR01 has a banding allocation of X-A-A-X for the 2005 to 2008 sampling occasions. The O/E family scores were 1.07±0.1 (mean ± SD), which is near to the boundary (1.15) of bands X (enriched) and A (undisturbed). However, if a site shows a large variation in the O/E family scores and shifts more than one band width then this site has probably changed in condition. Two sites, HAR21 and MRY43, changed from band X (enriched, more than reference) to band B (slightly impaired) (Figure 4). It is interesting to note that both of these sites are reset sites for the dam disturbance and it is possible that there were a higher number of observed families present in some years due to slight disturbance rather than the site being an ecological hot spot. Both these sites are discussed briefly below and in more detail in the Dam section later in the report.

HAR21 is the reset site for Stirling Dam. It showed a large decrease in species and family richness between 2005 and 2006 (but no change in band, Figure 4) and then a further decline between 2006 and 2007 (and a change from band X to band B). The decrease in EPT richness was only between 2006 and 2007 (Figure 4). Dam construction works in 2006/7, which caused substantial sedimentation at HAR21, may be the cause of the decline in biodiversity measures between 2006 and 2007, especially the virtual elimination of EPT taxa. Another explanation for the decrease in biodiversity at HAR21, especially between 2005 and 2006, may be the catchment's fire history. In the period between the 2005 and 2006 samples (prior to the dam construction works commencing) there was a decrease in most biodiversity measures which may have been a response to fire disturbance over this time when 14% of the catchment was burned adjacent to the river between sites HAR20 and HAR21.

MRY43 is the reset site for the Serpentine Dam and recorded the highest O/E family score (1.21, band X) in 2005, which infers the site had a greater number of families present than the reference sites used in the AUSRIVAS model. Species and family richness was high at this site in 2005 (34 and 23 respectively) but decreased in 2006 (29 and 17 respectively) and the banding level dropped to B (slightly impaired) (Figure 4). Samples taken in 2007 and 2008 recorded a slight increase in these numbers resulting in the site being upgraded to band A (similar to reference) in 2008. The last record of logging at this site was in the 1990's with no logging recorded since

1998. Control burns have been recorded in the catchment area every year since 1998. The largest burn area recorded in the past ten years occurred in 2005/06 (10.5% of the catchment).

It is interesting to note that even though EPT richness increased at MRY43 in 2008, the other biodiversity measures decreased and yet the site jumped from band B to band A. This may be associated with the fact that some families recorded in this project are not included in the AUSRIVAS model, so a change in family richness may not be reflected in model outputs. Most differences between the AUSRIVAS model and family richness measure are due to the AUSRIVAS model only using taxa that were calculated to have a probability of 50% or greater of occurring at a test site and some taxa being classified to a higher level, especially Oligochaeta (class) and Acarina (order). For example; for MRY43 there were 11 families (over half the family richness) that were not used in the AUSRIVAS model calculations in 2007. Nine of these families (mainly families within the Order Acarina, Paramelitidae and some Dipteran) were not collected in 2008 so the family richness for the site decreased between 2007 and 2008. As these families were not used in the model the O/E scores and banding did not reflect the decrease in family richness. In this case the banding actually increased (B to A), partly due to 4 taxa (Ceratogonidae, Leptopheliidae, Caenidae and Oligochaeta) which are used in the model, being collected in 2008, but not present in 2007. This explains why sometimes there is a change in family richness at a site, but the AUSRIVAS O/E scores and banding allocation does not reflect the change.

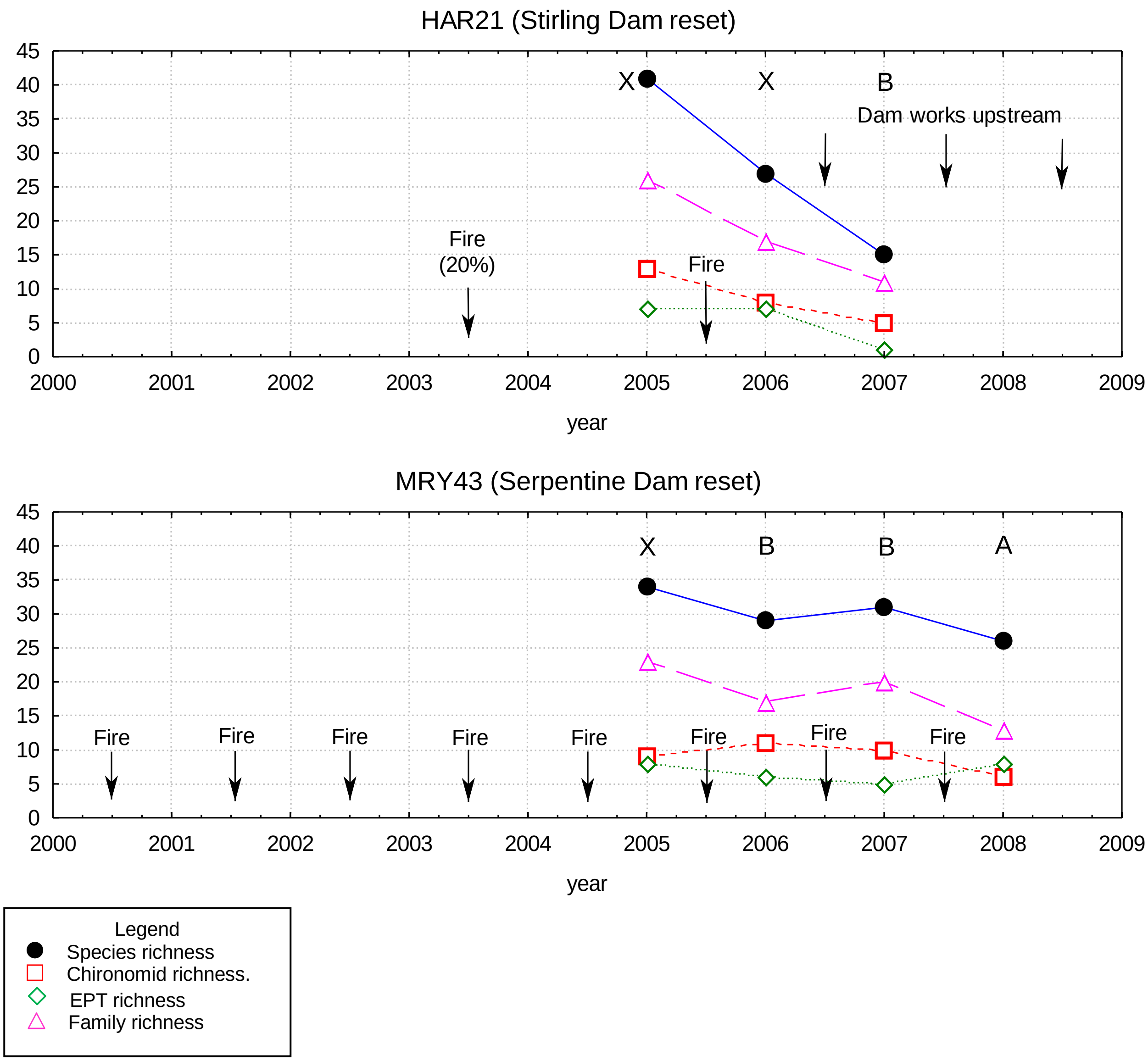


Figure 4. Sites which changed from an AUSRIVAS X band (better than reference) to a B band (slightly impaired). Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets.

Seven sites (approximately 14% of total) were allocated to band C (severely impaired) at least once: COL38 (2007, 2008), DEN09 (2008), FRA18 (2007), SWA33 (2007), SWA34 (2007, 2008), SWA35 (2006), and WAR05 (2006, 2007, 2008). Figures 5 to 7 show the variation in biodiversity measures at these sites along with points indicating events (such as fire, logging, site dry) that have occurred within the site's catchment since the year 2000.

All of the sites receiving a C banding were Jarrah sites and, except for SWA34 and 35, are located in the drier eastern zone of the FMP area and receive an average annual rainfall of less than 850mm. Several of these sites decreased from a B band to a C band in 2007 after the site had dried out in 2006 (DEN09, FRA18 and SWA33, Figure 5). However, not all sites which dried out in 2006 reduced their banding level, so there are probably other factors involved in the change at these sites.

Of the above sites, DEN09, WAR05 and FRA18 have also recorded high salinities (>1300µS/cm, see Appendix 2). In the case of DEN09 it is probable that the combination of drying out, high salinity and additional disturbances of fire reduced the number of species, resulting in the C banding (Figure 5).

While SWA33 and COL38 have low rainfall, they do not have consistently high salinity. These two sites, along with WAR05, have had repeated disturbances of fire and logging in their catchments which may have contributed to the low band score. However, other sites in this project have also had repeated fire and logging disturbances and have not received a C banding score.

COL38 and WAR05 were severely impaired for at least two consecutive years (Figure 6). It is possible that other factors (such as the extent and intensity of the repeated disturbance) may be influencing changes in the aquatic system. At COL38, between 2007 and 2008 samples, 100% of the catchment was burnt. Although there were no high water chemistry readings at the site (Appendix 2) the fire may have still had an effect as COL38 received the lowest O/E family score in 2008 (0.25), almost at the cut-off (0.24) of band D (extremely impaired). WAR05 had consistently high salinities, and in 2007 and 2008 had high concentrations of Total N (1.4 and 0.98 $\mu g.L^{-1}$) and NH_3 (0.08 and 0.19 $\mu g.L^{-1}$ respectively). Part of this catchment is within an agricultural area which, combined with frequent fire disturbances (2006, 2007 and 2008), may have affected the water chemistry and stream invertebrates at this location.

Sites SWA34 and 35 (Figure 7) are the “dam” and “reset” sites for the Canning Reservoir. SWA34 had the lowest richness of species (6 in 2007), chironomids (2 in 2006) and O/E SIGNAL score (0.65 in 2007). The O/E family score (0.28) in 2007 was near the boundary (0.24) of band D (extremely impaired) in 2008. Low biodiversity measures at these sites, especially at SWA34, are possibly due to the influence of the dam and resultant altered flow regime below the dam. These sites are discussed further in the Dam section.

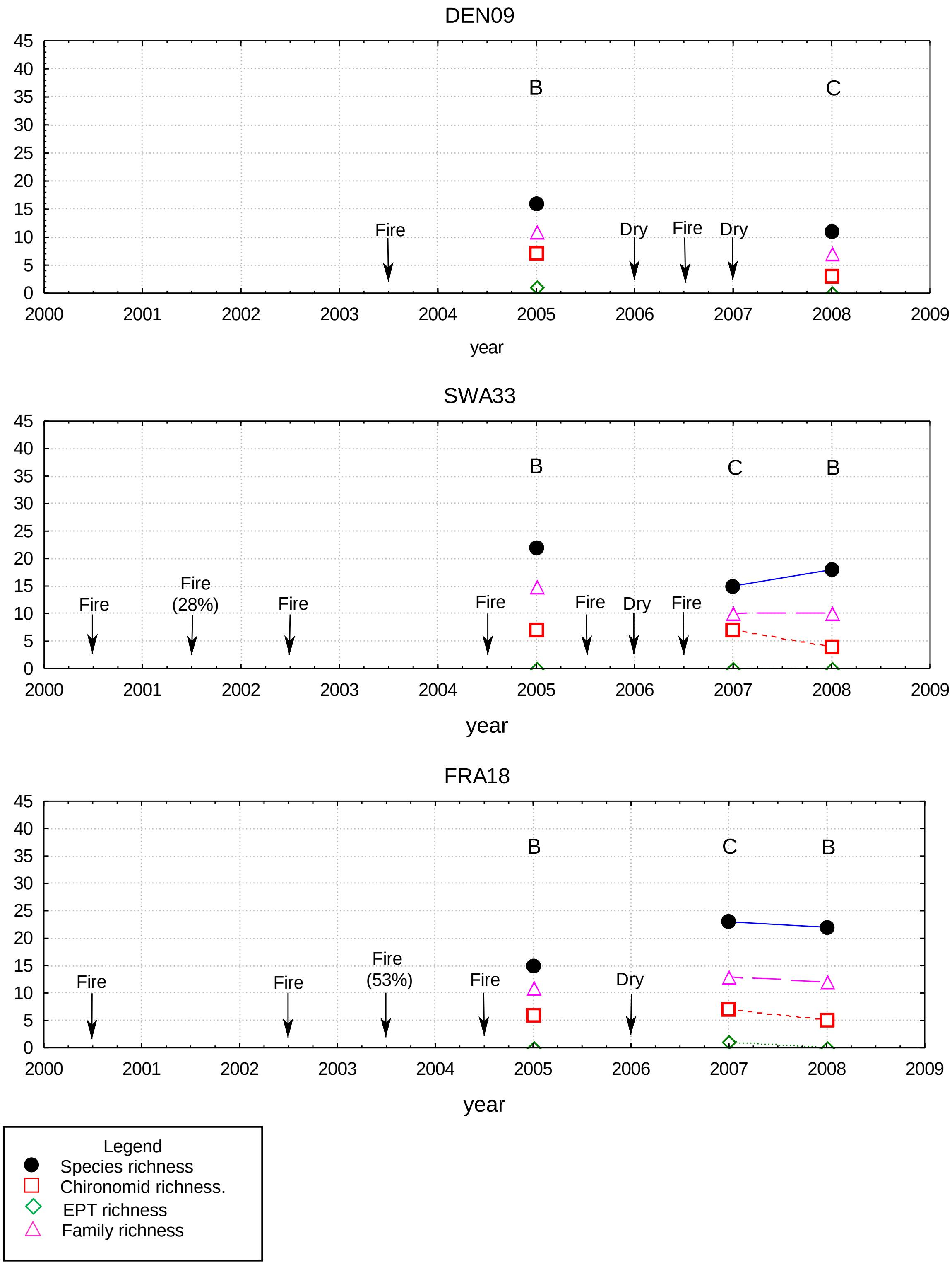


Figure 5. Sites which dried out in 2006 and received a band C (severely impaired) from the AUSRIVAS model. Bands are shown above the sampling year. Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets.

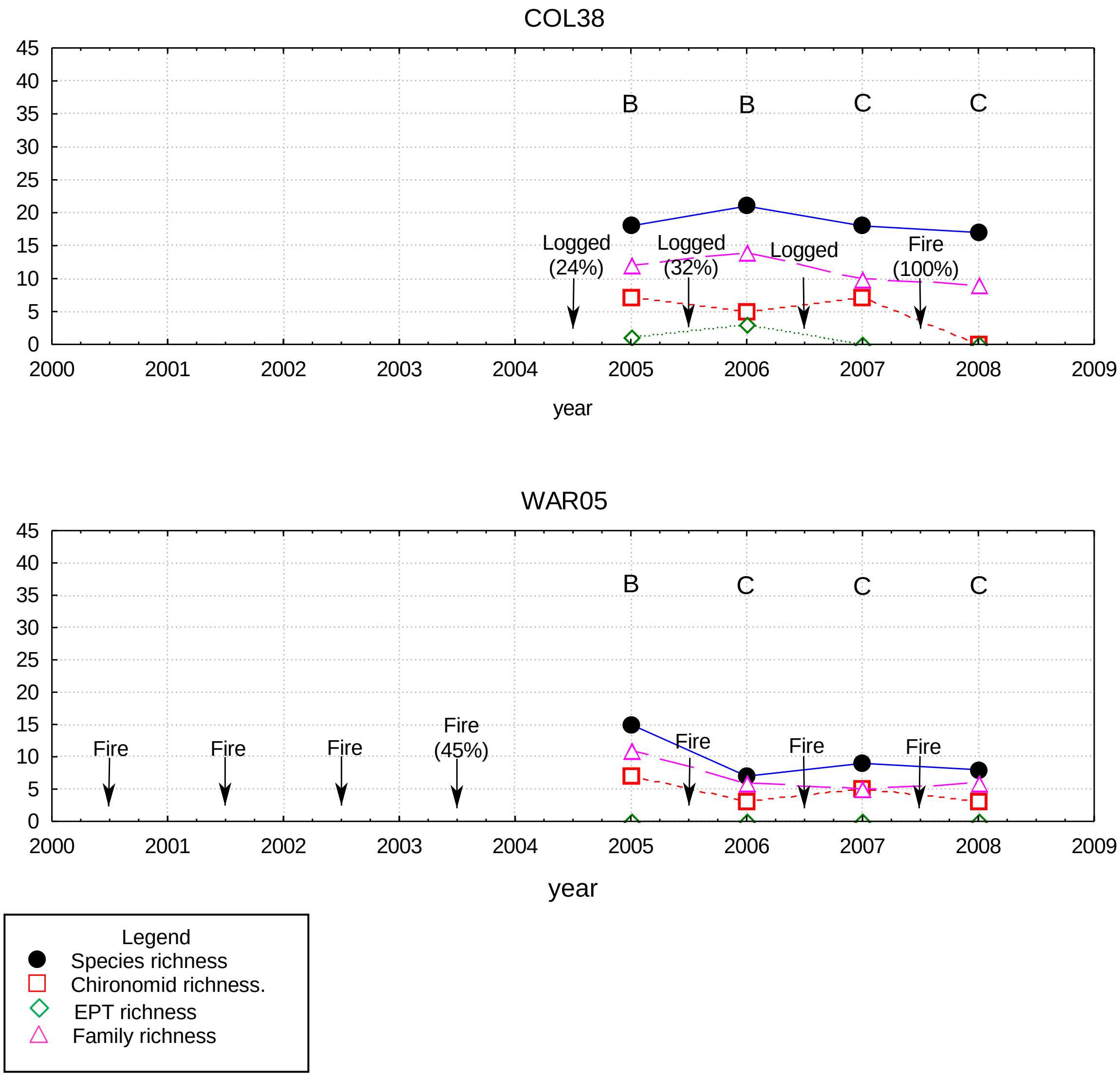


Figure 6. Sites which received a band C (severely impaired) from the AUSRIVAS model. Bands are shown above the sampling year. Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets.

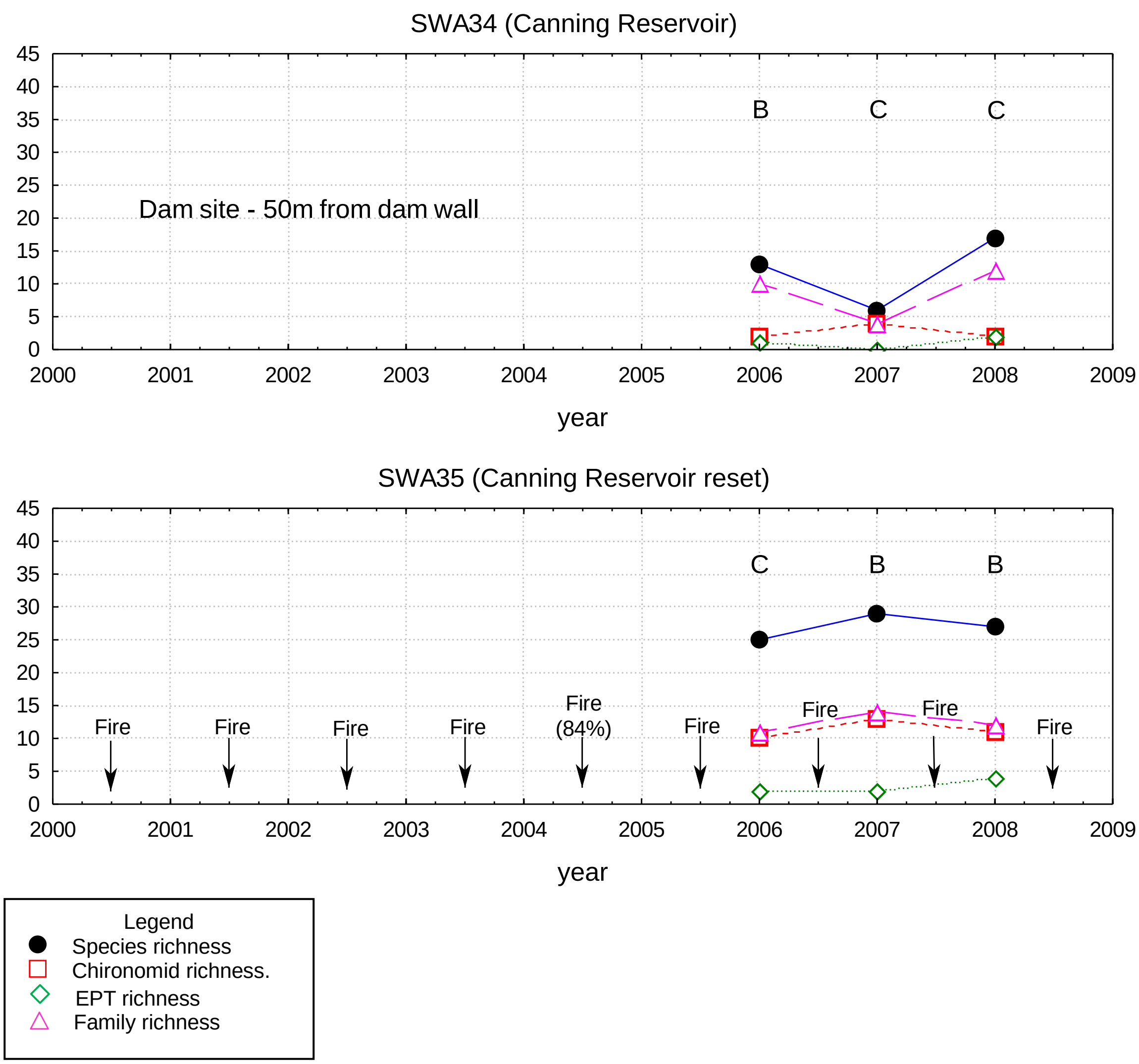


Figure 7. Sites associated with the Canning Reservoir which received a band C (severely impaired) from the AUSRIVAS model. Bands are shown above the sampling year. Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets.

Environmental variables.

Table 8 shows the mean, maximum and minimum values for environmental measures for all samples. Environmental measures for each sample are shown in Appendix 2.

Table 8. Mean , maximum and minimum values for environmental measures.

	mean	maximum	minimum
Alkalinity (mg.L^{-1})	25	340	<0.5
Colour (TCU)	65	730	1
NH3 (mg.L^{-1})	0.087	1.1	<0.01
NO3 (mg.L^{-1})	0.046	0.42	<0.01
N Total (mg.L^{-1})	0.43	2.8	<0.02
P SR (mg.L^{-1})	0.05	0.04	<0.01
P Total (mg.L^{-1})	0.01	0.05	<0.01
Turbidity (NTU)	2.9	97	<0.5
Conductivity (µS.cm^{-1})	1152	23700	26.4
pH	6.4	7.6	3.9
Temperature (°C)	14.2	24.7	7.6
DO (%)	89.8	163.6	23.8
Min flow (cm.sec^{-1})	1.4	21.1	0
Max flow (cm.sec^{-1})	34.2	142.9	0

It should be noted that all soluble reactive phosphorus (SRP) concentrations were 0.05mg.L^{-1} or less and most measurements were below detectable concentrations (<0.01mg.L^{-1}). Total P was only found above detectable levels (>0.01mg.L^{-1}) at 6 sites. Minimum flow was mostly zero. Therefore these data were only assessed visually.

Even though some sites had a large range for some environmental measures, several sites had consistently high or low records. Three Karri sites (SHA21, SHA22 and FRA17) had consistently low pH values (<4.5) and should be considered acidic streams according to Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000). Several Jarrah sites (BLA51, FRA18, SWA31 and WAR02) had average salinities between 2000 and 4000 µS.cm^{-1} which would classify these sites as highly brackish. DEN09, WAR05 and WAR19 had average salinities greater than 4000 µS.cm^{-1} classifing these sites as saline. All of these Jarrah sites mentioned above, have low annual rainfall (<850mm) and are located on the eastern edge of the forest area near the Wheatbelt region. Even though the whole catchment area for WAR19 is DEC managed land, the other sites have from 24% (WAR05) up to 86% (DEN09) of the catchment outside of DEC estate (Appendix 3). Therefore it is possible that some of these sites are impacted by adjacent farmlands.

Correlations between different environmental variables are shown in Table 9. There are some significant, albeit moderate correlations between the environmental variables which one would normally expect (e.g. alkalinity with pH and conductivity, DO (%) with maximum flow). Some of the environmental variables did differ between forest types and this is discussed later.

Table 9. Correlations between the environmental variables. Values are r and corresponding p values. R values with bold * denoting a significant value (p<0.05).

	pH	Temp.	DO (%)	Max flow	Alkalinity	Colour	NH3	NO3	Total N	Turbidity	Conductivity
pH	1.0000 p= ---	.0370 p=.622	.1479 **p=.047**	.0625 p=.404	.6937 **p=0.00**	-.3012 **p=.000**	-.4185 **p=.000**	.0119 p=.874	-.1657 **p=.026**	-.0410 p=.585	.1257 p=.093
Temperature (°C)	.0370 p=.622	1.0000 p= ---	.1525 **p=.041**	-.1754 **p=.019**	.1221 p=.102	.0688 p=.359	.1839 **p=.013**	.1616 **p=.030**	.1085 p=.147	-.1458 p=.051	.2768 **p=.000**
DO (%)	.1479 **p=.047**	.1525 **p=.041**	1.0000 p= ---	.4062 **p=.000**	-.2309 **p=.002**	-.2367 **p=.001**	-.2906 **p=.000**	.0126 p=.866	-.4108 **p=.000**	-.1412 p=.059	-.1793 **p=.016**
Max flow (cm/sec)	.0625 p=.404	-.1754 **p=.019**	.4062 **p=.000**	1.0000 p= ---	-.2314 **p=.002**	-.2323 **p=.002**	-.2135 **p=.004**	.0566 p=.450	-.3505 **p=.000**	-.1156 p=.122	-.2108 **p=.004**
Alkalinity	.6937 **p=0.00**	.1221 p=.102	-.2309 **p=.002**	-.2314 **p=.002**	1.0000 p= ---	.0269 p=.720	-.1013 p=.176	-.0241 p=.748	.2238 **p=.003**	.0249 p=.740	.3954 **p=.000**
Colour	-.3012 **p=.000**	.0688 p=.359	-.2367 **p=.001**	-.2323 **p=.002**	.0269 p=.720	1.0000 p= ---	.2886 p=.000	.1373 p=.066	.6037 **p=0.00**	.3545 **p=.000**	.0914 p=.222
NH3	-.4185 **p=.000**	.1839 **p=.013**	-.2906 **p=.000**	-.2135 **p=.004**	-.1013 p=.176	.2886 **p=.000**	1.0000 p= ---	.1310 p=.080	.5669 **p=.000**	-.1030 p=.169	.2335 **p=.002**
NO3	.0119 p=.874	.1616 **p=.030**	.0126 p=.866	.0566 p=.450	-.0241 p=.748	.1373 p=.066	.1310 p=.080	1.0000 p= ---	.3350 **p=.000**	.1493 **p=.046**	-.1389 p=.063
Total N	-.1657 **p=.026**	.1085 p=.147	-.4108 **p=.000**	-.3505 **p=.000**	.2238 **p=.003**	.6037 **p=0.00**	.5669 **p=.000**	.3350 **p=.000**	1.0000 p= ---	.2385 **p=.001**	.2557 **p=.001**
Turbidity	-.0410 p=.585	-.1458 p=.051	-.1412 p=.059	-.1156 p=.122	.0249 p=.740	.3545 **p=.000**	-.1030 p=.169	.1493 **p=.046**	.2385 **p=.001**	1.0000 p= ---	-.1220 p=.103
Conductivity	.1257 p=.093	.2768 **p=.000**	-.1793 **p=.016**	-.2108 **p=.004**	.3954 **p=.000**	.0914 p=.222	.2335 **p=.002**	-.1389 p=.063	.2557 **p=.001**	-.1220 p=.103	1.0000 p= ---

Environmental variables and biodiversity measures

Correlations between environmental variables and biodiversity measures are shown in Table 10.

Although there are several significant correlations between environmental variables and the biodiversity measures most of these correlations are weak; the highest being for EPT richness and maximum flow (r =0.489). All of the biodiversity measures had a significant positive correlation with conductivity and a significant positive correlation with maximum flow (Figure 8).

Table 10. Correlations between environmental variables and invertebrate biodiversity measures (Jarrah and Karri combined). Bold denotes significant difference (p<0.05).

	Species richness		Chironomid richness		EPT richness		Family richness		O/E50Signal		O/E50family	
	r	p	r	p	r	p	r	p	r	p	r	p
pH	0.189	**0.012***	0.241	**0.001***	0.060	0.431	0.090	0.235	-0.095	0.207	-0.038	0.616
Temperature (°C)	-0.062	0.416	-0.036	0.639	-0.174	**0.021***	-0.078	0.305	-0.240	**0.001***	-0.144	0.057
DO (%)	0.348	**0.000***	0.290	**0.000***	0.304	**0.000***	0.370	**0.000***	0.131	0.081	0.334	**0.000***
Max flow (cm/sec)	0.380	**0.000***	0.225	**0.003***	0.489	**0.000***	0.412	**0.000***	0.312	**0.000***	0.386	**0.000***
Alkalinity	-0.170	**0.023***	-0.021	0.781	-0.266	**0.000***	-0.236	**0.002***	-0.280	**0.000***	-0.290	**0.000***
Colour	-0.235	**0.002***	-0.242	**0.001***	-0.123	0.104	-0.160	**0.034***	-0.048	0.527	-0.072	0.340
NH3	-0.177	**0.018***	-0.314	**0.000***	-0.145	0.055	-0.110	0.147	0.000	0.996	-0.128	0.089
NO3	0.147	0.051	0.061	0.419	0.180	**0.017***	0.186	**0.013***	0.242	**0.001***	0.205	**0.006***
N total	-0.274	**0.000***	-0.296	**0.000***	-0.277	**0.000***	-0.194	**0.010***	-0.139	0.065	-0.184	**0.014***
Turbidity	-0.089	0.239	-0.043	0.570	-0.042	0.581	-0.061	0.418	0.002	0.983	-0.035	0.642
Conductivity	-0.230	**0.002***	-0.216	**0.004***	-0.314	**0.000***	-0.182	**0.015***	-0.205	**0.006***	-0.197	**0.009***

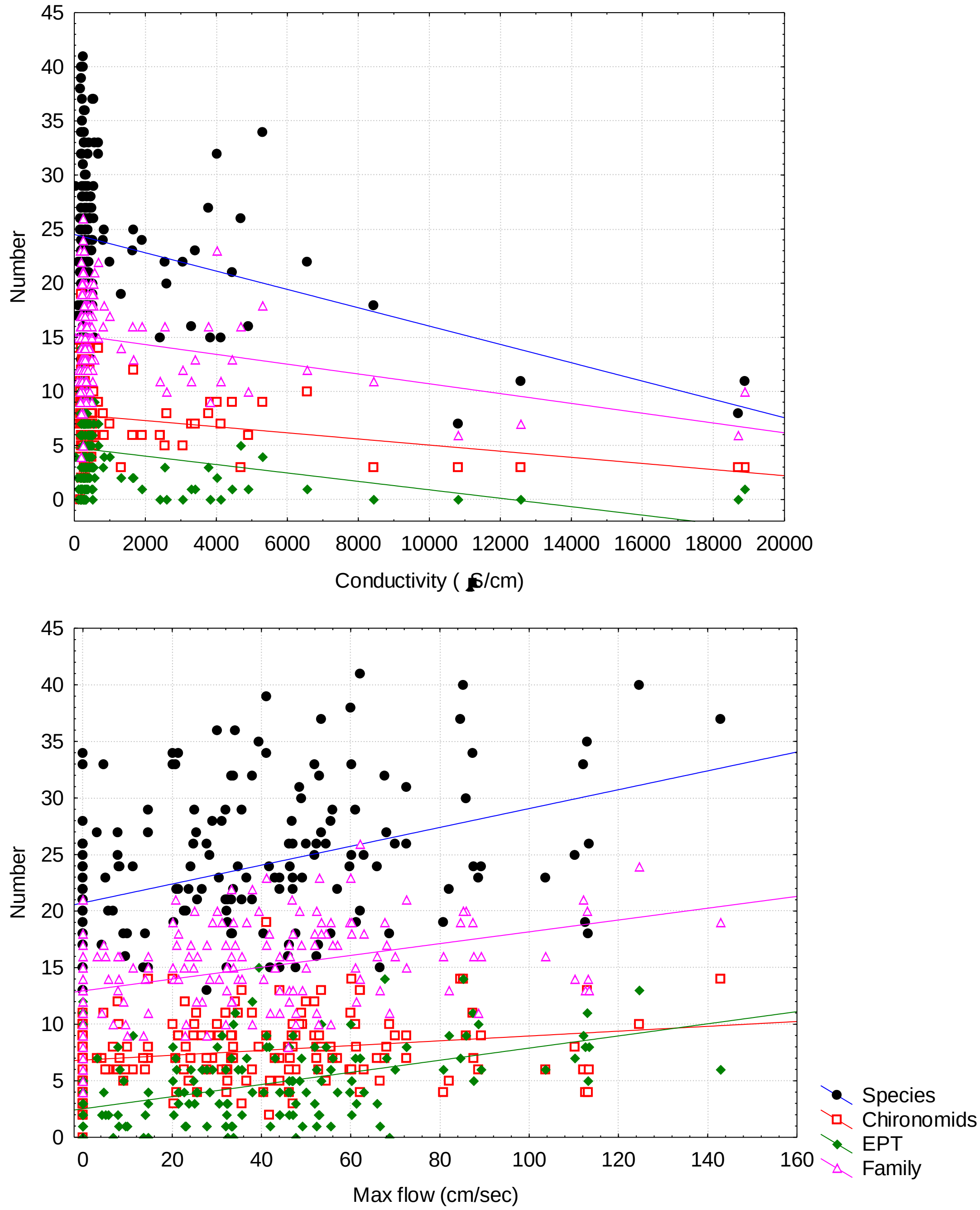


Figure 8. Invertebrate biodiversity measures plotted against 1) Conductivity and 2) Maximum flow. Lines of fit show significant correlations between variables; p and r values are shown in Table 7.

Comparisons in Forest type

The dominant type of forest which occurred at each site is shown in Table 4. Between 2005 and 2008 131 invertebrate samples were collected from 39 sites within Jarrah forest and 46 invertebrate samples collected from 12 sites within Karri forest.

Biodiversity measures in Jarrah and Karri forests.

A repeated measures ANOVA (within factor being year) was carried out to determine if there were differences in biodiversity measures between forest type (Table 11). Only sites sampled in all four years were used in the analysis (total of 33 sites; 23 Jarrah and 10 Karri). The repeated measures ANOVA showed there was a significant effect of forest type, with Karri sites having higher EPT (p=0.042) and family richness (p=0.030). O/E SIGNAL was only marginally non-significant. There was a significant difference between years for chironomid richness (p=0.000), EPT richness (p=0.040) and O/E SIGNAL (p=0.043) (Figure 9). The higher EPT richness measured in the Karri forest may explain some of the significant difference in O/E SIGNAL scores. Most EPT have a higher SIGNAL score as these families are generally more sensitive to disturbances and environmental impacts.

Table 11. Repeated measures ANOVA between Forest type and biodiversity measures. Df for forest type (between factor) = 1, df for year (within factor) = 3. Bold and * denotes significant difference (p<0.05).

Species richness	SS	MS	F	p
Forest Type	115.8	115.8	0.859	0.361
Year	77.7	1.317	0.274	0.274
Year*Forest Type	21.7	0.368	0.776	0.776

Chironomid Richness	SS	MS	F	p
Forest Type	.2	.21	.01	0.908
Year	173.5	57.84	11.10	**0.000***
Year*Forest Type	30.2	10.08	1.94	0.129

EPT richness	SS	MS	F	p
Forest Type	164.8	164.8	4.484	**0.042***
Year	28.8	9.6	2.885	**0.040***
Year*Forest Type	19.7	6.6	1.975	0.123

Family richness	SS	MS	F	p
Forest Type	393.2	393.2	4.9977	**0.030***
Year	25.2	8.39	0.3830	0.765
Year*Forest Type	105.09	35.03	1.599	0.192

O/ESIGNAL	SS	MS	F	p
Forest Type	.076	.076	3.801	0.060
Year	.039	.013	2.826	**0.043***
Year*Forest Type	.019	.006	1.333	0.268

O/E family	SS	MS	F	p
Forest Type	.163	.163	1.820	0.187
Year	.044	.015	.881	0.454
Year*Forest Type	.024	.008	.475	0.700

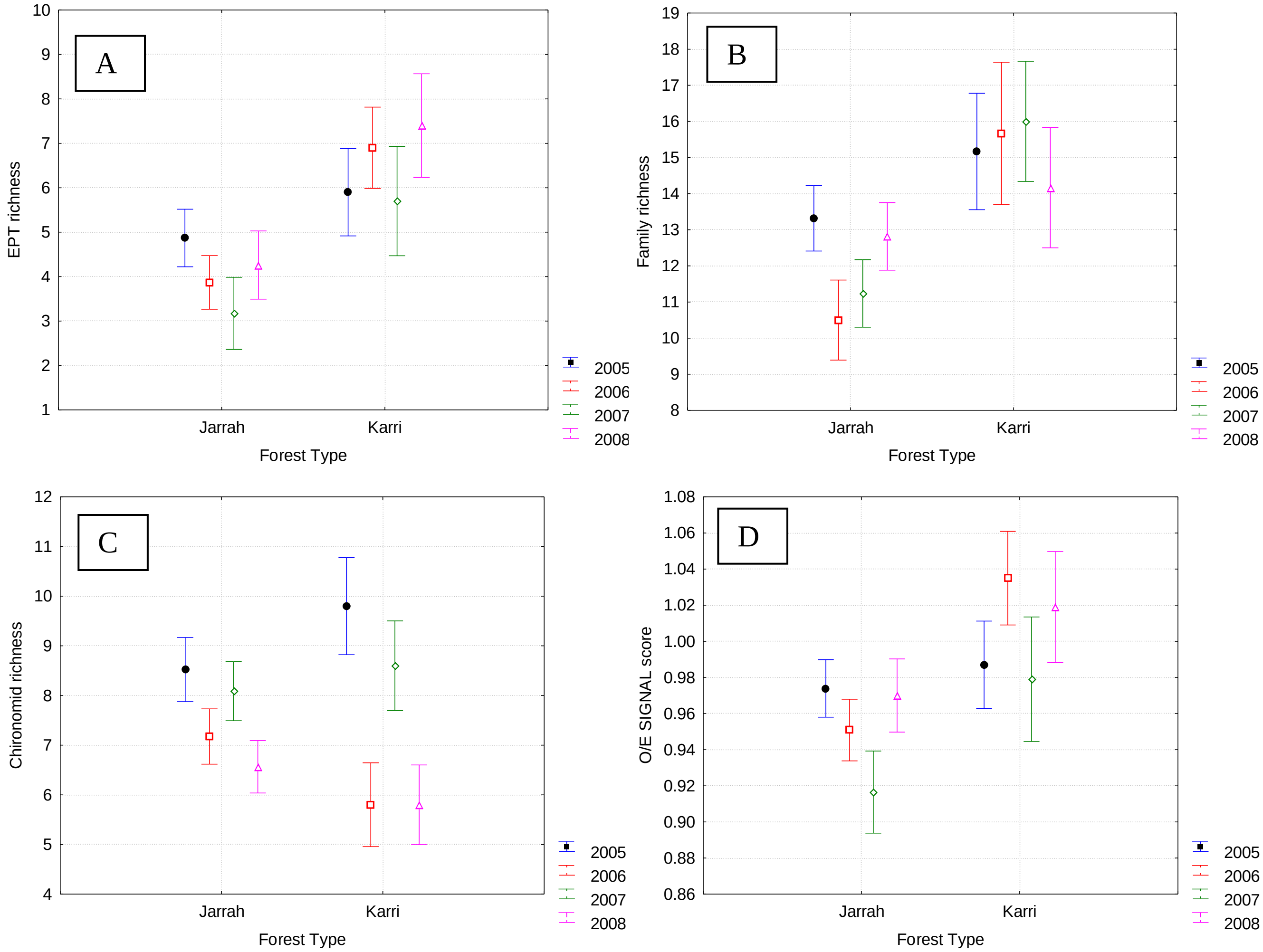


Figure 9. Biodiversity measures (mean ± SE) which showed a significant effect of forest type or year. A) EPT richness, B) Family richness, C) Chironomid richness and D) O/E SIGNAL score.

The repeated measures ANOVA analysis between forest type and biodiversity measures does not take into account the disturbances occurring within the catchment areas, so the results may be confounded with the degree of disturbance. There is insufficient replication to carry out this analysis using only undisturbed sites over the whole four year period, as only 5 sites have had no disturbances since 2004 (two Karri – FRA17, WAR16, and three Jarrah – BLA52, BUS06, BUS26). As disturbances change annually, sites can be analysed by contrasting forest types using ANOVA's, if each year is examined separately. Figure 10 shows the means and standard errors of biodiversity measures for undisturbed sites in the Jarrah and Karri forests from 2005 to 2008. Table 12 shows the number of undisturbed Jarrah and Karri sites sampled each year.

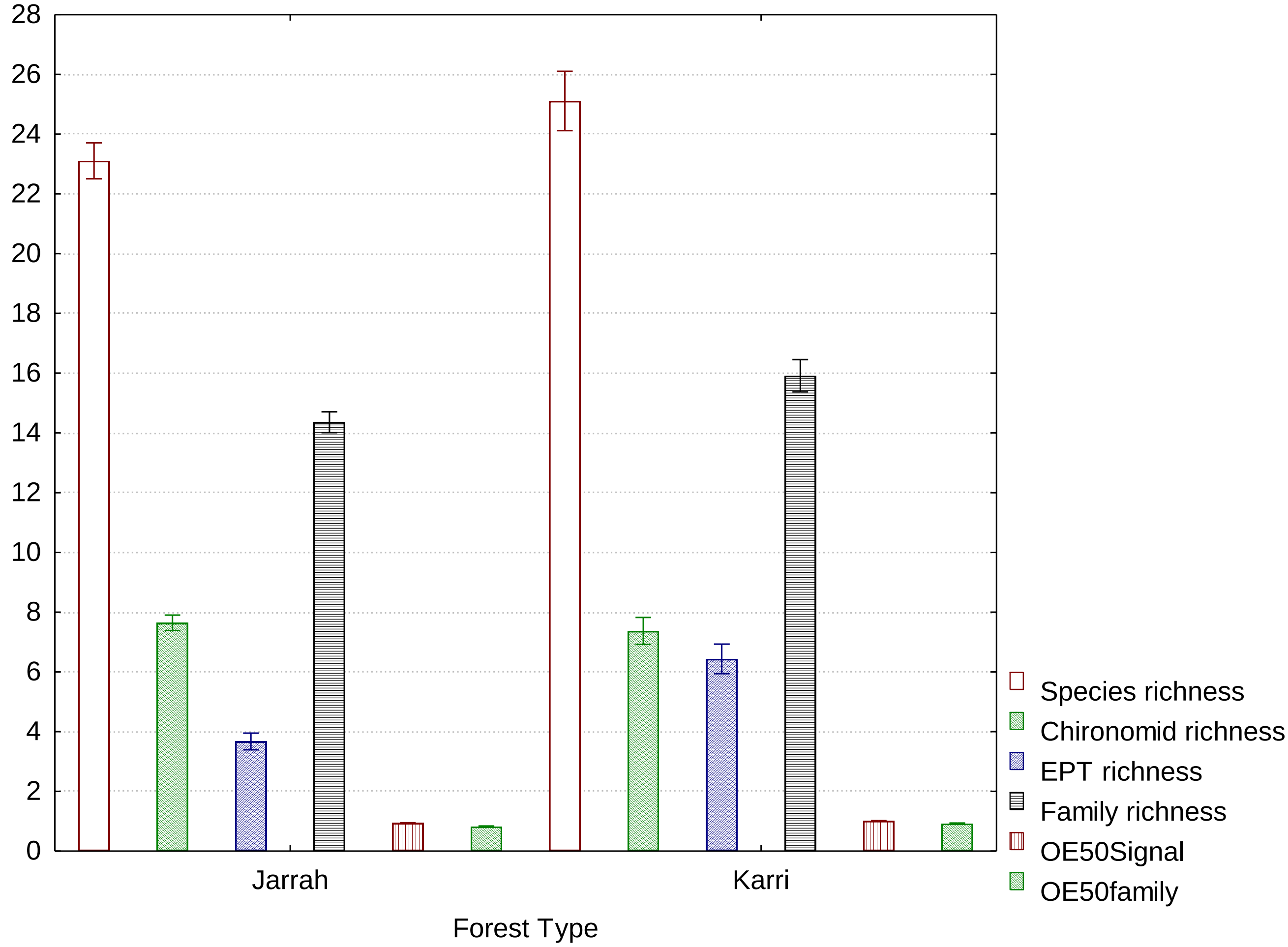


Figure 10. Biodiversity measures from undisturbed sites from within the Jarrah and Karri forests sampled between 2005 and 2008. Jarrah n= 49, Karri n = 23, columns show mean ± SE

Table 12. The number of undisturbed sites sampled in each forest type for each year

Year	Karri	Jarrah	Total
2005	5	14	19
2006	6	10	16
2007	6	11	17
2008	6	14	20

Results of ANOVAs investigating differences between forest types for the invertebrate biodiversity measures for each year are shown in Table 13. Results varied between years, with 2005 showing no significant differences between Jarrah and Karri forest in any of the biodiversity measures. On the other hand, 2008 showed a significant difference between forest types for species richness (p=0.025), EPT richness (p<0.000) and family richness (p=0.037). EPT richness was significantly different between the Jarrah and Karri forests in 2006, 2007 and 2008 (Figure 11). These results suggests that there is value in forest type being a separate factor in analyses even though other factors such as the annual variation may be confounding the results. Forest type seems to have the greatest effect on EPT richness (higher in Karri forest streams).

Table 13. ANOVA's between Forest type and invertebrate measures for each year sampled. Df for forest type = 1, df for error is shown for each year. Bold * denotes significant difference

2005 df=17	SS Model	MS Model	SS Residual	MS Residual	F	p
Species richness	5.691	5.691	1052.414	61.907	0.092	0.765
Chironomid richness.	0.301	0.301	98.857	5.815	0.052	0.823
EPT richness	0.723	0.723	162.014	9.530	0.076	0.786
Family richness	10.469	10.469	356.057	20.945	0.500	0.489
O/E50Signal	0.000	0.000	0.115	0.007	0.007	0.934
O/E50family	0.000	0.000	0.416	0.024	0.012	0.915

2006 df=14	SS Model	MS Model	SS Residual	MS Residual	F	p
Species richness	57.037	57.037	351.900	25.136	2.269	0.154
Chironomid richness.	2.204	2.204	75.233	5.374	0.410	0.532
EPT richness	**45.938**	**45.938**	**57.500**	**4.107**	**11.185**	**0.005 ***
Family richness	**51.338**	**51.338**	**101.100**	**7.221**	**7.109**	**0.018 ***
O/E50Signal	0.028	0.028	0.097	0.007	4.001	0.065
O/E50family	0.000	0.000	0.490	0.035	0.014	0.908

2007 df=15	SS Model	MS Model	SS Residual	MS Residual	F	p
Species richness	42.357	42.357	527.879	35.192	1.204	0.290
Chironomid richness.	0.289	0.289	104.182	6.945	0.042	0.841
EPT richness	**103.637**	**103.637**	**124.833**	**8.322**	**12.453**	**0.003 ***
Family richness	18.998	18.998	236.061	15.737	1.207	0.289
O/E50Signal	0.042	0.042	0.198	0.013	3.175	0.095
O/E50family	0.053	0.053	0.486	0.032	1.649	0.219

2008 df=18	SS Model	MS Model	SS Residual	MS Residual	F	p
Species richness	**201.621**	**201.621**	**602.929**	**33.496**	**6.019**	**0.025 ***
Chironomid richness.	0.193	0.193	62.357	3.464	0.056	0.816
EPT richness	**193.393**	**193.393**	**130.357**	**7.242**	**26.704**	**0.000 ***
Family richness	**63.260**	**63.260**	**223.690**	**12.427**	**5.090**	**0.037 ***
O/E50Signal	0.032	0.032	0.208	0.012	2.772	0.113
O/E50family	0.053	0.053	0.550	0.031	1.723	0.206

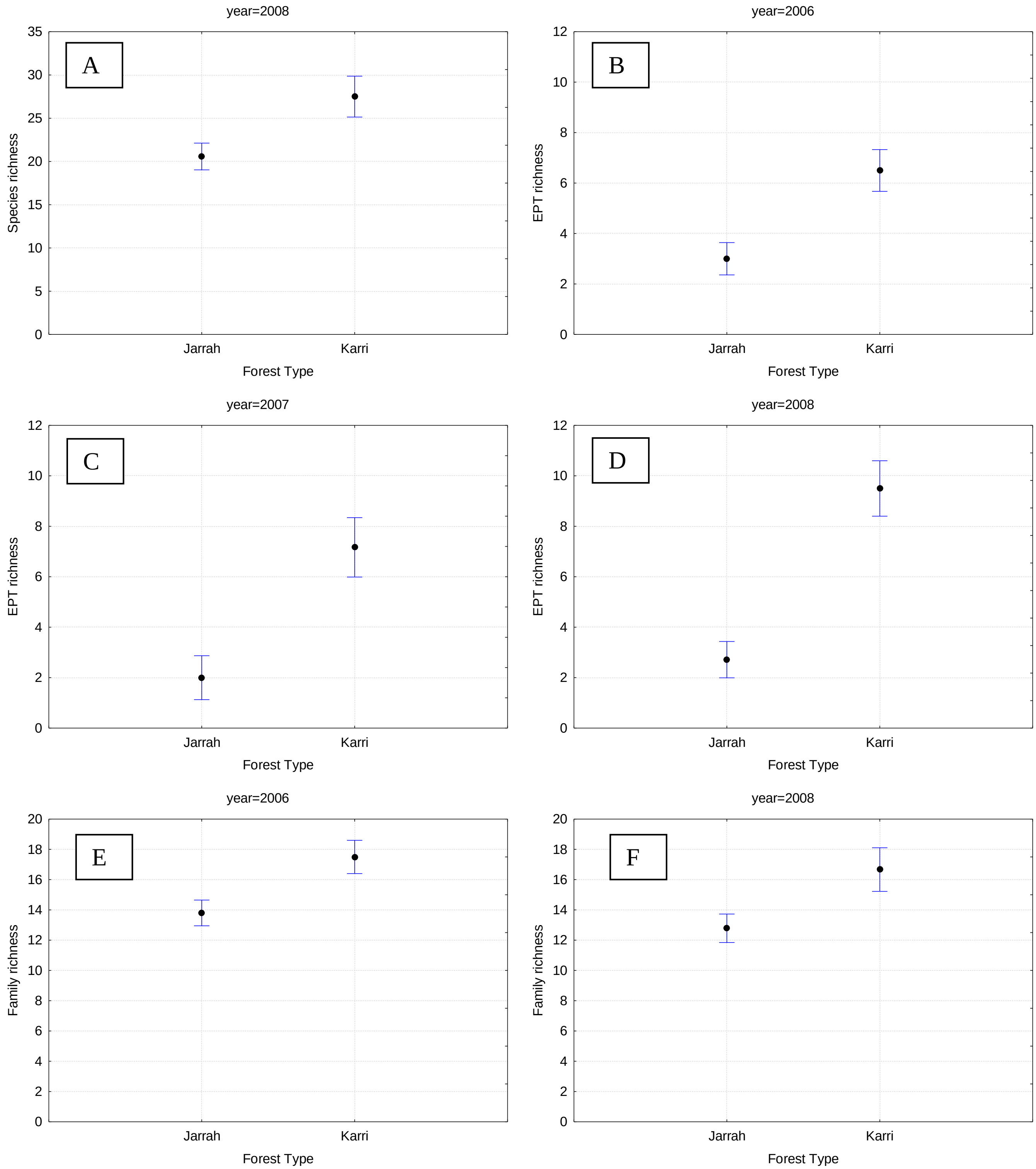


Figure 11. Biodiversity measures (mean±SE) which showed a significant difference between forest types in annual data. Species richness for 2008 (A), EPT richness for 2006 (B), 2007 (C) and 2008 (D), family richness for 2006 (E) and 2008 (F).

Environmental variables and forest type

A repeated measures ANOVA (within factor being year) was carried out to determine if there was difference between forest types and environmental variables (Table 14). Karri sites had significantly higher levels for colour (p=0.016), NH_3 (p=0.036), NO_3 (p=0.020) and turbidity (p=0.033). There was a significant difference between sampling years for pH (p=0.000), NH_3 (p=0.000), NO_3 (p=0.000), Total N (p=0.000) and turbidity (p=0.000). NO3 (p=0.003) and pH (p=0.000) showed a significant interaction between sampling year and forest.

Table 14. Repeated measures ANOVA between Forest type and environmental variables. Df for forest type = 1, df for year (repeated measure) = 3. Bold and * denotes significant difference (p<0.05).

		SS	MS	F	p
Conductivity	Forest Type	1.33	1.33	2.081	0.160
	Year	0.37	0.12	1.836	0.147
	Year*Forest Type	0.15	0.05	0.723	0.541
		SS	MS	F	p
pH	Forest Type	6.41	6.41	2.309	0.139
	Year	3.09	1.03	13.563	**0.000 ***
	Year*Forest Type	1.20	0.40	5.280	**0.002 ***
		SS	MS	F	p
Alkalinity	Forest Type	2.96	2.96	3.822	0.060
	Year	0.38	0.13	1.921	0.132
	Year*Forest Type	0.49	0.16	2.472	0.067
		SS	MS	F	p
Colour	Forest Type	6.68	6.68	6.593	**0.016 ***
	Year	0.27	0.09	1.254	0.295
	Year*Forest Type	0.48	0.16	2.177	0.096
		SS	MS	F	p
NH_3	Forest Type	1.99	1.99	4.826	**0.036 ***
	Year	12.13	4.04	31.568	**0.000 ***
	Year*Forest Type	0.42	0.14	1.105	0.352
		SS	MS	F	p
NO_3	Forest Type	4.40	4.40	6.010	**0.020 ***
	Year	1.41	0.47	7.222	**0.000 ***
	Year*Forest Type	1.01	0.34	5.148	**0.003 ***
		SS	MS	F	p
Total N	Forest Type	0.83	0.83	1.460	0.237
	Year	2.90	0.97	10.649	**0.000 ***
	Year*Forest Type	0.17	0.06	0.633	0.596
		SS	MS	F	p
Turbidity	Forest Type	1.21	1.21	5.038	**0.033 ***
	Year	14.95	4.98	26.344	**0.000 ***
	Year*Forest Type	0.77	0.26	1.351	0.263

As for the biodiversity measures, repeated measures ANOVA analysis between environmental variables and forest type does not take into account the disturbances occurring within the catchment areas. Since the disturbances changed annually at each site, sites can be analysed by contrasting forest types using ANOVA's, if each year is examined separately (Table 15). There was no significant difference between forest types for conductivity or Total N in any year sampled. Most other variables were significantly different for one or two years but not all. Nitrate showed the most consistent pattern with significantly higher concentrations in the Karri forest for 2006 (p=0.020), 2007 (p=0.014) and 2008 (p=0.006). The data collected in 2007 showed the most significant differences between the Jarrah and Karri forest streams. The Karri streams had lower alkalinity (p=0.041) and higher colour (p=0.017), NH_3 (p=0.006), NO_3 (p=0.014) and turbidity (p=0.028) than the Jarrah forest streams.

Table 15 ANOVA's between Forest type and environmental variables for each year sampled. Df for forest type = 1, df for error is shown for each year. Bold * denotes significant difference

	2005 df=17		2006 df =14		2007 df=16		2008 df = 18	
	F	p	F	p	F	p	F	p
Conductivity	1.554	0.229	1.156	0.301	0.348	0.563	1.357	0.259
pH	**7.784**	**0.013 ***	0.958	0.344	3.673	0.073	0.252	0.622
Temperature	1.073	0.315	0.091	0.768	0.467	0.504	1.431	0.247
Alkalinity	**5.505**	**0.031 ***	2.421	0.142	**4.916**	**0.041***	0.069	0.796
Colour	1.855	0.191	3.216	0.095	**7.051**	**0.017***	**6.419**	**0.021***
NH3	4.155	0.057	**6.306**	**0.025***	**10.032**	**0.006***	0.049	0.828
NO3	0.026	0.874	**6.847**	**0.020***	**7.629**	**0.014***	**9.809**	**0.006***
Total N	0.085	0.775	1.095	0.313	1.612	0.222	0.308	0.586
Turbidity	0.109	0.745	1.648	0.220	**5.829**	**0.028***	0.006	0.939

Comparison of invertebrate communities in Jarrah and Karri Forest streams

Of the 252 taxa identified to family level or lower, 99 occurred only in Jarrah forest streams whereas only 10 were restricted to Karri streams. The larger number of taxa recorded only in Jarrah streams would be at least partly due to the higher number of sites sampled in Jarrah forest and their distribution over a wider latitudinal range. Most species restricted to one forest type were rare. Species commonly occurring in Jarrah streams but absent from Karri streams include *Archiargiolestes* dragonflies and the chironomid *Dicrotendipes* sp. A. Species commonly occurring in Karri streams but absent from Jarrah streams include the caddisflies *Kosreithius* sp. and *Diplectrona* sp. AV9 and the chironomid *Tanytarsus* sp. I. Another 67 species occurred in both forest types but were more than twice as likely to occur in one forest type as in the other (33 more common in Jarrah and 34 more common in Karri). This leaves 76 species that were not substantially more common in either forest type.

An nMDS ordination suggested that Karri forest streams had more homogenous community structure than Jarrah forest streams (Figure 12), probably due at least in part to the greater latitudinal gradient in the Jarrah forest, although latitude alone accounted for only a small proportion of variation in overall community composition ($r^2 = 0.04$ in a DistLM analysis). A PermDisp analysis confirmed slightly greater variation in Jarrah forest samples. When only those invertebrates identified to species were considered, mean deviation from the centroid was 55.2 for Jarrah forest samples and 50.0 for Karri forest samples ($p<0.001$). For all taxa identified to family level or lower, mean deviations for Jarrah and Karri forest samples were 52.4 and 44.0 respectively ($p<0.001$).

The ordination in Figure 12 shows considerable overlap in composition between Jarrah and Karri forest samples, more so when only species level identifications were used. However, the overlap is mostly between Karri and southern Jarrah sites (latitude >33.6º), with little overlap in composition between northern Jarrah samples and Karri samples. The four northern Jarrah forest samples to the right of each plot are all from site MRY09. This site had an exceptional number of EPT taxa which explains their occurrence near Karri samples since EPT taxa are generally richer in Karri forest streams.

Despite the strong overlap in composition between Jarrah and Karri communities, a repeated measures Permanova analysis suggested community composition was significantly different between forest types, irrespective of whether all taxa ($p<0.01$) or just those groups identified to species ($p<0.001$) were included. In this analysis there were also significant differences between years and sites and a significant year by forest interaction ($p<0.001$). Permanova assumes homogeneity of variance between groups but the Permdisp analysis (above) suggested that community composition was more heterogeneous in Jarrah forest than in Karri forest streams. However, the difference in dispersion between forest type is low and the effect of forest type was strongly significant.

Since there are differences in community composition between Jarrah and Karri forest samples, the effects of catchment history on community composition is analysed separately in the following section. This makes analyses simpler by removing one level of variation.

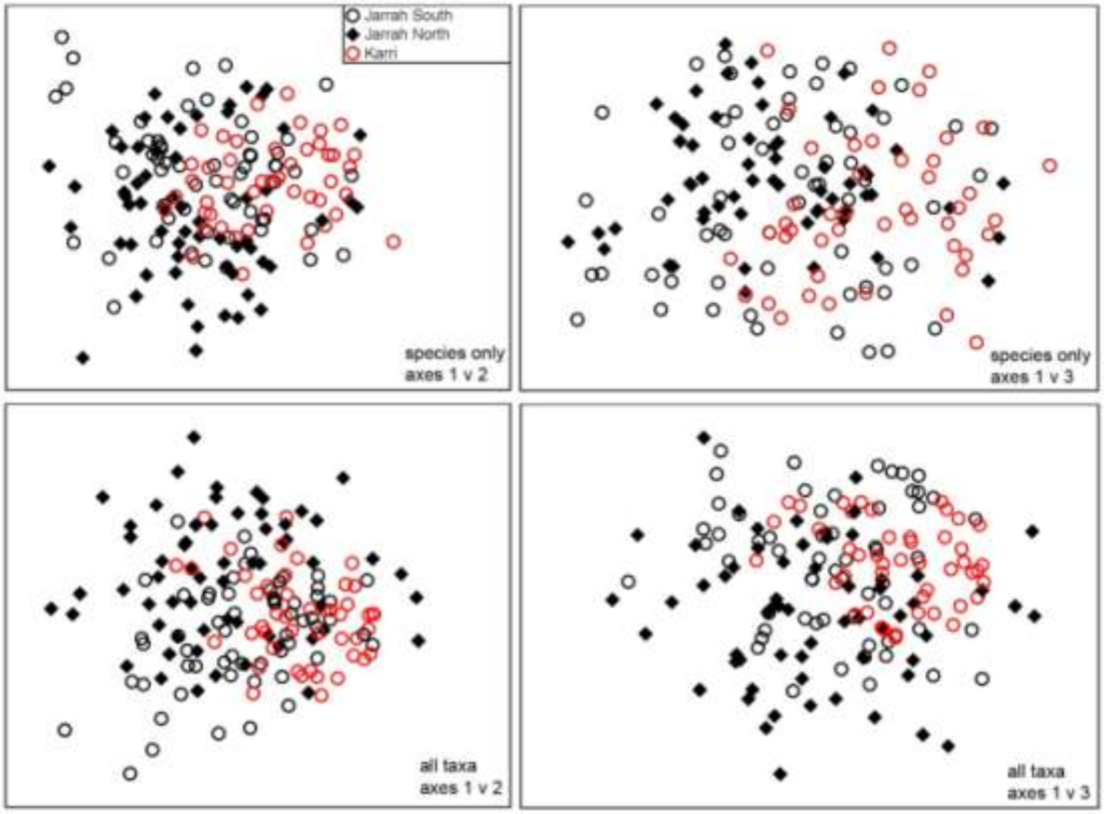


Figure 12. nMDS ordinations of samples based on community composition with forest type indicated and northern and southern Jarrah forest samples indicated. Top graphs are for taxa identified to species whereas bottom graphs are for all taxa identified to family level or lower.

Disturbance categories and history within the catchments

Three types of disturbances (logging, fire and dam) were recorded for the catchment area for each site. The disturbance categories assigned to each catchment are shown in Table 16. Tables 17 and 18 show the number of sites within each disturbance category split by year and forest type respectively. The area (ha) of disturbance ("Fire" or "Logging") which had occurred in the catchment area of each site was calculated using GIS software (Table 19). It is important to note that where the amount or proportion of logging or burning associated with a site is mentioned in the following text, this refers to the whole upstream catchment and does not imply logging or burning at the site itself.

Tables 20 and 21 show the records of harvested areas and areas burned within fuel age groups for each catchment area. Two sites, BLA52 and FRA17, have no record of harvest activity in their catchments since the 1920's (Table 19). Several catchments have not been logged in the past 3-4 decades; DEN09 was last logged in the 1960's and DEN26, SHA23, SWA31, WAR05 and WAR19 have not been logged since the 1970's. KEN11 was logged in 2007-2008 but prior to this was not logged since the 1970's. FRA17 also has had only one burn in the catchment, recorded in the 1999-2000 fire season, otherwise the fuel age in this catchment is over 20 years (Table 21).

The number of years since the last burn or logging was calculated for each catchment (Table 22). BLA53 was the catchment with the longest time since the last burn (6yrs prior to sampling in 2005) and it had been >10years since the catchment was last logged prior to sampling in 2005 (Table 21). Several catchments (BLA52, BUS26, FRA17, MRY41, MRY45, and WAR15) have not been burned in the last five years (since 2004, the year before sampling began). Only 5 catchments have had no logging or burning disturbances (two Karri – FRA17, WAR16, and three Jarrah – BLA52, BUS06, BUS26) since sampling began in 2005.

Table 16 : Disturbance categories recorded in the catchment area for sites. FT – Forest type, Disturbances denoted by; F- Fire, L- Logging; F+L- Fire and logging, D-dam. Grey cells are sites that were not sampled in that year, Blue cells denotes site with only water samples taken.

SITE	FT	2005	2006	2007	2008
BLA06	J	F+L	F+L	F+L	F+L
BLA43	J	F		F	
BLA51	J	L	F+L	L	F
BLA52	J				
BLA53	J			F	
BLA54	J	L	F+L		F
BLA55	J	F	L	L	F
BLA56	J	F			
BUS05	J				
BUS26	J				
COL36	J			F	
COL37	J	F			F
COL38	J	L	L	L	F
DEN09	J			F	
DEN26	J	F			
DON03	J	F+L	F+L	F+L	F+L
DON14	K	L	F+L	F+L	
DON15	K	F	F		
DON16	K		F	L	L
FRA17	K				
FRA18	J	F			
HAR01	J		F		
HAR20	J	D	D	D	D
HAR21	J			F	
KEN11	J	F	F		
MRY09	J	L	F	L	L
MRY33	J		F		L
MRY41	J		L		
MRY42	J	D	D	D	D
MRY43	J	F	F	F	F
MRY44	J	F			
MRY45	J				F
SHA21	K				L
SHA22	K		F	L	F+L
SHA23	K	F			F
SHA24	K	F+L		F+L	F+L
SWA04	J	F	F	F	F+L
SWA24	J	F			
SWA31	J	F	F	F	F
SWA32	J	F	F		F
SWA33	J	F	F	F	
SWA34	J	D	D	D	D
SWA35	J	F	F	F	F
WAR01	K	F+L			
WAR02	J			F	F
WAR05	J		F	F	F
WAR15	K	F+L	F+L	F+L	F+L
WAR16	K				
WAR17	K	F		F	
WAR18	J				F
WAR19	J	F	F		

Table 17: The number of sites within each disturbance category in each year. Note: Not all sites were sampled for invertebrates each year, the number of sites sampled are shown in brackets.

	2005	2006	2007	2008
Fire	19 (16)	15 (12)	13 (12)	14 (12)
Log	5 (5)	3 (3)	6 (6)	4 (4)
Fire+log	5 (4)	6 (6)	5 (5)	6 (6)
Dam	3 (2)	3 (3)	3 (3)	3 (3)
Total disturbed	32 (27)	27 (24)	27 (26)	27 (25)
No disturbance	19 (19)	24 (16)	24 (20)	24 (23)
Total sampled	46	40	46	48

Table 18. The number of Jarrah and Karri forest sites within each disturbance category.

	Jarrah	Karri
Fire	43	7
Log	17	5
Fire+log	10	11
Dam	11	0
Total disturbed	83	23
No disturbance	50	23

Table 19: Area of the catchment which was burned or logged during the year before sampling. "%1yr" denotes the percentage of the catchment which was burned or logged in the year prior to sampling.

SITE	Forest type	Catchment Area (ha)	year	burn area (ha)	log area (ha)	%1yr burn	%1yr log
BLA06	Jarrah	55244	2005	1764	121	3.2	0.2
			2006	2811	363	5.1	0.7
			2007	1292	182	2.3	0.3
			2008	708	173	1.3	0.3
BLA43	Jarrah	10011	2005	1878	0	18.8	0.0
			2006	0	0	0.0	0.0
			2007	72	0	0.7	0.0
			2008	0	0	0.0	0.0
BLA51	Jarrah	6433	2005	0	229	0	3.6
			2006	968	366	15.0	5.7
			2007	0	205	0	3.2
			2008	0.8	0	0.0	0.0
BLA52	Jarrah	401	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
BLA53	Jarrah	1525	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	169	0	11.1	0.0
			2008	0	0	0.0	0.0
BLA54	Jarrah	2409	2005	0	443	0.0	18.4
			2006	1286	9	53.4	0.4
			2007	0	0	0.0	0.0
			2008	423	0	17.6	0.0
BLA55	Jarrah	4741	2005	1085	0	22.9	0.0
			2006	0	269	0.0	5.7
			2007	0	36	0.0	0.8
			2008	1	0	0.0	0.0
BLA56	Jarrah	4731	2005	2029	0	42.9	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
BUS05	Jarrah	4689	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
BUS26	Jarrah	550	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
COL36	Jarrah	425	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	184	0	43.2	0.0
			2008	0	0	0.0	0.0
COL37	Jarrah	420	2005	418	0	99.6	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	2	0	0.4	0.0
COL38	Jarrah	81	2005	0	20	0.0	24.2
			2006	0	26	0.0	32.2
			2007	0	0	0.0	0.1
			2008	81	0	100.0	0.0
DEN09	Jarrah	3832	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	671	0	17.5	0.0
			2008	0	0	0.0	0.0

SITE	Forest type	Catchment Area (ha)	year	burn area (ha)	log area (ha)	%1yr burn	%1yr log
DEN26	Jarrah	718	2005	434	0	60.5	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
DON03	Jarrah	15681	2005	475	149	3.0	0.9
			2006	189	516	1.2	3.3
			2007	1501	288	9.6	1.8
			2008	335	117	2.1	0.7
DON14	Karri	1400	2005	0	45	0.0	3.2
			2006	67	3	4.8	0.2
			2007	1	2	0.1	0.1
			2008	0	0	0.0	0.0
DON15	Karri	2420	2005	2070	0	85.5	0.0
			2006	247	0	10.2	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
DON16	Karri	3307	2005	0	0	0.0	0.0
			2006	656	0	19.9	0.0
			2007	0	17	0.0	0.5
			2008	0	9	0.0	0.3
FRA17	Karri	221	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
FRA18	Jarrah	2347	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0
			2008	0	0	0.0	0
HAR01	Jarrah	2802	2005	0	0	0.0	0.0
			2006	408	0	14.6	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
HAR21	Jarrah	185	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	26	0	13.9	0.0
			2008	0	0	0.0	0.0
KEN11	Jarrah	2867	2005	4	0	0.1	0.0
			2006	71	0	2.5	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
MRY09	Jarrah	1697	2005	0	101	0.0	5.9
			2006	1303	0	76.8	0.0
			2007	0	2	0.0	0.1
			2008	0	9	0.0	0.5
MRY33	Jarrah	1756	2005	0	0	0.0	0.0
			2006	3	0	0.2	0.0
			2007	0	0	0.0	0.0
			2008	0	35	0.0	2.0
MRY41	Jarrah	3510	2005	0	0	0.0	0.0
			2006	0	18	0.0	0.5
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
MRY43	Jarrah	6783	2005	717	0	10.6	0.0
			2006	632	0	9.3	0.0
			2007	295	0	4.4	0.0
			2008	121	0	1.8	0.0
MRY44	Jarrah	2574	2005	671	0	26.1	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0

SITE	Forest type	Catchment Area (ha)	year	burn area (ha)	log area (ha)	%1yr burn	%1yr log
MRY45	Jarrah	2465	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	113	0	4.6	0.0
SHA21	Karri	768	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
SHA22	Karri	2242	2005	0	0	0.0	0.0
			2006	776	0	34.6	0.0
			2007	0	13	0.0	0.6
			2008	0	0	0.0	0.0
SHA23	Karri	150	2005	74	0	49.2	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	77	0	51.5	0.0
SHA24	Karri	1768	2005	586	51	33.2	2.9
			2006	0	0	0.0	0.0
			2007	68	84	3.9	4.8
			2008	75	52	4.2	3.0
SWA04	Jarrah	1395	2005	2	0	0.1	0.0
			2006	2	0	0.1	0.0
			2007	25	0	1.8	0.0
			2008	50	145	3.6	10.4
SWA24	Jarrah	2984	2005	2689	0	90.1	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
SWA31	Jarrah	24566	2005	12266	0	49.9	0.0
			2006	7471	0	30.4	0.0
			2007	4563	0	18.6	0.0
			2008	254	0	1.0	0.0
SWA32	Jarrah	28331	2005	194	0	0.7	0.0
			2006	1115	0	3.9	0.0
			2007	0	0	0.0	0.0
			2008	624	0	2.2	0.0
SWA33	Jarrah	14110	2005	2	0	0.0	0.0
			2006	286	0	2.0	0.0
			2007	820	0	5.8	0.0
			2008	0	0	0.0	0.0
SWA35	Jarrah	7555	2005	6375	0	84.4	0.0
			2006	29	0	0.4	0.0
			2007	313	0	4.1	0.0
			2008	376	0	5.0	0.0
WAR01	Karri	1130	2005	17	12	1.5	1.1
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
WAR02	Jarrah	2707	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	4	0	0.1	0.0
			2008	65	0	2.4	0.0
WAR05	Jarrah	5793	2005	0	0	0.0	0.0
			2006	351	0	6.1	0.0
			2007	60	0	1.0	0.0
			2008	465	0	8.0	0.0
WAR15	Karri	9203	2005	114	20	1.2	0.2
			2006	92	174	1.0	1.9
			2007	347	346	3.8	3.8
			2008	49	112	0.5	1.2

SITE	Forest type	Catchment Area (ha)	year	burn area (ha)	log area (ha)	%1yr burn	%1yr log
WAR16	Karri	498	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
WAR17	Karri	3441	2005	23	0	0.7	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0
WAR18	Jarrah	3681	2005	0	0	0.0	0.0
			2006	0	0	0.0	0.0
			2007	0	0	0.0	0.0
			2008	2970	0	80.7	0.0
WAR19	Jarrah	918	2005	25	0	2.7	0.0
			2006	29	0	3.1	0.0
			2007	0	0	0.0	0.0
			2008	0	0	0.0	0.0

Table 20. Record of harvested areas within each catchment.

Catchment	Total Area (Ha)	Area Public Land	<1920	1920-29	1930-39	1940-49	1950-59	1960-69	1970-79	1980-89	1990-99	2000-08	No record of harvesting
BLA06	55,241	49,488	3,659	6,580	4,076	3,006	2,409	1,592	6,043	4,085	11,820	6,148	69
BLA43	10,015	10,015	0	0	0	0	0	22	217	794	772	0	8,211
BLA51	6,431	4,063	401	0	88	0	188	550	976	0	796	1,064	0
BLA52	400	400	0	0	0	0	0	0	0	0	0	0	400
BLA53	1,523	1,523	0	0	0	0	1,267	26	33	0	0	19	178
BLA54	2,409	2,409	0	0	0	0	35	354	826	392	7	795	0
BLA55	4,739	4,162	230	1,249	0	99	217	0	389	525	1,111	304	37
BLA56	4,724	4,724	0	0	0	352	0	107	1,023	2,127	21	0	1,094
BUS05	4,694	1,587	31	0	0	105	606	311	21	107	0	0	406
BUS26	551	551	0	1	0	0	24	8	394	125	0	0	0
COL36	425	425	0	0	110	0	0	0	0	0	316	0	0
COL37	419	419	0	0	0	0	0	0	256	163	0	0	0
COL38	81	81	0	0	0	0	0	35	0	0	0	45	0
DEN09	3,827	1,106	0	0	0	258	161	460	0	0	0	0	228
DEN26	718	664	0	0	0	0	340	0	153	0	0	0	172
DON03	15,679	15,558	57	1,140	0	357	3,150	2,425	637	2,560	1,981	2,118	1,134
DON14	1,398	1,183	0	17	327	0	0	0	0	60	392	388	0
DON15	2,422	2,422	0	0	821	0	0	0	0	0	32	0	1,569
DON16	3,308	3,308	0	0	728	1,498	328	38	4	22	616	74	0
FRA17	221	221	0	0	0	0	0	0	0	0	0	0	221
FRA18	2,346	1,437	0	0	0	0	0	638	0	0	31	0	768
HAR01	2,798	2,798	11	44	719	339	2	0	312	1,243	83	0	45
HAR21	185	84	0	0	0	10	30	17	0	3	0	0	24
KEN11	2,861	2,861	0	0	0	0	0	56	484	0	0	0	2,321
MYR09	1,698	1,698	13	20	588	162	26	0	3	153	312	421	0
MYR33	1,756	1,756	40	0	0	96	0	124	877	560	0	58	0
MYR41	3,510	3,510	0	2	1,576	0	0	0	62	0	377	1,478	14
MRY43	6,788	5,681	652	614	0	761	27	663	1,401	1,071	269	0	224
MYR44	2,576	2,576	27	19	312	0	0	0	0	291	1,061	865	0
MYR45	2,463	2,421	0	0	0	0	0	1,845	465	0	90	0	21
SHA21	768	768	0	0	0	3	3	0	285	224	13	0	239
SHA22	2,244	2,244	11	0	0	0	108	375	484	97	0	13	1,156
SHA23	148	148	0	0	27	10	0	0	37	0	0	0	73
SHA24	1,767	1,767	0	0	0	0	278	614	265	0	240	312	58
SWA04	1,396	1,347	18	1	112	101	155	101	196	19	32	612	0
SWA24	2,977	2,977	1,102	13	453	0	0	0	0	66	1,253	0	90
SWA31	24,567	20,482	0	0	0	0	1,080	14,539	221	0	0	0	4,643
SWA32	28,329	28,329	0	1,138	1,379	0	2,790	7,061	4,743	1,329	2,179	4,848	2,862
SWA33	14,113	14,113	0	14	20	138	245	2,269	6,790	1,180	424	184	2,850
SWA35	7,557	6,249	269	52	1,077	1,698	0	441	187	2,122	259	0	143
WAR01	1,130	941	0	0	432	0	0	0	0	421	75	13	0
WAR02	2,705	2,039	0	0	264	749	6	0	888	78	54	0	0
WAR05	5,795	4,974	0	0	0	0	303	1,865	2,715	0	0	0	91
WAR15	9,200	4,058	0	116	912	130	284	29	0	452	509	1,011	618
WAR16	497	497	0	0	0	236	22	0	0	9	210	20	0
WAR17	3,439	3,439	0	0	0	0	0	58	721	1,223	611	7	818
WAR18	3,681	3,581	0	0	0	0	0	843	146	2,537	9	0	46
WAR19	919	919	0	0	0	0	0	326	245	0	0	0	348

Data is courtesy of FMB using Forest Management Information System (FMIS), note that catchment areas may be slightly different (<5ha) due to different GIS systems used to calculate areas.

Table 21 Area of the catchment burned within Fuel age groups.

Catchment	Total Area (Ha)	Area of Public Land	Fuel age at 30.06.09					
			1 - 5	6 - 10	11 - 15	16 - 20	>20	No fire record
BLA06	55,241	49,488	10,435	14,657	14,259	3,963	1,001	5,172
BLA43	10,015	10,015	2,104	3,682	2,332	1,897	0	0
BLA51	6,431	4,063	967	962	1,683	166	281	3
BLA52	400	400	0	322	78	0	0	0
BLA53	1,523	1,523	168	14	1,341	0	0	0
BLA54	2,409	2,409	1,707	93	33	0	0	576
BLA55	4,739	4,162	1,219	271	1,839	142	5	685
BLA56	4,724	4,724	2,031	795	1,045	853	0	0
BUS05	4,694	1,587	66	732	35	171	0	582
BUS26	551	551	0	229	213	110	0	0
COL36	425	425	183	128	115	0	0	0
COL37	419	419	419	0	0	0	0	0
COL38	81	81	81	0	0	0	0	0
DEN09	3,827	1,106	405	233	0	0	0	467
DEN26	718	664	410	31	224	0	0	0
DON03	15,679	15,558	2,733	3,655	2,884	2,520	3,759	6
DON14	1,398	1,183	69	498	342	165	100	8
DON15	2,422	2,422	2,320	59	3	34	6	0
DON16	3,308	3,308	658	16	555	2,077	2	0
FRA17	221	221	0	137	0	0	84	0
FRA18	2,346	1,437	3	1,427	4	0	1	0
HAR01	2,798	2,798	408	1,346	677	367	0	0
HAR21	185	84	26	23	16	0	13	6
KEN11	2,861	2,861	342	2,350	169	0	0	0
MYR09	1,698	1,698	1,304	0	1	103	289	0
MYR33	1,756	1,756	5	1,751	0	0	0	0
MYR41	3,510	3,510	0	644	2,801	0	65	0
MRY43	6,788	5,681	1,638	1,130	507	588	1,688	129
MYR44	2,576	2,576	672	885	1,018	0	0	0
MYR45	2,463	2,421	112	2,306	0	0	0	3
SHA21	768	768	0	13	1	153	600	0
SHA22	2,244	2,244	777	57	882	1	526	0
SHA23	148	148	148	0	0	0	0	0
SHA24	1,767	1,767	679	101	631	328	28	0
SWA04	1,396	1,347	81	904	91	0	241	30
SWA24	2,977	2,977	2,685	229	0	63	0	0
SWA31	24,567	20,482	10,272	1,050	2,047	2,964	133	4,016
SWA32	28,329	28,329	1,938	22,748	2,736	8	899	0
SWA33	14,113	14,113	6,845	5,655	1,613	0	0	0
SWA35	7,557	6,249	5,809	33	153	239	0	15
WAR01	1,130	941	17	173	65	617	63	7
WAR02	2,705	2,039	1,306	21	98	587	27	0
WAR05	5,795	4,974	901	3,480	39	0	547	7
WAR15	9,200	4,058	922	1,038	522	177	1,038	361
WAR16	497	497	0	404	77	2	15	0
WAR17	3,439	3,439	24	0	1,603	392	1,366	54
WAR18	3,681	3,581	3,464	18	51	48	0	0
WAR19	919	919	28	891	0	0	0	0

Data is courtesy of FMB using FMIS, note that catchment areas may be slightly different (<5ha) due to different GIS systems used to calculate areas.

Table 22. The number of years since the last burn (YSLB), logging (YSLL) and disturbance (YSLDist- fire and/or logging) occurred in the catchment area for a site prior to sampling (2005). "D" denotes dam site..

SITE	YSLB	YSLL	YSLDist
BLA06	0	0	0
BLA43	0	>10	0
BLA51	1	0	0
BLA52	2	>10	2
BLA53	6	>10	6
BLA54	2	0	0
BLA55	0	>10	0
BLA56	0	>10	0
BUS05	1	>10	1
BUS26	2	>10	2
COL36	1	>10	1
COL37	0	>10	0
COL38	>10	0	0
DEN09	2	>10	2
DEN26	0	>10	0
DON03	0	0	0
DON14	1	0	0
DON15	0	6	0
DON16	5	1	1
FRA17	5	>10	5
FRA18	0	>10	0
HAR01	1	6	1
HAR20	D	D	D
HAR21	1	>10	1
KEN11	0	>10	0
MRY09	>10	0	0
MRY33	2	>10	2
MRY41	5	1	1
MRY42	D	D	D
MRY43	0	>10	0
MRY44	0	1	0
MRY45	1	>10	1
SHA21	1	1	1
SHA22	1	1	1
SHA23	0	>10	0
SHA24	0	0	0
SWA04	0	>10	0
SWA24	0	6	0
SWA31	0	>10	0
SWA32	0	1	0
SWA33	0	4	0
SWA34	D	D	D
SWA35	0	6	0
WAR01	0	0	0
WAR02	2	>10	2
WAR05	1	>10	1
WAR15	0	0	0
WAR16	2	4	2
WAR17	0	3	0
WAR18	1	>10	1
WAR19	0	>10	0

Invertebrate biodiversity measures recorded for the different forest types and disturbance categories are shown in Figures 13 to 17. Variability plots, rather than mean and standard errors, were used to plot the data as some disturbance categories within a forest type and year have only two data points and mean plots with standard errors may misrepresent the data with such few points. Variability plots show the raw data split into various groupings (forest type, year and disturbances) to help show the amount of variability within the groups and trends in the data. There is only "dam" disturbance in the Jarrah forest as there are no "dam" sites sampled in the Karri forest.

The following paragraphs highlight some qualitative features of Figures 13 to 17 but see the following section for statistical analyses.

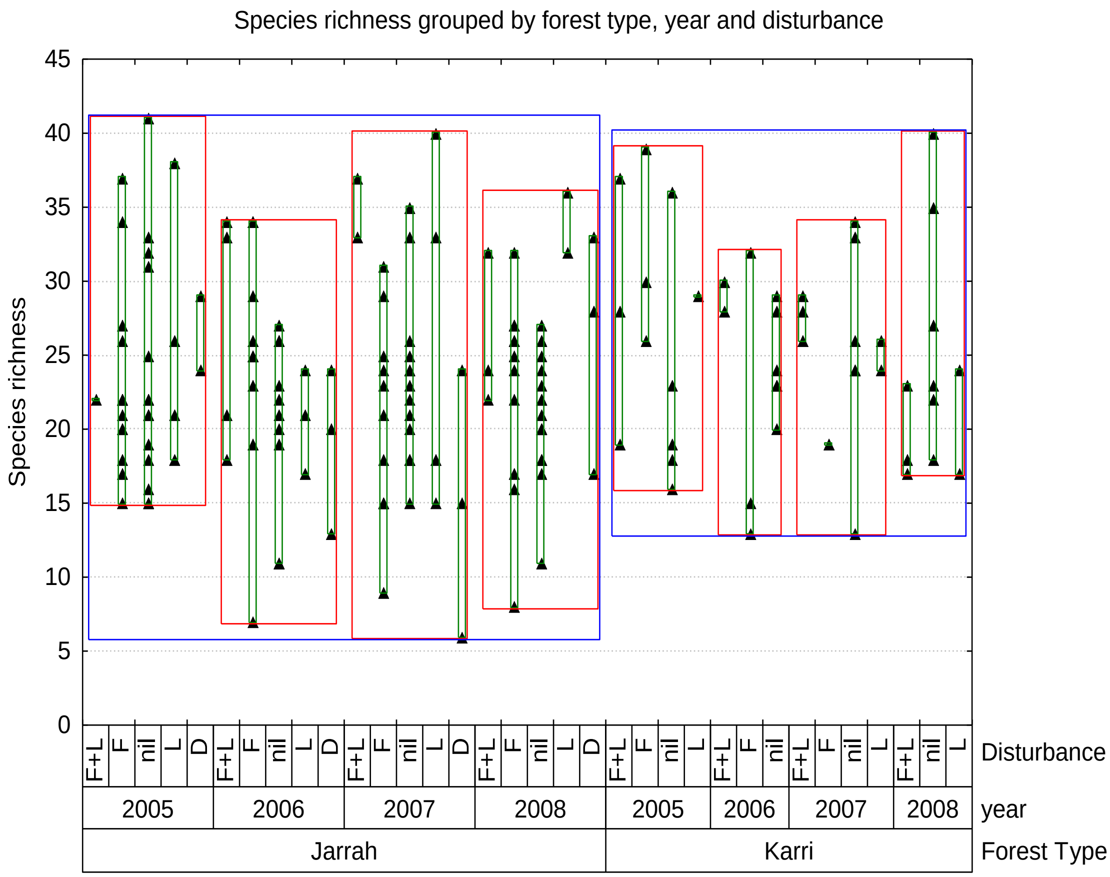
Figure 13 shows that Karri forest streams tend to be richer, with Karri samples having a minimum of 12 species. Samples from catchments which had been logged (with or without fire) seemed to have more species present (always having more than 15 species) than sites which were undisturbed or burned only (F). However the total number of species at logged sites were not higher than the other disturbance groups.

Figure 14 shows that except for two samples (one Karri, F disturbance in 2005 and one Jarrah, F disturbance in 2008) chironomid richness was evenly distributed between groups (forest type, year and disturbance).

Karri sites generally had slightly higher EPT richness and only 1 Karri sample lacked any EPT taxa (Figure 15). Dams seemed to have an impact on EPT richness with all dam samples having less than 6 species. Sites with logging disturbance "L" showed opposite trends within the two forest types. Karri "L" sites tended to have a lower EPT richness (average 3.5) than other Karri sites, whereas Jarrah forest "L" sites tended to have higher EPT richness (average 6.9) compared to other Jarrah sites. However there was large variability within all groups; forest, disturbance and year.

Figure 16 shows that family richness was slightly higher in the Jarrah forest in 2005, than in the other years. The Karri sites had at least 8 families found at each site, compared to a minimum for 4 families found at the Jarrah sites. There seems to be more families present at sites with "F+L" and "L" disturbances with a minimum of at least 9 families found in both Jarrah and Karri sites.

AUSRIVAS O/E family scores were generally higher in the Karri sites compared to the Jarrah sites. Within Jarrah sites, O/E scores in 2005 were higher than for other years, with all sites scoring at least 0.64, therefore all sites received at least a B band for 2005 (Figure 17). Karri sites generally higher O/E family scores than the Jarrah sites, all receiving at least a B band. It is interesting to note that the Jarrah "F+L" sites had similar scores and range in values to those from the Karri sites.



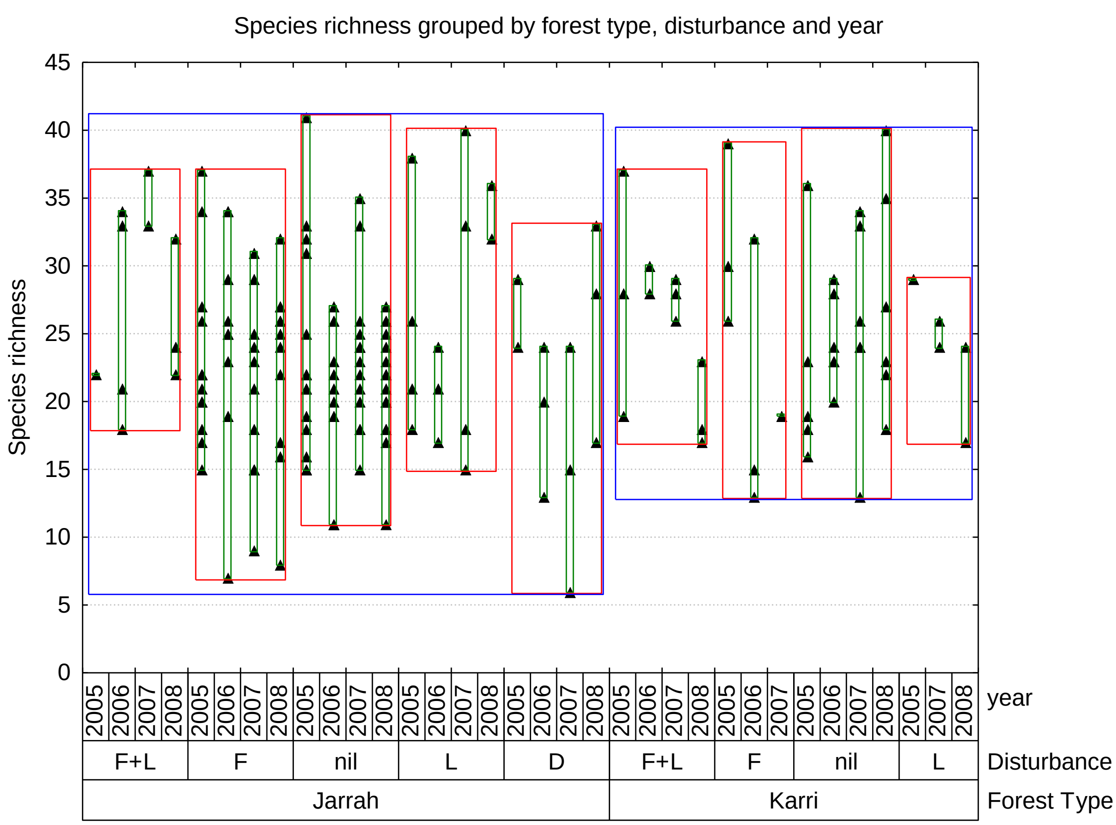


Figure 13. Variability plots showing species richness raw data grouped by forest type, year and disturbance categories.

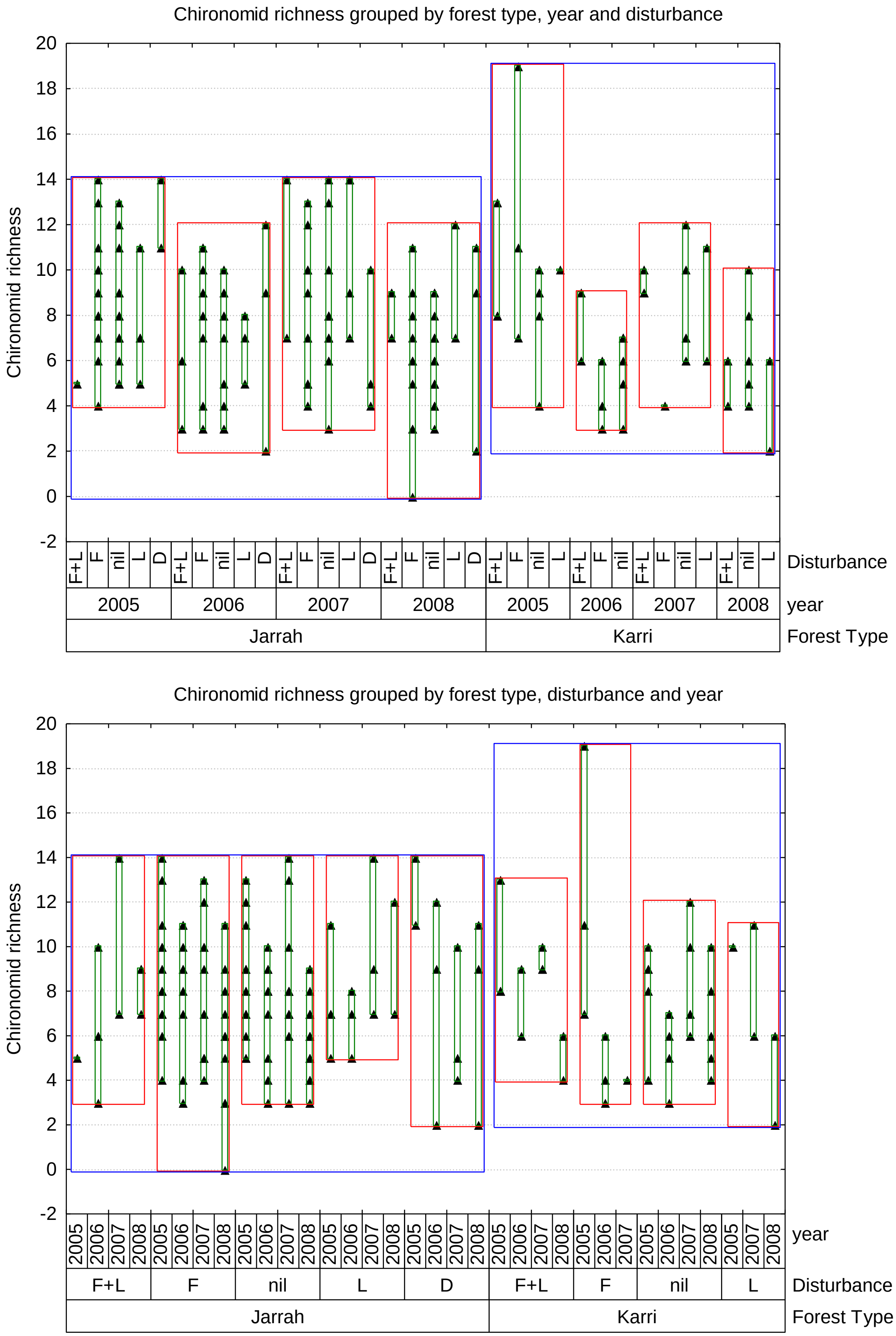
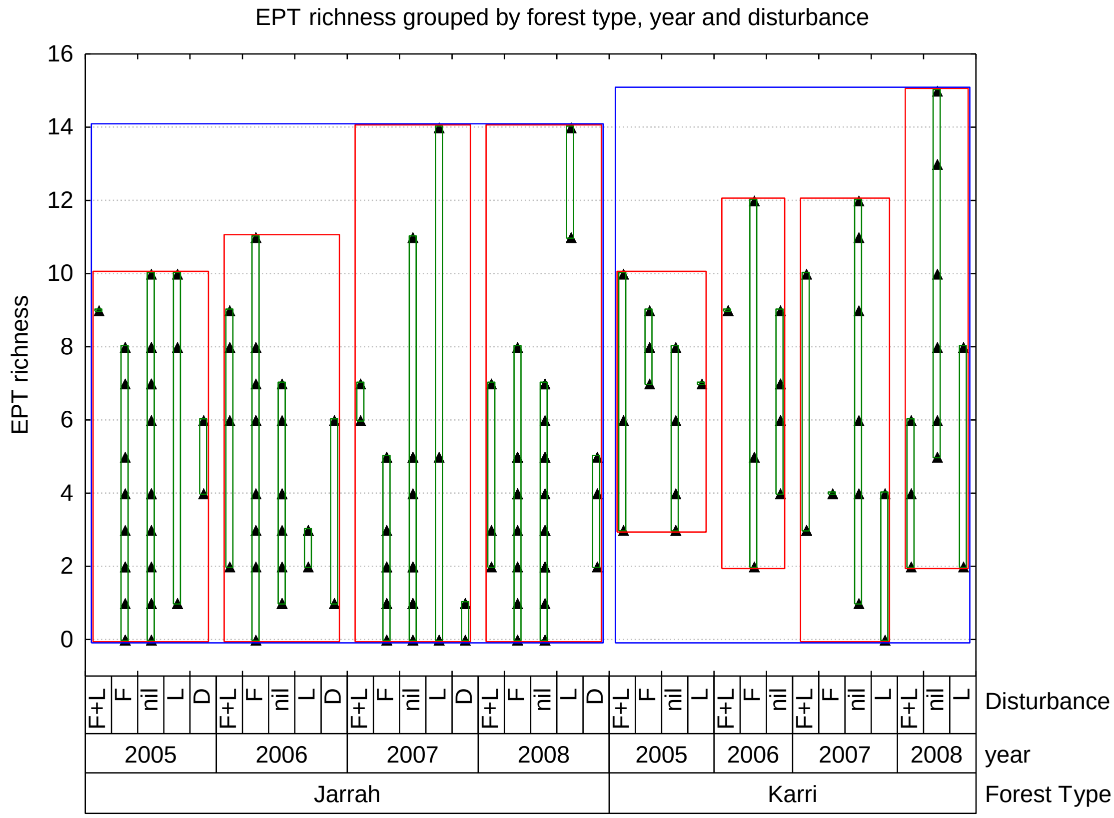


Figure 14. Variability plots showing Chironomid richness raw data grouped by forest type, year and disturbance categories.



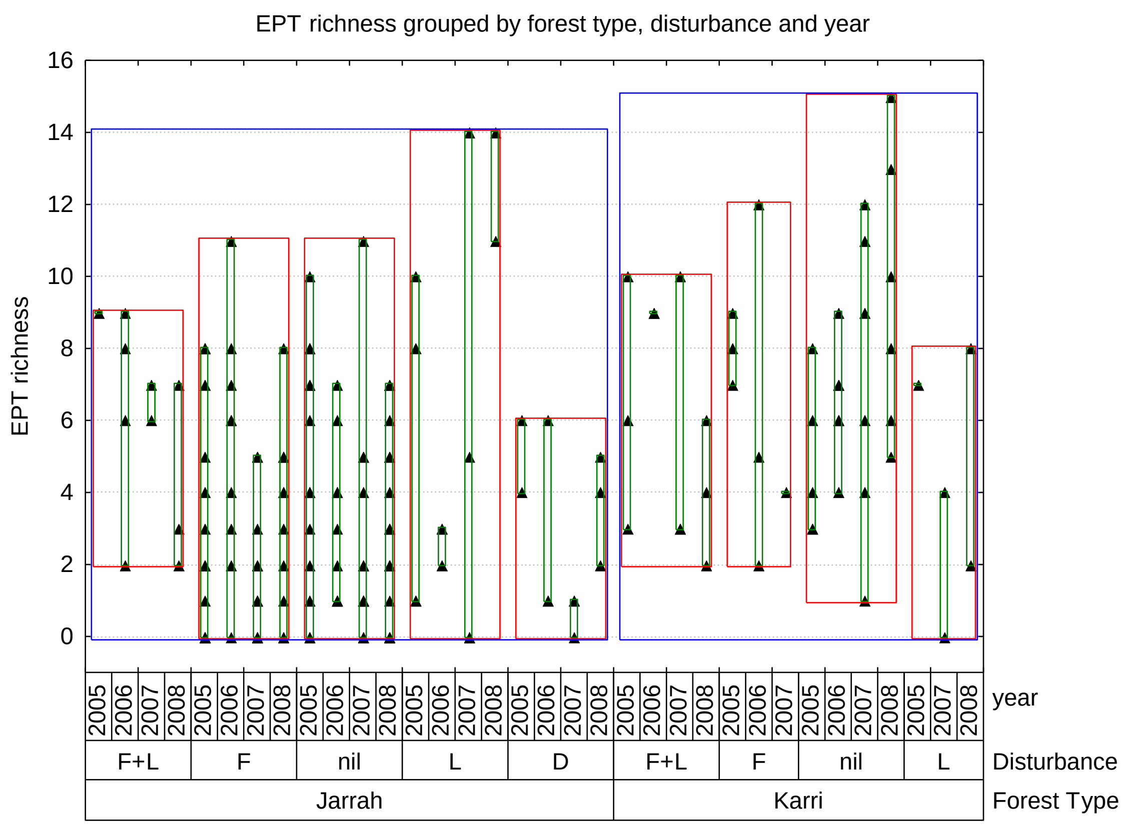


Figure 15. Variability plots showing EPT richness raw data grouped by forest type, year and disturbance categories.

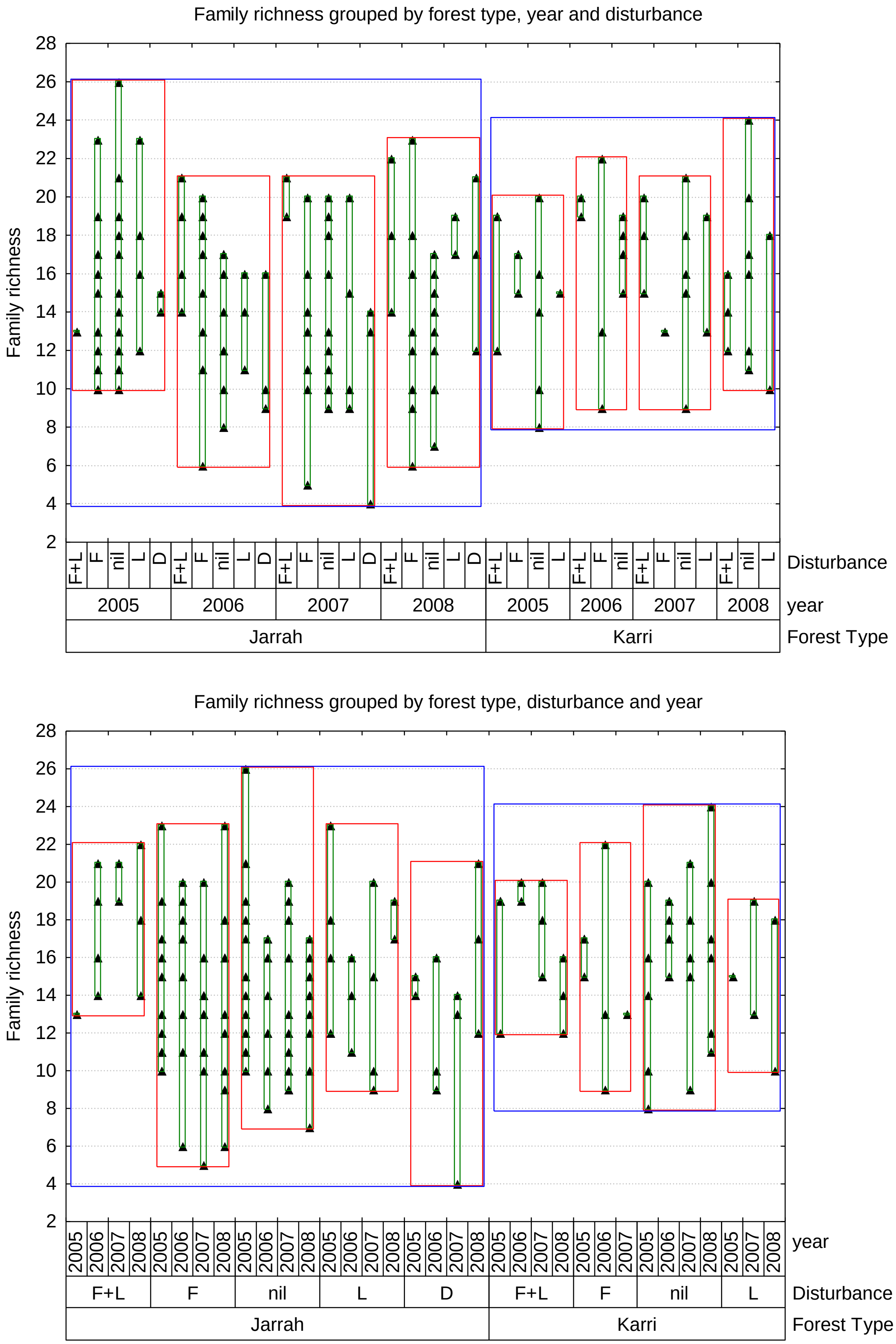
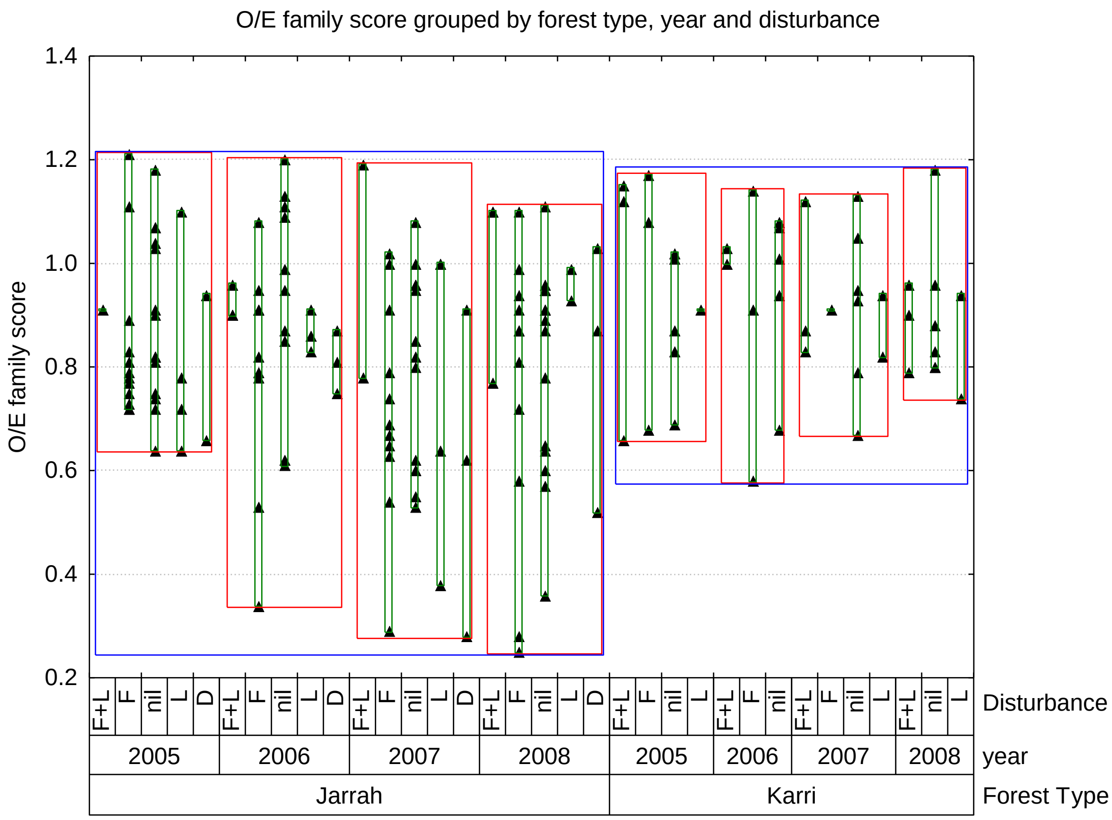


Figure 16. Variability plots showing family richness raw data grouped by forest type, year and disturbance categories.



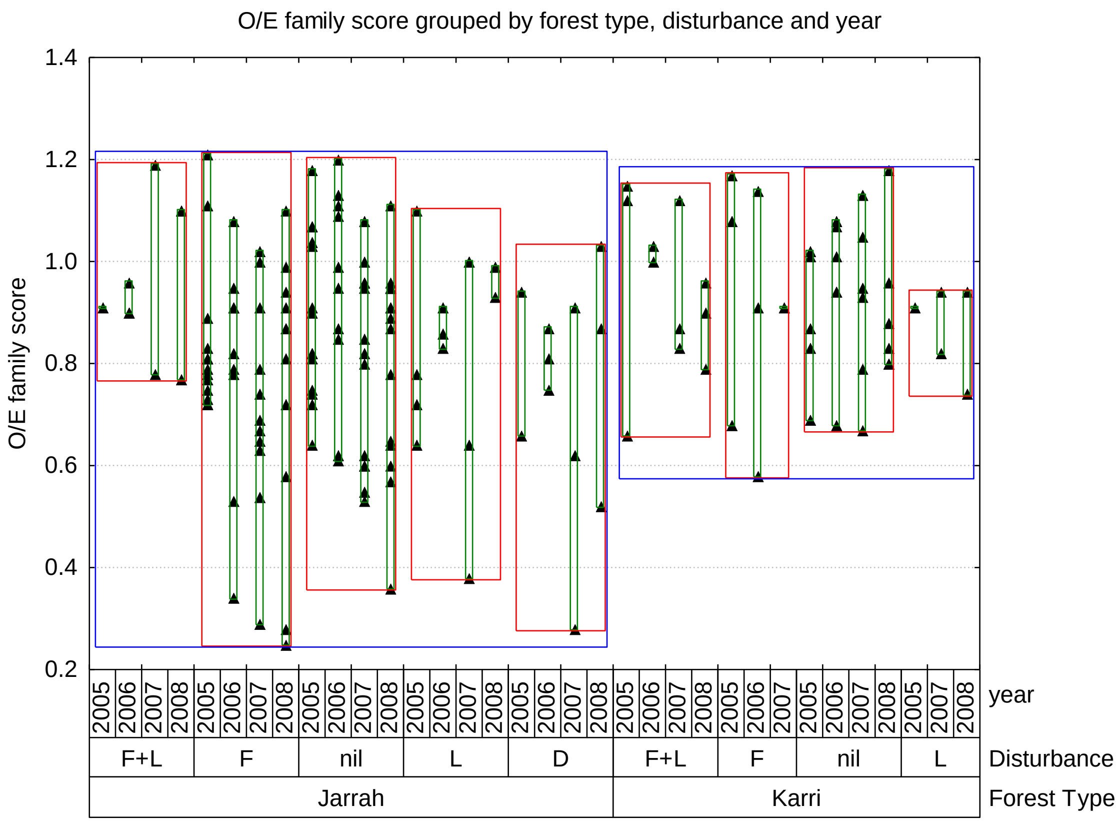


Figure 17. Variability plots showing O/E family scores grouped by forest type, year and disturbance categories.

Effect of fire and logging in the catchment on biodiversity measures

The effects of logging and fire on biodiversity were examined by a series of ANOVAs.

Analysis has been carried out separately on the Jarrah and Karri forests, as it was previously demonstrated that there are differences in community composition and richness between forest types. The data was analysed on a year by year basis as the disturbance categories change annually for a catchment.

Jarrah forest streams

In the Jarrah forest, disturbance category ("F", "F+L", "L", "nil") had a significant effect on species richness and EPT richness in 2008 (Table 23). Tukey's HSD test showed species richness was significantly higher in "L" than "undisturbed" and "F" catchments. EPT richness was significantly higher in "L" than "undisturbed", "F" and "F+L" catchments in 2008.

Separate analyses for each disturbance type were also performed.

Table 23. ANOVA's between disturbance category in Jarrah catchments and invertebrate measures for each year sampled . Df for disturbance category = 3, df for each year is shown next to the year. Bold * denotes significant difference

2005 df=28	SS	MS	F	p
Species richness	23.562	7.854	0.145	0.932
Chironomid richness.	17.326	5.775	0.862	0.472
EPT richness	41.738	13.913	1.209	0.325
Family richness	40.189	13.396	0.732	0.542
O/E50Signal	0.020	0.007	0.657	0.585
O/E50family	0.033	0.011	0.414	0.744
2006 df=22	SS	MS	F	p
Species richness	147.779	49.260	1.020	0.403
Chironomid richness.	13.145	4.382	0.611	0.615
EPT richness	47.643	15.881	2.144	0.124
Family richness	43.883	14.628	1.109	0.367
O/E50Signal	0.003	0.001	0.095	0.962
O/E50family	0.116	0.039	1.071	0.382
2007 df=26	SS	MS	F	p
Species richness	402.696	134.232	2.742	0.064
Chironomid richness.	39.034	13.011	1.310	0.292
EPT richness	53.503	17.834	1.680	0.196
Family richness	90.062	30.021	1.876	0.158
O/E50Signal	0.018	0.006	0.470	0.705
O/E50family	0.127	0.042	0.882	0.463
2008 df=28	SS	MS	F	p
Species richness	318.818	106.273	3.899	**0.019**
Chironomid richness.	35.322	11.774	2.133	0.118
EPT richness	160.705	53.568	9.213	**0.000**
Family richness	86.037	28.679	2.107	0.122
O/E50Signal	0.012	0.004	0.335	0.800
O/E50family	0.171	0.057	1.115	0.360

Fire disturbances on biodiversity measures in the Jarrah forest streams.

The effect of fire on biodiversity measures was analysed using ANOVA's on the annual data. Fire disturbance was defined as a catchment which had a fire disturbance, which includes "F+L" sites. There was no significant disturbance of fire on any of the biodiversity measures within the Jarrah forest in 2005, 2007 and 2008, however there was a significant effect of fire on EPT richness (p= 0.018) in 2006 (Figure 18)

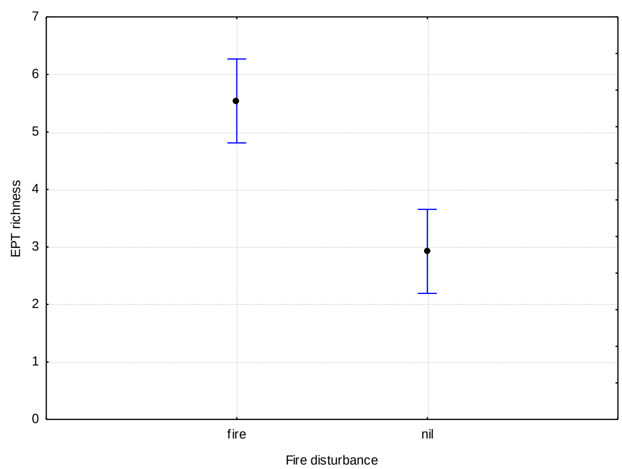


Figure 18. Biodiversity measures which showed a significant disturbance effect of fire for the Jarrah forest catchments in 2006.

When ANOVA's were carried out on Fire only data (i.e. doesn't included "F+L" sites) there was no significance effect of fire on any biodiversity measures in any year. This may indicate that the significant effect of fire in 2006 (when "F+L" catchments are included) is due to the logging interaction. However when a two way ANOVA was used to analyse both fire and logging disturbances, there was no significant interaction between fire and logging for any biodiversity measures for any year. It should be noted that 2006 was a dry year with ten sites being dry. It may be that the "F+L" disturbance had a positive effect on the aquatic invertebrates this year by increasing runoff into the streams resulting in higher water levels and increased flow, which EPTs prefer.

Logging disturbances on biodiversity measures in the Jarrah forest streams.

The effect of logging on the biodiversity measures was analysed using ANOVA's on the annual data only. Logging disturbance was defined as a catchment which had a logging disturbance, which includes "F+L" sites. There was no significant disturbance of logging on any of the biodiversity measures within the Jarrah forest in 2005 and 2006. In 2008 there was a significant effect of logging on species (p=0.008), chironomid (p=0.017), EPT (p=0.005) and family (p=0.019) richness (Figure 19). The significant increase in species richness at logged sites in 2008 may be partly due to the increase in EPT richness at these sites.

When ANOVA's were carried out on Logging only data ("L") there was still a significance effect of logging on species (p<0.001), chironomid (p=0.031), EPT (p<0.001) and family (p=0.031) richness in 2008. This result infers that logging may have an effect on the biodiversity indices however the effect varies annually and may be influenced by other factors.

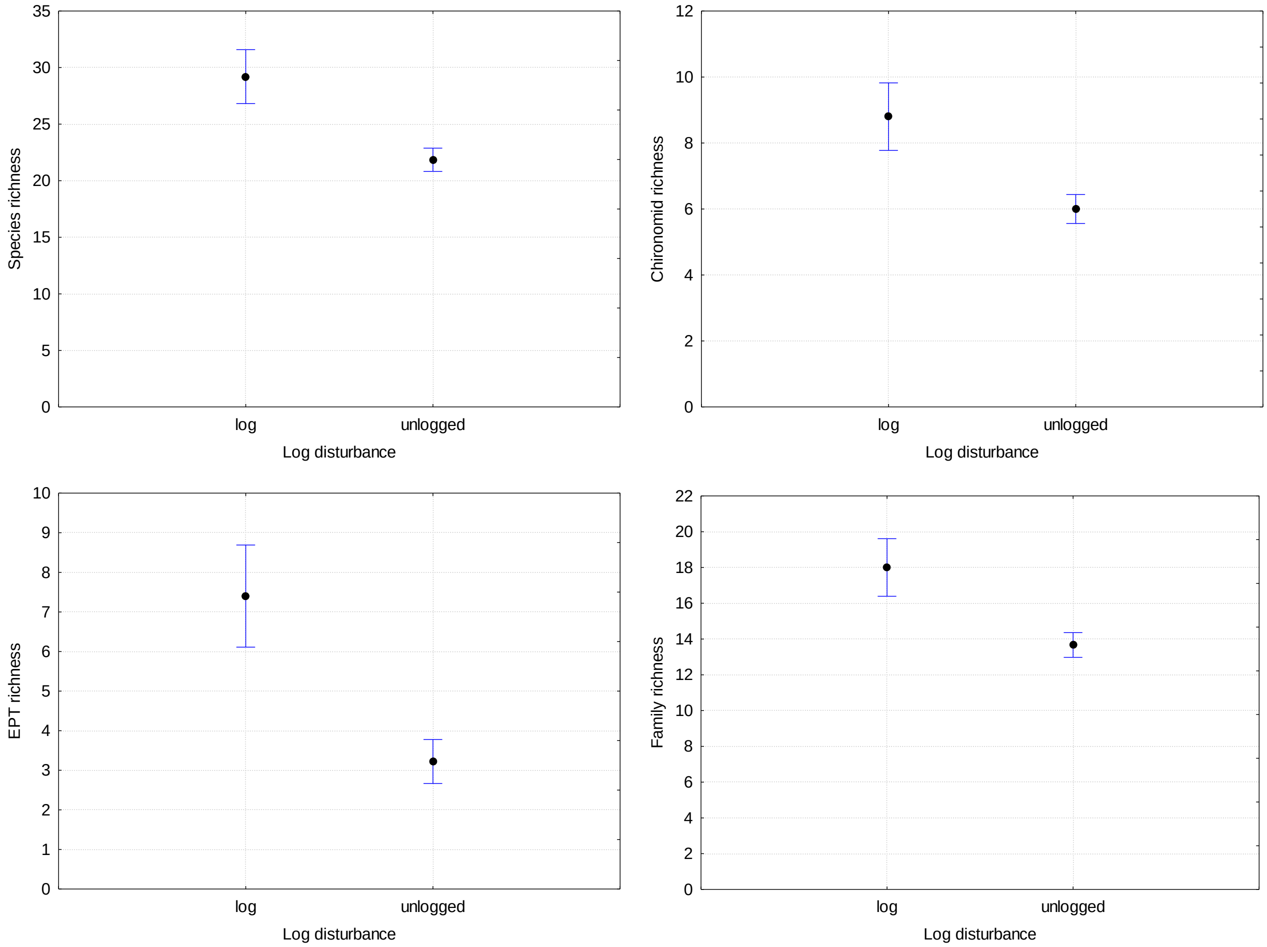


Figure 19. Biodiversity measures which showed a significant disturbance effect of logging for the Jarrah forest catchments in 2008.

Karri Forest Streams

As there are only 12 Karri sites some years could not be analysed due to insufficient data (< 3 samples) for the disturbance categories. In the Karri catchments there was no data for logging only (L) in 2006 or fire only (F) in 2008. Consequently, ANOVA's were not carried out to determine to effect of the disturbance categories on biodiversity measures on the annual data in the Karri forests. Only the years with sufficient data have been analysed for the disturbance of fire and logging in the Karri forests.

Fire disturbances on biodiversity measures in the Karri forest streams.

The effect of fire on the biodiversity measures was analysed using ANOVA's on annual data. Fire disturbance was defined as a catchment which had a fire disturbance, which includes "F+L" sites. There was no significant impact of fire on any of the biodiversity measures within the Karri forest for any year. There was only sufficient data (> 3 samples) to analysis Fire only disturbances ("F") in the Karri forests for 2005 and 2006. There was no significant impact of fire only on any biodiversity measures for either 2005 or 2006.

Logging disturbances on biodiversity measures in the Karri forest streams.

The effect of logging on the biodiversity measures was analysed using ANOVA's on the annual data only. Logging disturbance was defined as a catchment which had a logging impact, which includes "F+L" sites. There was a significant impact of logging on EPT richness (p=0.038) in 2008 (Figure 20). There was insufficient data to analysis logging only impacts ("L") in the Karri forests for any individual year. Due to insufficient data the interaction between fire and logging disturbances in the Karri forest could not be analysed

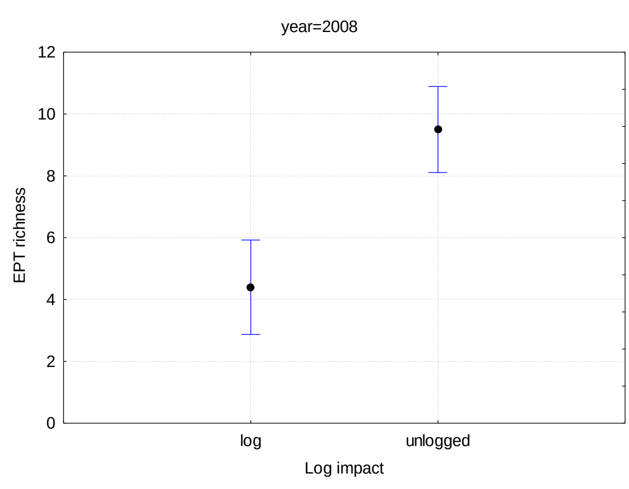


Figure 20. EPT richness for the Karri catchments for 2008 which shows a significant disturbance of logging.

Effects of the proportion of the catchment disturbed on biodiversity measures

One way of dealing with repeated measures in ecological data is to examine change in the response variable between sampling occasions rather than the raw response data (in this case biodiversity measures). The hypothesis here is that, where there is greater catchment disturbance between sampling events then there will be greater change in biodiversity measures. This hypothesis is examined at two scales; change between consecutive years (2005 to 2006, 2006 to 2007 and 2007 to 2008) and over the entire sampling period (2005 and 2008). For the former, catchment disturbance is the amount of logging or burning in the year prior to collection of the second sample, while for the latter catchment disturbance is the cumulative proportion of the catchment logged or burned in the three years prior to 2008.

The proportion of the catchments affected by fire or logging was much less in the Karri forests (refer to Table 19). All Karri forest catchments had less than 5% of the catchment logged in any year and only three sites had more than 35% of the catchment burned in any year. In contrast, eleven Jarrah catchments had over 35% of the catchment burned and four sites had over 10% of the catchment logged in any year.

Jarrah forest streams

Figures 21 and 22 show the change in biodiversity measures at each site for all consecutive years (2005 to 2006, 2006 to 2007 and 2007 to 2008) versus the proportion of the catchment burned or logged in the year proceeding the second sampling event. There were no significant correlations between the change in biodiversity measures and the proportion of the catchment burned (Figure 21) or logged (Figure 22). It is of interest to note that correlations between the proportion of the catchment disturbed and the change in biodiversity measures varied greatly between years. When changes in consecutive years were examined separately, significant correlations were found between the proportion of the catchment burned between 2006 and 2007 and the change in species richness (p=0.035), and EPT richness (p=0.049) between these years. The significant changes in biodiversity measures between the 2006 and 2007 samples may be due to others factors (for example this was a very dry year) rather than the fire disturbance. Future sampling will provide more data which may clarify the differences between annual variations and disturbances.

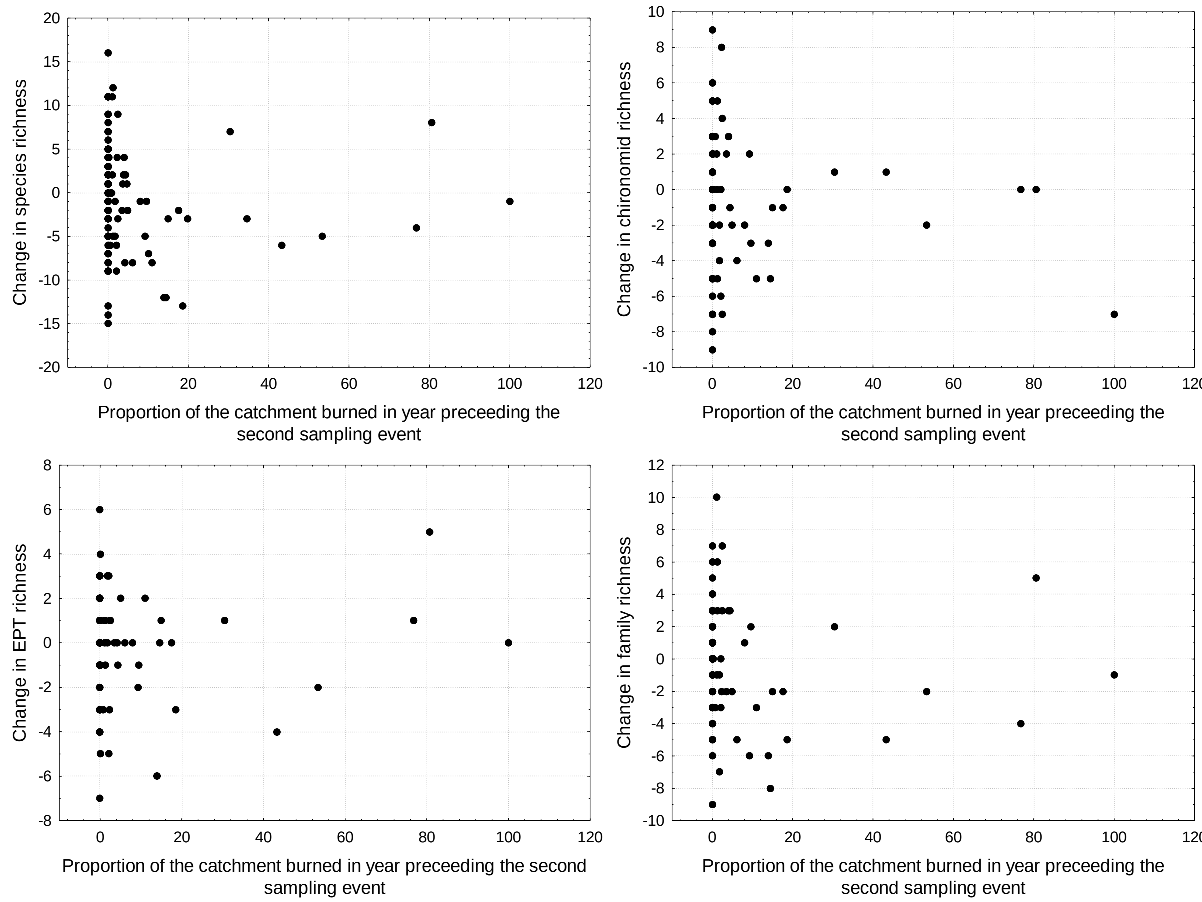


Figure 21. Change in biodiversity measures in the Jarrah forest between consecutive years (2005-2006, 2006-2007 and 2007-2008) versus the proportion of the catchment burned over the same time period.

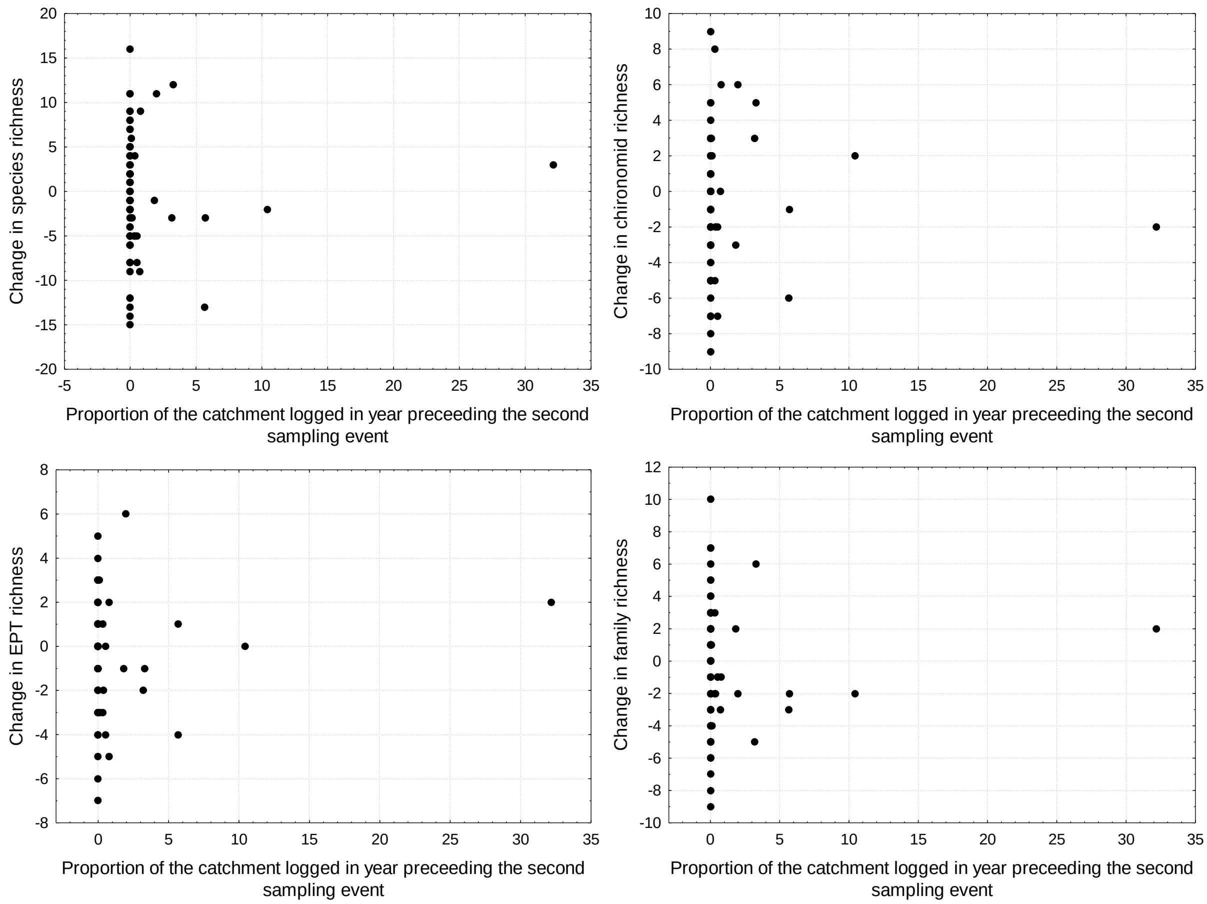


Figure 22. Change in biodiversity measures in the Jarrah forest between consecutive years (2005-2006, 2006-2007 and 2007-2008) versus the proportion of the catchment logged over the same period.

To examine effects of catchment management over longer time periods, correlations were calculated between of the proportion of catchment (% area) burned or logged over a 4 year period (2005-2008) and the change in biodiversity measures over the same time period. Only sites that were sampled in both 2005 and 2008 could be analysed (Jarrah n=21). There were no significant correlations between changes in the biodiversity measures and the proportion of the catchment which was burned (Figure 23), logged (Figure 24) or disturbed by fire and/or logging (Figure 25).

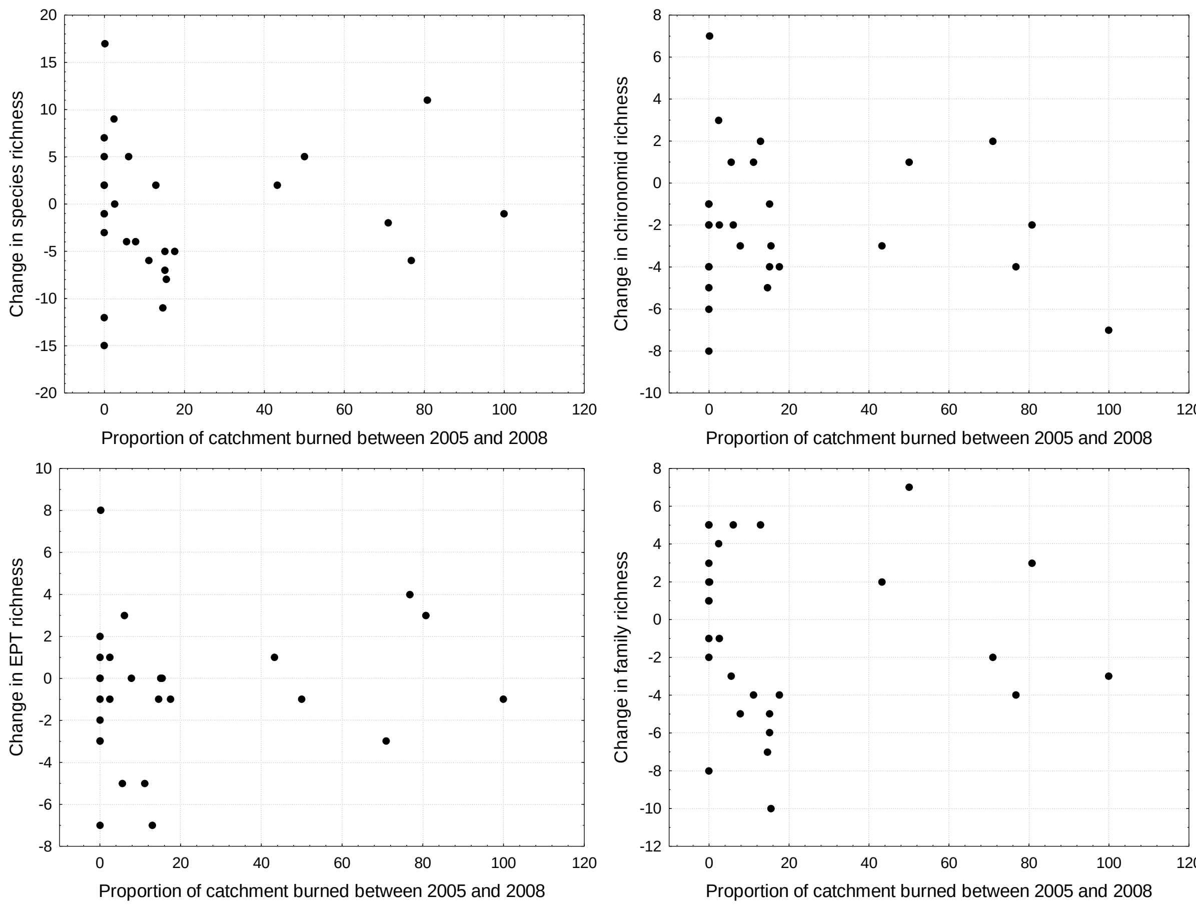


Figure 23. Change in biodiversity measures in the Jarrah forest between 2005 and 2008 versus the proportion of the catchment burned over the same period.

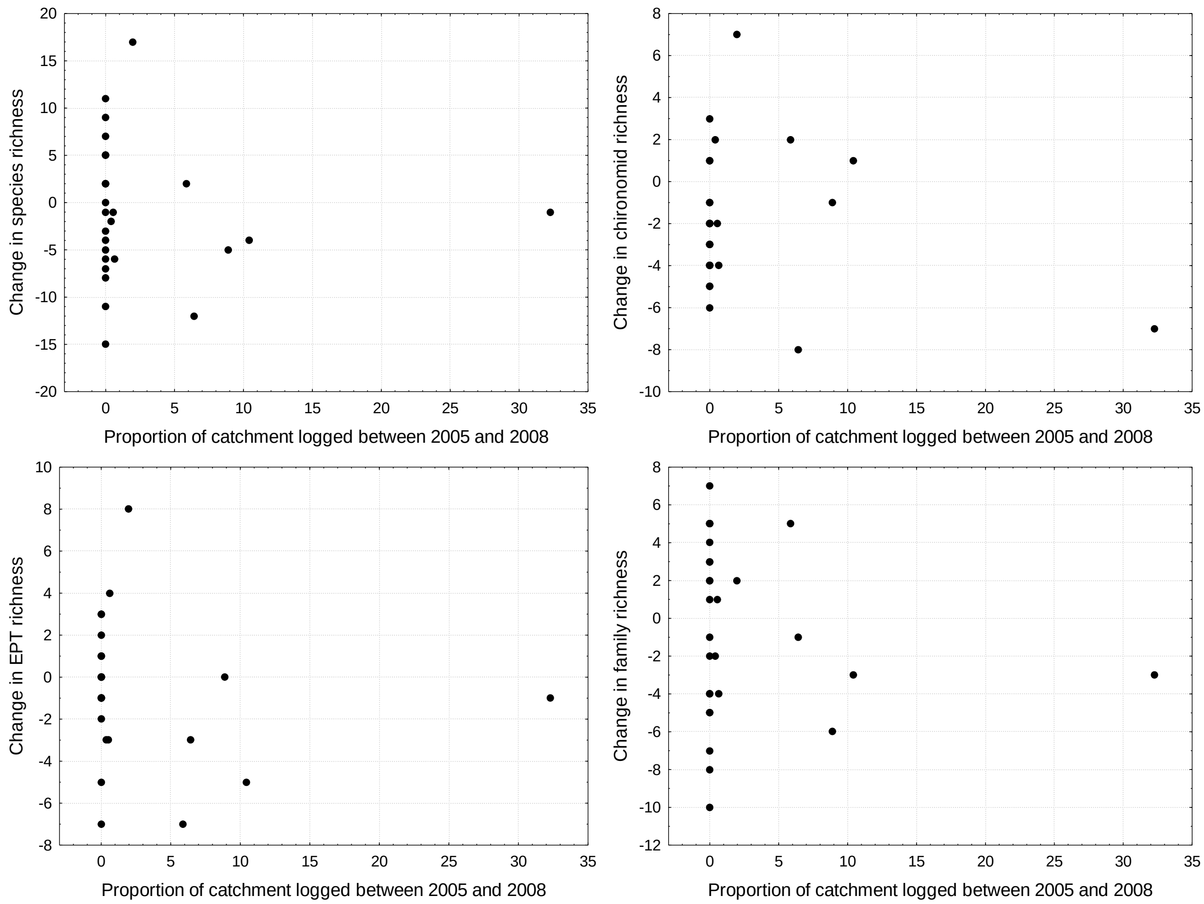


Figure 24. Change in biodiversity measures in the Jarrah forest between 2005 and 2008 versus the proportion of the catchment logged over the same period.

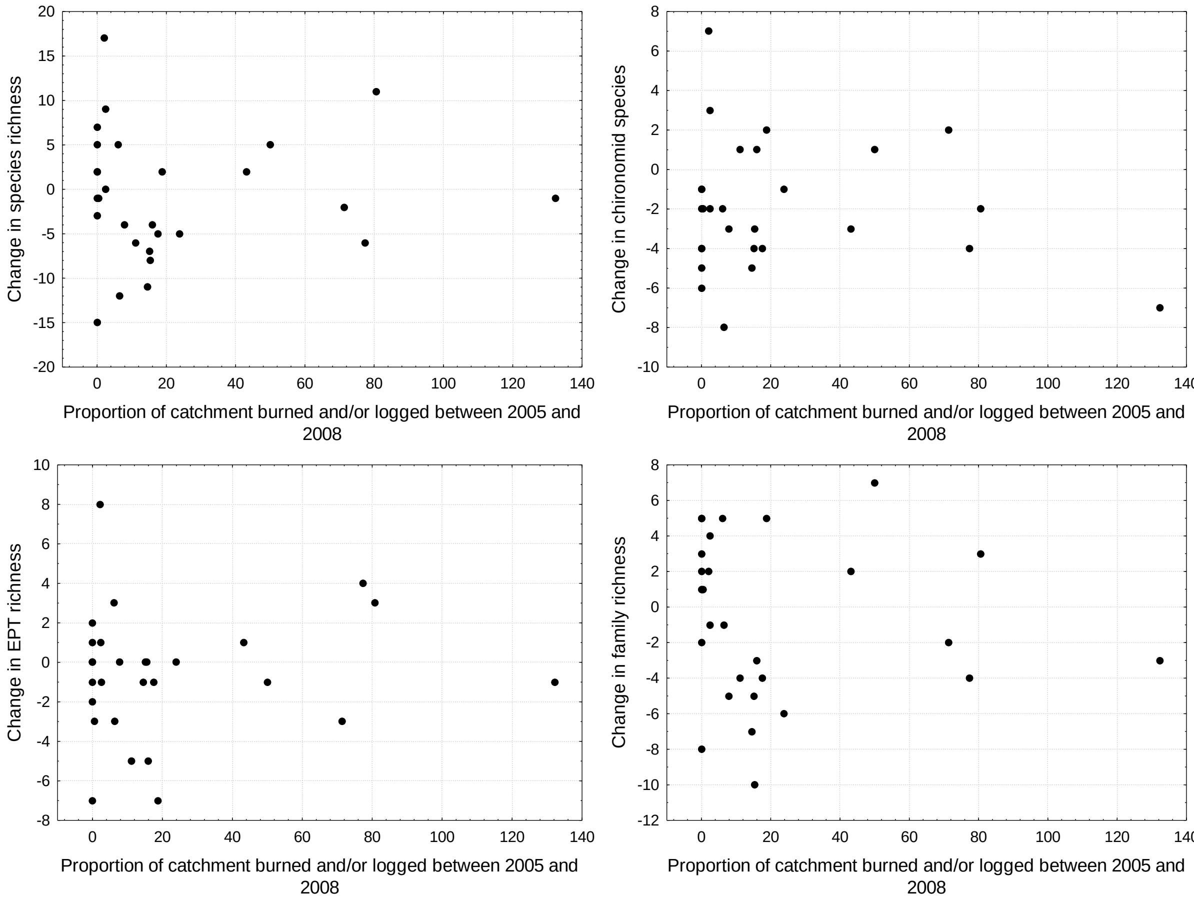


Figure 25. Change in biodiversity measures in the Jarrah forest between 2005 and 2008 versus the proportion of the catchment burned and/or logged over the same period.

Karri forest streams

The change in biodiversity measures at each site for consecutive years (2005-2006, 2006-2007 and 2007-2008) were examined for correlations with the proportion of the catchment burned or logged over the same time period. There were no significant correlations between the change in biodiversity measures and the proportion of the catchment burned (Figure 26) or logged (Figure 27). When changes in consecutive years were examined separately, significant correlations were found between the proportion of the catchment burned between 2006 and 2007 and the change in EPT richness (p=0.064) between these years. As for the Jarrah forest sites, the significant change in EPT richness at the Karri sites between 2006 and 2007 may be due to others factors (e.g. low flow and water levels due to this being a dry year) rather than the fire disturbance for that particular year.

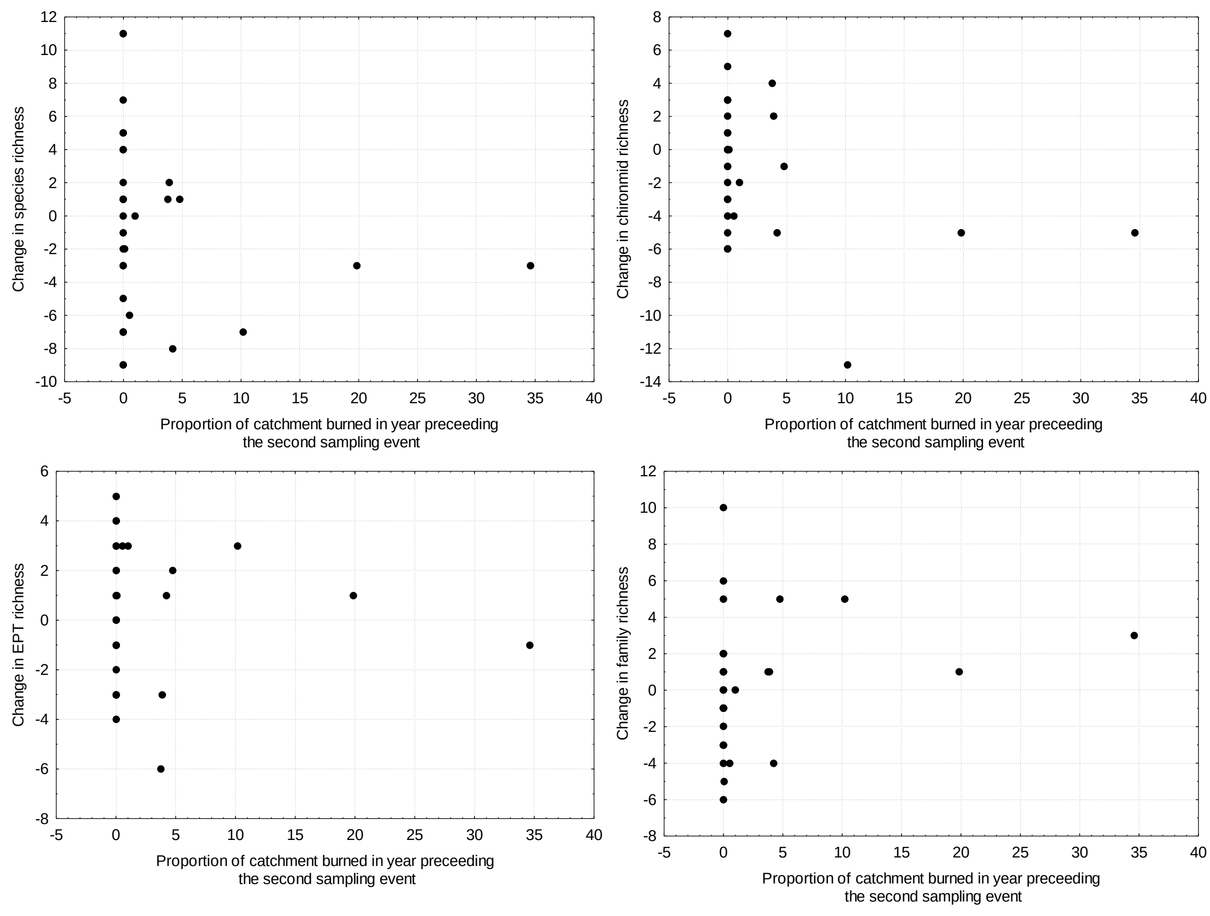


Figure 26. Change in biodiversity measures in the Karri forest between consecutive years (2005-2006, 2006-2007 and 2007-2008) versus the proportion of the catchment burned over the same period.

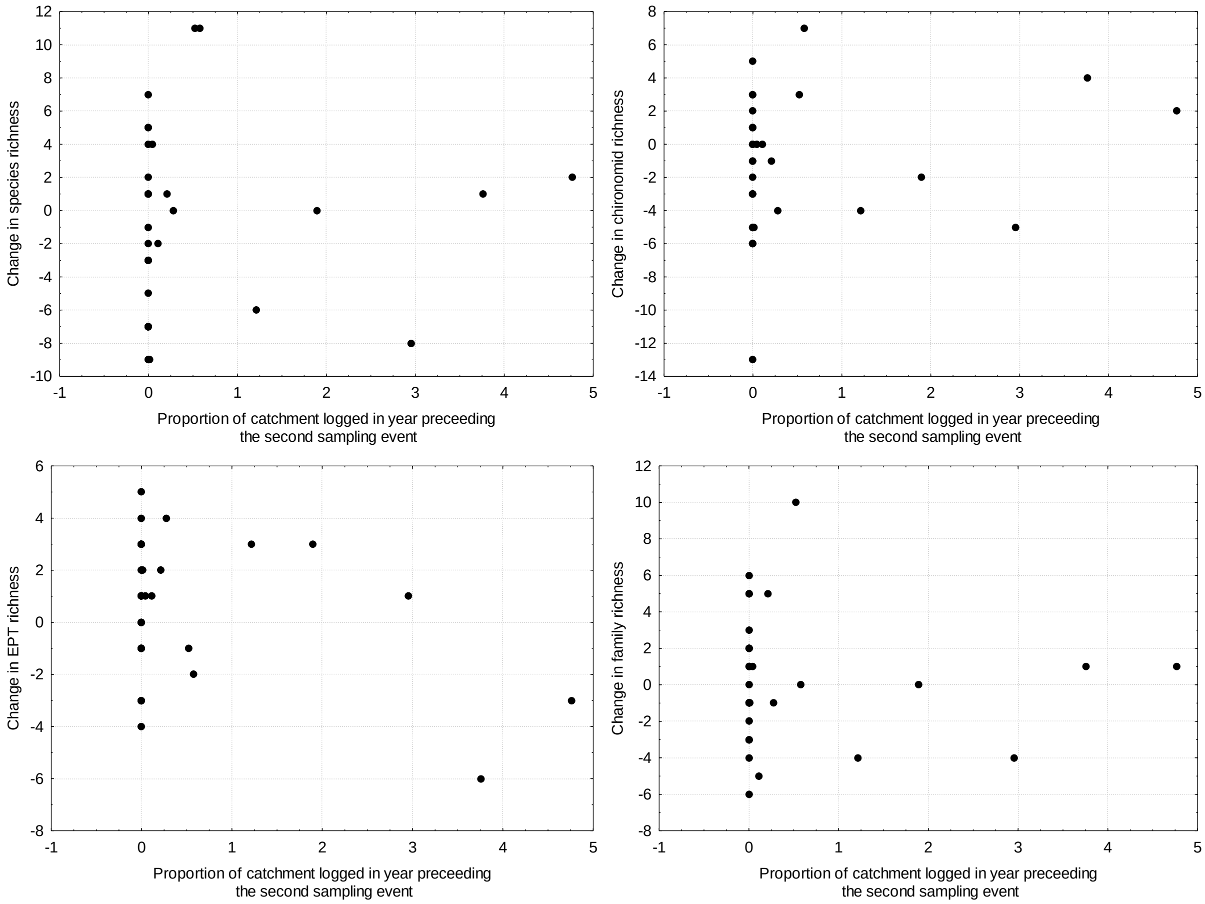


Figure 27. Change in biodiversity measures in the Karri forest between consecutive years (2005-2006, 2006-2007 and 2007-2008) versus the proportion of the catchment logged over the same period.

To determine if aquatic invertebrates responded to catchment management practices over longer periods, correlations were calculated between the proportion of the catchment burned or logged over a 4 year period (2005-2008) and the change in biodiversity measures over the same time period. Only sites that were sampled in both 2005 and 2008 could be analysed (Karri n=10). There were no significant correlations between changes in the biodiversity measures and the proportion of the catchment which was burned (Figure 28), logged (Figure 29) or disturbed by fire and/or logging (Figure 30) over the 4 year period (2005-2008).

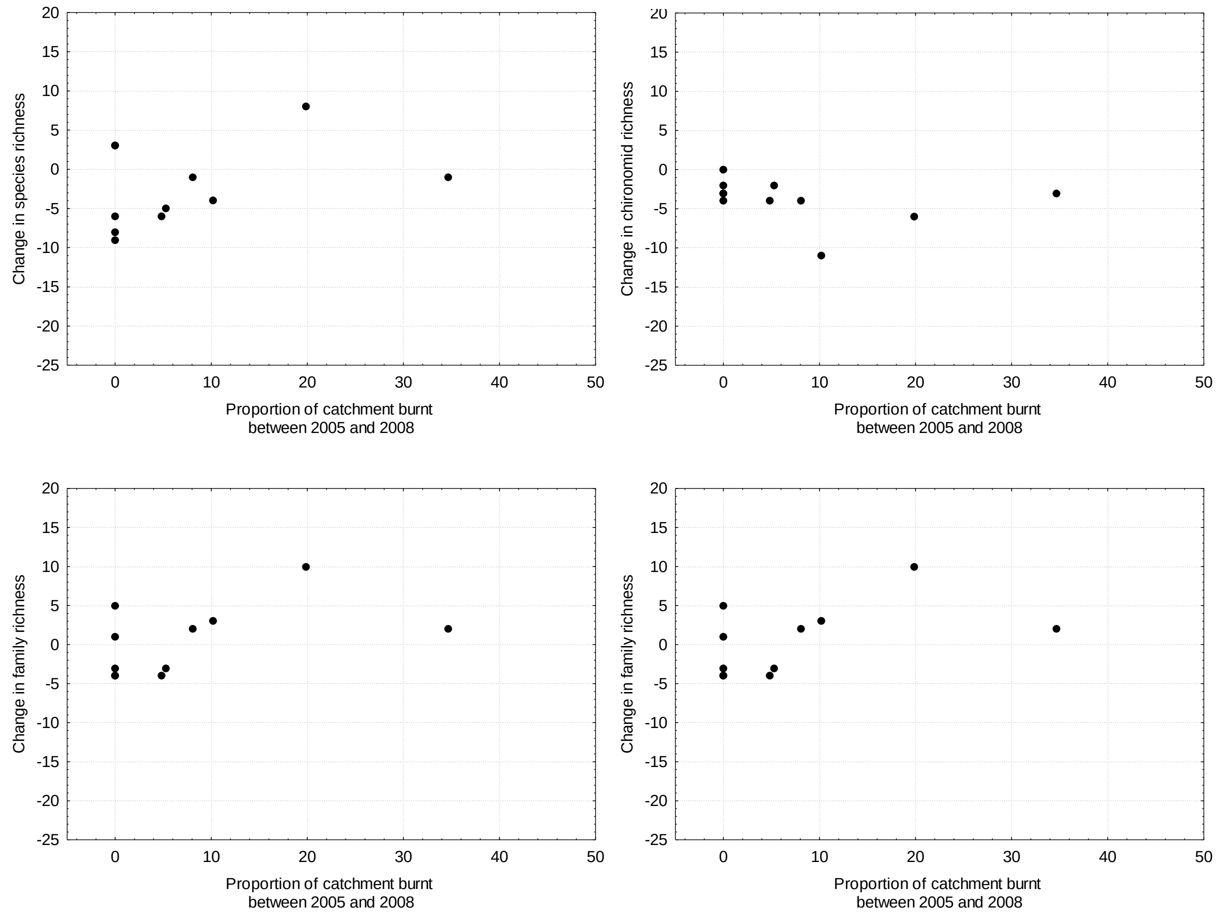


Figure 28. Change in biodiversity measures in the Karri forest between 2005 and 2008 versus the proportion of the catchment burned over the same period.

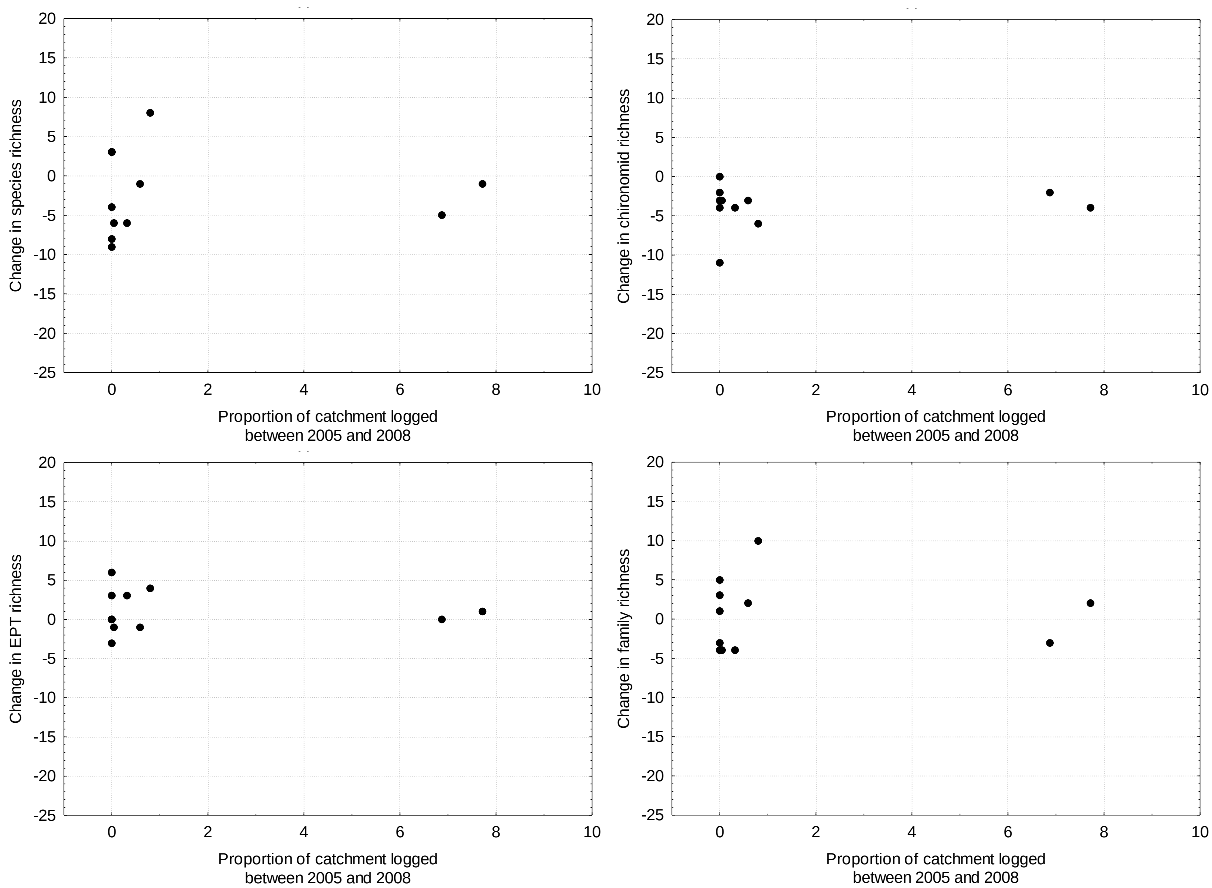


Figure 29. Change in biodiversity measures in the Karri forest between 2005 and 2008 versus the proportion of the catchment logged over the same period.

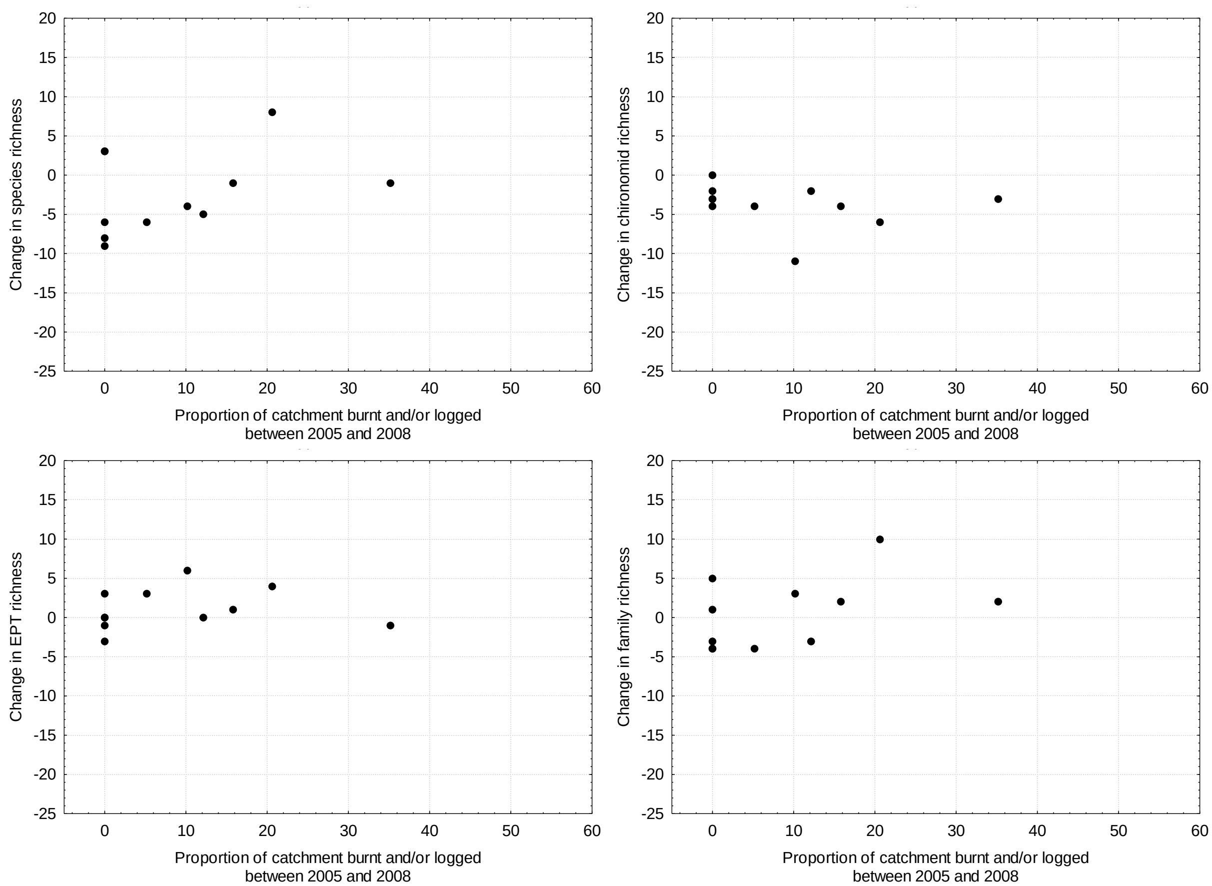


Figure 30. Change in biodiversity measures in the Karri forest between 2005 and 2008 versus the proportion of the catchment burned and/or logged over the same period.

<u>Relationship between biodiversity measures and the time since a disturbance has occurred in the catchment.</u>

It is possible that the time since a disturbance has occurred is an important determinant of aquatic invertebrate diversity. The number of years since a catchment was logged or burned before each sampling occasion was calculated (refer to Table 22). Only two sites (COL38 and MRY09, both in the Jarrah forests) had not been burned for over 10 years at the beginning of the project. Both have been burned since; MRY09 in 2006 and COL38 in 2008. Twenty five catchments (22 Jarrah and 3 Karri) had not been logged for over 10 years at the beginning of the project but two of these (MRY33 and SWA04) have been logged since the project began.

To determine if there were any effects of logging and burning over a longer time period, biodiversity measures were plotted against the year since last logged or burned in the Jarrah (Figures 31 and 32 respectively) and Karri catchments (Figures 33 and 34). There were no significant correlations between year since last burned, or year since last logged, for any biodiversity measures in either the Jarrah or Karri forests. Figures 31 to 34 show that there is a large variation in the biodiversity measures between sites which have had zero years since been logged or burned and also for sites which have had >10years since fire or logging.

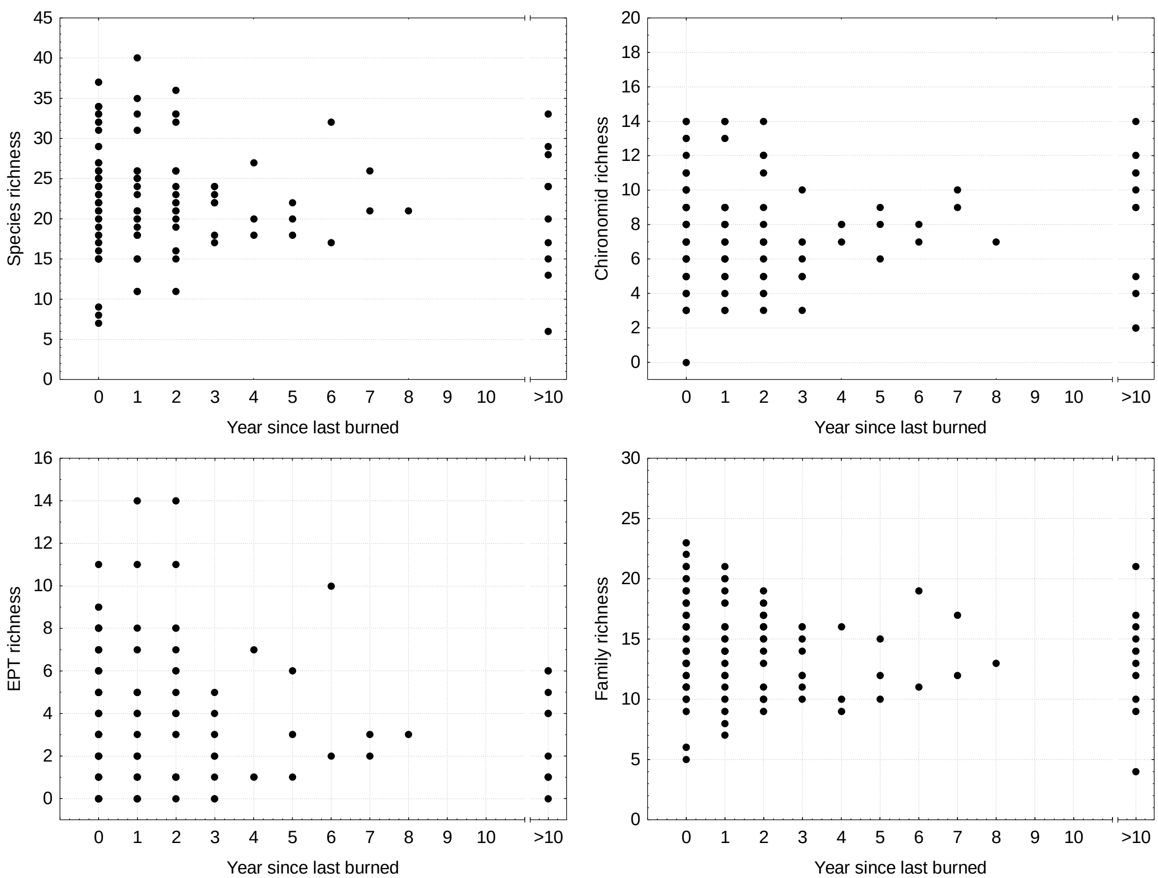


Figure 31. Year since the Jarrah catchment was last burned versus biodiversity measures (species richness, chironomid richness, EPT richness and family richness).

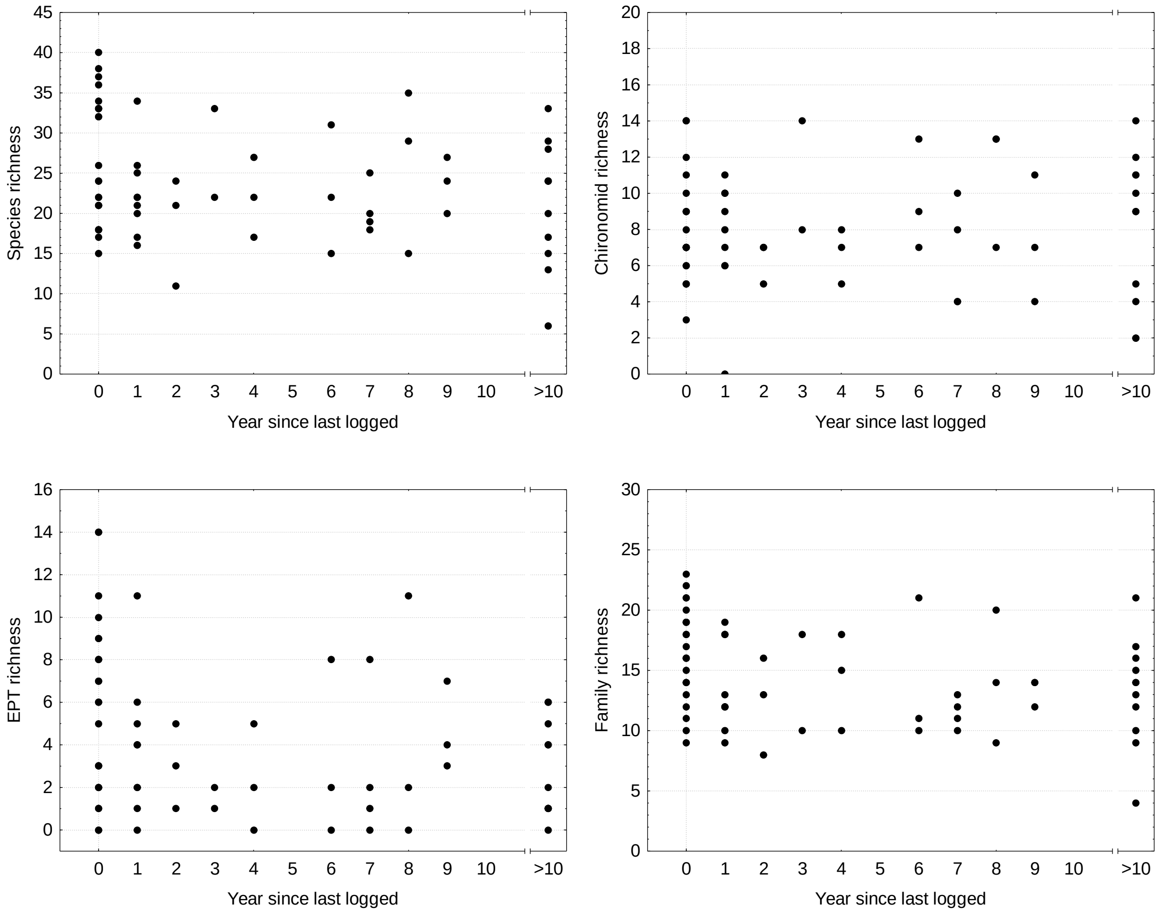


Figure 32. Year since the Jarrah catchment was last logged versus biodiversity measures (species richness, chironomid richness, EPT richness and family richness).

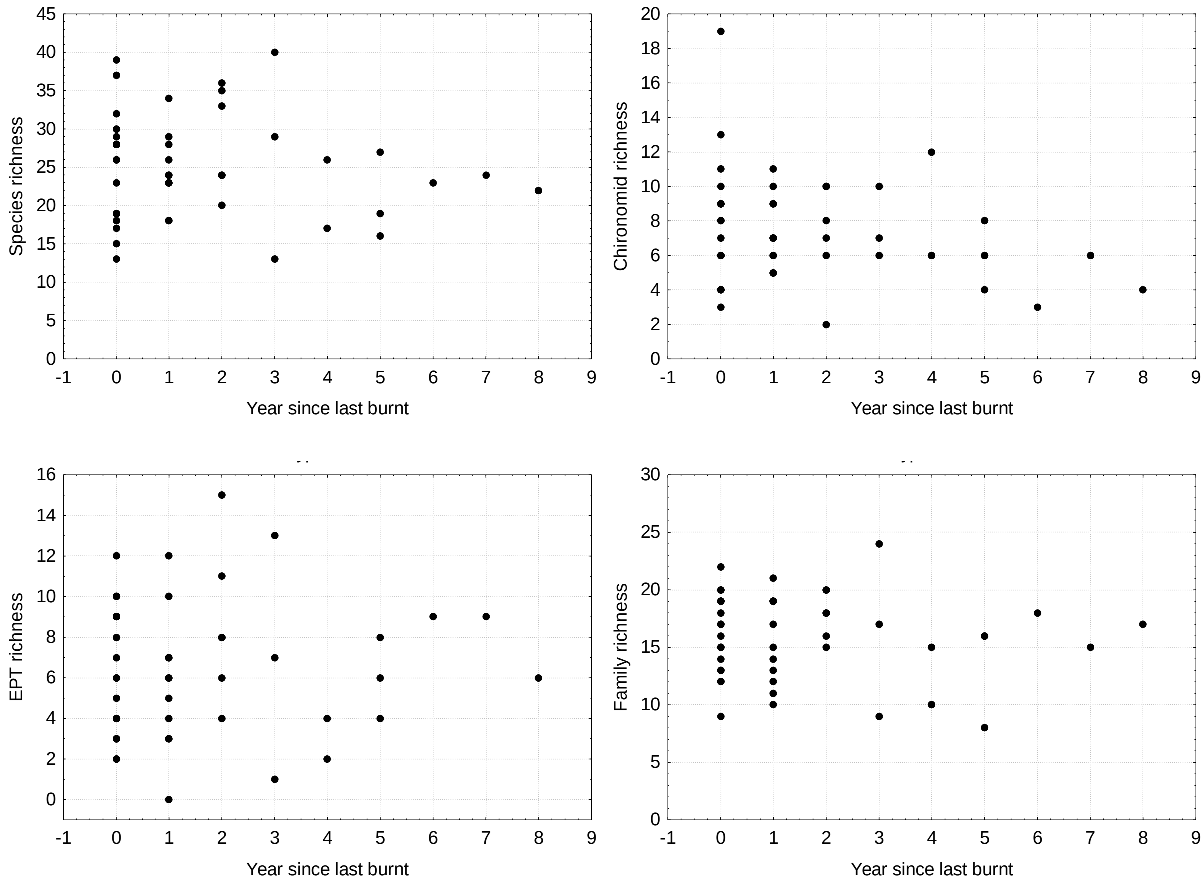


Figure 33. Year since the Karri catchment was last burned versus biodiversity measures (species richness, chironomid richness, EPT richness and family richness).

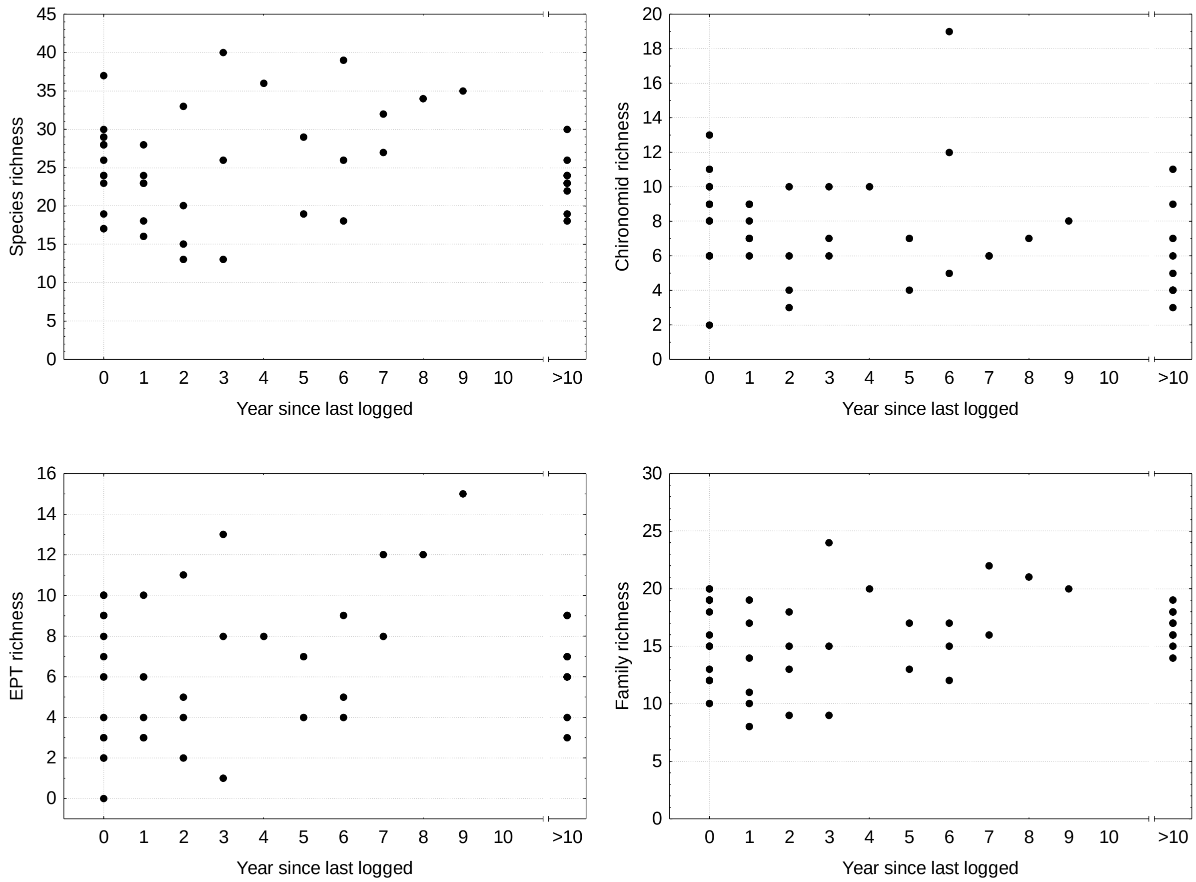


Figure 34. Year since the Karri catchment was last logged versus biodiversity measures (species richness, chironomid richness, EPT richness and family richness).

Invertebrate community composition and catchment history

Jarrah forest streams

Ordinations.

3D nMDS ordinations of community composition for species level data only or for all taxa identified to at least family level (herein referred to as “all taxa”) are shown in Figures 35 and 36 respectively, with symbols scaled to proportion of catchment affected by logging or burning in the previous one (%1yr) or five years (%5yr). In some of these plots there is a degree of separation of communities from sites with greater proportions of the catchment logged or burned from those of sites with less logging or burning. However, the separation is a case of communities in more affected catchments being spread around the periphery of communities in less affected catchments, rather than a gradient of change along the axes. This effect is most noticeable for %1yr Burn and %5yr Log. This pattern suggests that, while there may be changes in community composition as a result of logging and burning over these time periods, the nature of the change is not consistent.

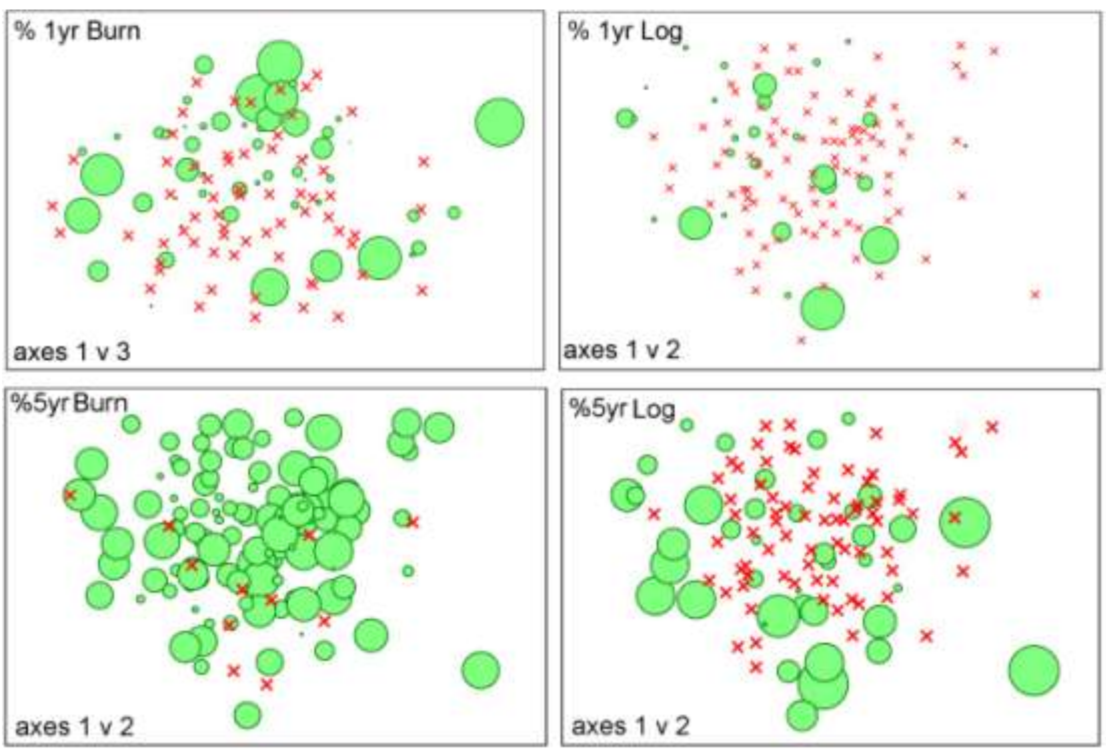


Figure 35. 3D nMDS ordination of all samples from Jarrah forest, using only taxa identified to species level and with symbols scaled to proportion of catchment affected by burning or logging in previous 1 or 5 years (red crosses are those samples from catchments without burning or logging). Axes shown are those most strongly correlated with the respective catchment history variable. Note scales of symbols are different for each catchment history variable. Stress = 0.20.

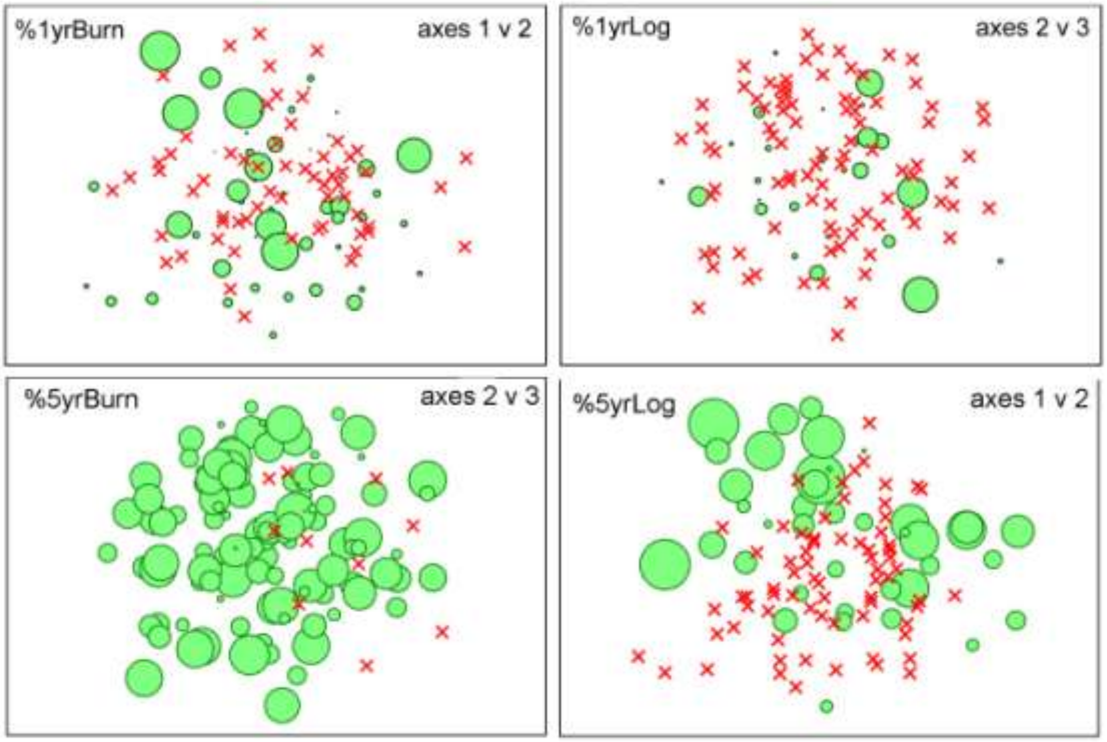


Figure 36. 3D nMDS ordination of all samples from Jarrah forest, using all taxa and with symbols scaled to proportion of catchment affected by burning or logging in previous 1 or 5 years (red crosses are those samples from catchments without burning or logging). Axes shown are those most strongly correlated with the respective catchment history variable. Note scales of symbols are different for each catchment history variable. Stress = 0.21.

Distance-based linear modelling.

In the DistLM analyses of species only data, the only significant relationships between community composition and catchment history were for %5yrLog in 2005 (r^2 = 0.06, p <0.05) and %1yrBurn (r^2 = 0.06, p<0.05) and %5yrBurn in 2008 (r^2 = 0.06, p <0.05). For the analyses of all taxa, only %5yrLog in 2005 (r^2 = 0.06, p <0.05) and %5yrBurn in 2008 (r^2 = 0.06, p<0.05) were significant (combined r^2 = 0.11).

Thus, catchment history was either not correlated with community composition or the relationships were very weak. The significant effect of %5yrLog in 2005 was solely due to site MRY41 which had the highest proportion of catchment logged in the previous five years (40.3%). When this site was removed the effect of the five year logging history variable was no longer significant for 2005.

Permanova

Tables 24 and 25 show the results of Permanova analyses for years and catchment variables where there were > 3 samples within each treatment, for species only data and all taxa respectively. For the five year data there were only 1 or 2 sites with no burning, so this test was run as a contrast between ≤ or > 20% burning in the catchment. The only analysis that suggested any significant differences in community composition at an alpha level of 0.05 was the contrast between samples in catchments with no logging in the five years prior to 2005 and those with some logging (average proportion of catchment logged = 20 %). However, the test was only marginally significant and the same test for 2006, 2007 and 2008 was not significant. In addition, a 3D nMDS ordination of the 2005 data, shows little separation of samples in catchments with no logging in the previous five years from those with some logging (Figure 37), other than a tendency for sites in catchments with logging to occur around the periphery of those with no logging. This significant effect is probably due solely to site MRY41 in 2005, as suggested by the DistLM analysis above.

Presence of burning in the catchment in the year prior to sampling was only marginally non-significant in 2006 (p=0.085 for all taxa and 0.06 for the species only data). Once again, however, in an nMDS ordination there is little separation of samples in burned catchments from those in catchments without burning (Figure 38).

Table 24. Results of Permanova analyses of differences in community composition (species only data) between sites in Jarrah forest catchments with contrasting proportions of burning or logging.

Catchment history variable	**Year**	**Contrast**	**p**
% 1yr Burn	2005	no burning (n=17) v some burning (n=15)	n.s. (p=0.91)
	2006	no burning (n=14) v some burning (n=12)	n.s. (p=0.06)
	2007	no burning (n=16) v some burning (n=14)	n.s. (p=0.26)
	2008	no burning (n=19) v some burning (n=13)	n.s. (p=0.09)
% 1 yr Log	2005	no logging (n=27) v some logging (n=5)	n.s. (p=0.404)
	2006	no logging (n=19) v some logging (n=7)	n.s. (p=0.90)
	2007	no logging (n=21) v some logging (n=9)	n.s. (p=0.08)
	2008	no logging (n=24) v some logging (n=8)	n.s. (p=0.14)
% 5yr Burn	2005	≤ 20% burning (n=10) versus > 20% burning (n=22)	n.s. (p=0.70)
	2006	≤ 20% burning (n=7) versus > 20% burning (n=19)	n.s. (p=0.74)
	2007	≤ 20% burning (n=10) versus > 20% burning (n=20)	n.s. (p=0.46)
	2008	≤ 20% burning (n=12) versus > 20% burning (n=20)	n.s. (p=0.19)
% 5yr Log	**2005**	**no logging (n=23) versus some logging (n=9)**	*** (p=0.04)**
	2006	no logging (n=17) versus some logging (n=9)	n.s. (p=0.36)
	2007	no logging (n=19) versus some logging (n=11)	n.s. (p=0.58)
	2008	no logging (n=19) versus some logging (n=13)	n.s. (p=0.54)

Table 25. Results of Permanova analyses of differences in community composition (all taxa identified to at least family level) between sites in Jarrah forest catchments with contrasting proportions of burning or logging.

Catchment history variable	**Year**	**Contrast**	**p**
% 1yr Burn	2005	no burning (n=17) v some burning (n=15)	n.s. (p=0.62)
	2006	no burning (n=14) v some burning (n=12)	n.s. (p=0.09)
	2007	no burning (n=16) v some burning (n=14)	n.s. (p=0.49)
	2008	no burning (n=19) v some burning (n=13)	n.s. (p=0.27)
% 1 yr Log	2005	no logging (n=27) v some logging (n=5)	n.s. (p=0.42)
	2006	no logging (n=19) v some logging (n=7)	n.s. (p=0.96)
	2007	no logging (n=21) v some logging (n=9)	n.s. (p=0.15)
	2008	no logging (n=24) v some logging (n=8)	n.s. (p=0.19)
% 5yr Burn	2005	≤ 20% burning (n=10) versus > 20% burning (n=22)	n.s. (p=0.47)
	2006	≤ 20% burning (n=7) versus > 20% burning (n=19)	n.s. (p=0.81)
	2007	≤ 20% burning (n=10) versus > 20% burning (n=20)	n.s. (p=0.46)
	2008	≤ 20% burning (n=12) versus > 20% burning (n=20)	n.s. (p=0.26)
% 5yr Log	**2005**	**no logging (n=23) versus some logging (n=9)**	*** (p=0.047)**
	2006	no logging (n=17) versus some logging (n=9)	n.s. (p=0.50)
	2007	no logging (n=19) versus some logging (n=11)	n.s. (p=0.44)
	2008	no logging (n=19) versus some logging (n=13)	n.s. (p=0.65)

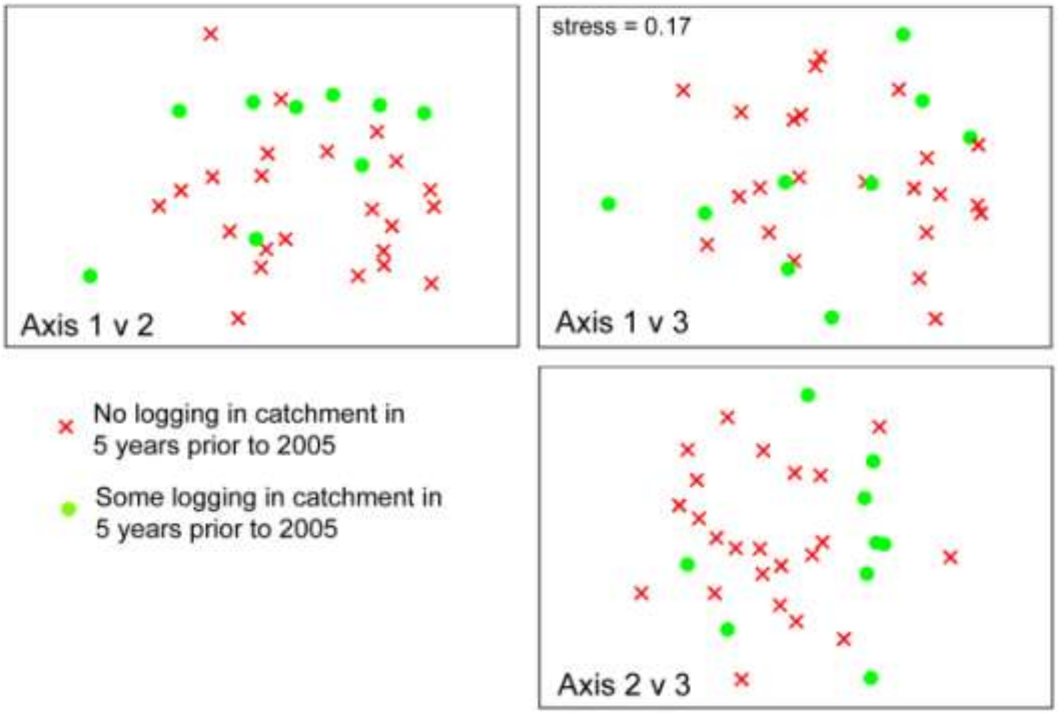


Figure 37. A 3D nMDS ordination of 2005 Jarrah forest species only data, indicating sites that had no logging or some logging in the previous five years.

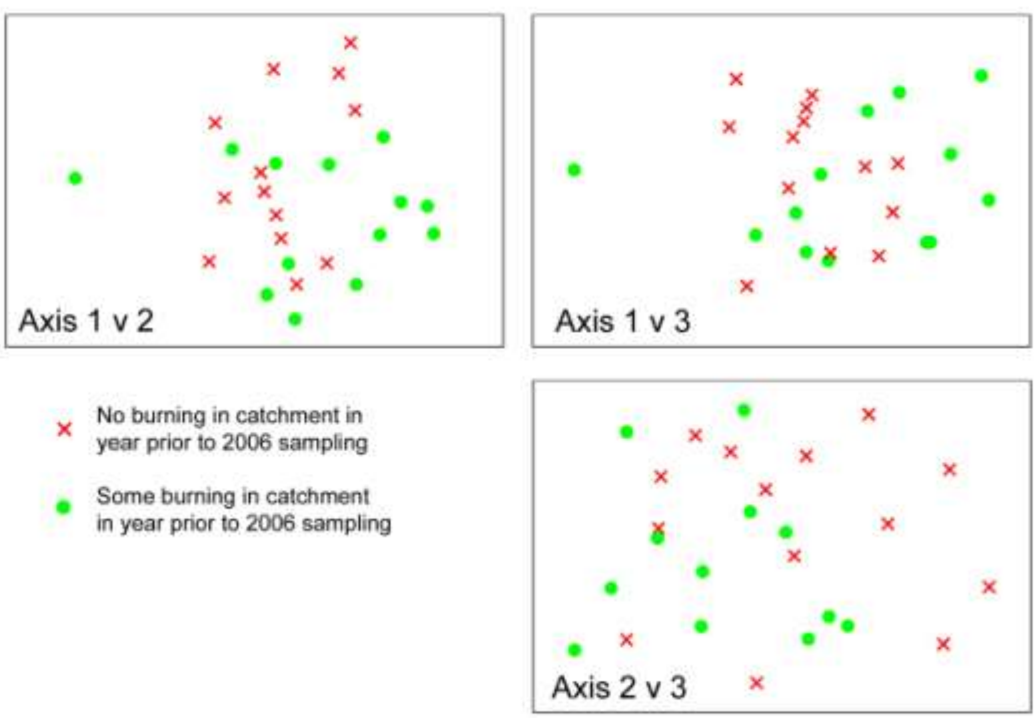


Figure 38. A 3D nMDS ordination of 2006 Jarrah forest species only data, indicating sites that had no burning or some burning in the previous year.

Relationships between community change and catchment history.

One way of dealing with repeated measures in ecological data is to examine change in the response variable between sampling occasions rather than the raw response data (in this case community composition). For community data this can be achieved by examining community similarity (as measured by a similarity index) between sampling occasions within a site. The hypothesis here is that where there is greater catchment disturbance between sampling events then there will be greater change in community composition. This hypothesis is examined at two scales; change between consecutive years (2005 to 2006, 2006 to 2007 and 2007 to 2008) and over the entire sampling period (2005 and 2008). For the former, catchment disturbance is the amount of logging or burning in the year prior to collection of the second sample, while for the latter catchment disturbance is the cumulative proportion of the catchment logged or burned in the three years prior to 2008.

Figures 39 and 40 show change in community composition at each site between 2005 and 2008 versus proportion of the catchment burned and/or logged in the intervening period. The proportion of each catchment affected by burning or logging is calculated as the sum of the 1 year proportions for 2006, 2007 and 2008. In these plots, the lower the Bray-Curtis index (on the y-axes) the greater the change in community composition between these years, so if the degree of community change is proportional to the amount of logging or burning, then there should be a significant negative relationship between these catchment history variables and Bray-Curtis similarity. However, for the 2005-2008 data, there were no significant correlations between the amount of community change and proportion of catchment burned and/or logged for both species only and all taxa to family level data.

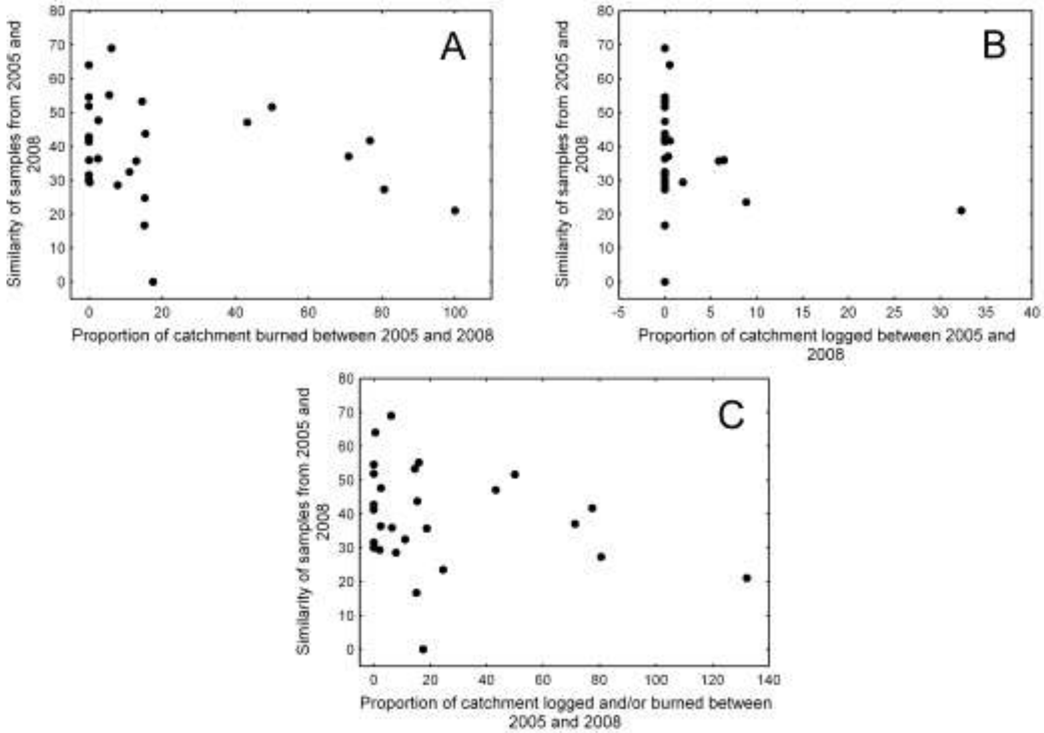


Figure 39. Change in composition of Jarrah forest invertebrate communities (species only data) between 2005 and 2008, as indicated by the Bray-Curtis similarity index, versus cumulative proportion of catchment affected by burning and/or logging over the same period. A = Burning, B = Logging, C = Logging plus burning.

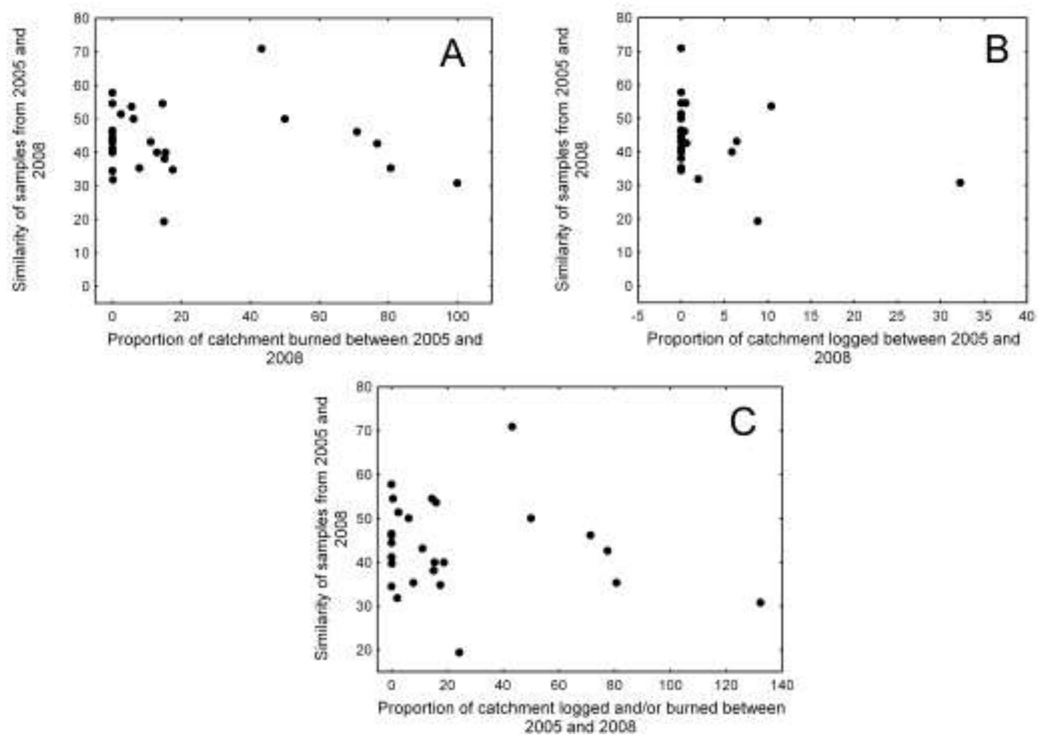


Figure 40. Change in composition of Jarrah forest invertebrate communities (all taxa identified to at least family) between 2005 and 2008, as indicated by the Bray-Curtis similarity index, versus cumulative proportion of catchment affected by burning and/or logging during the intervening period.

Figure 41 shows the change in community composition (for species only data) at each site for all consecutive years. As for the four year period above, there is little in these graphs to suggest that the degree of community change is correlated with the proportion of the catchment burned or logged.

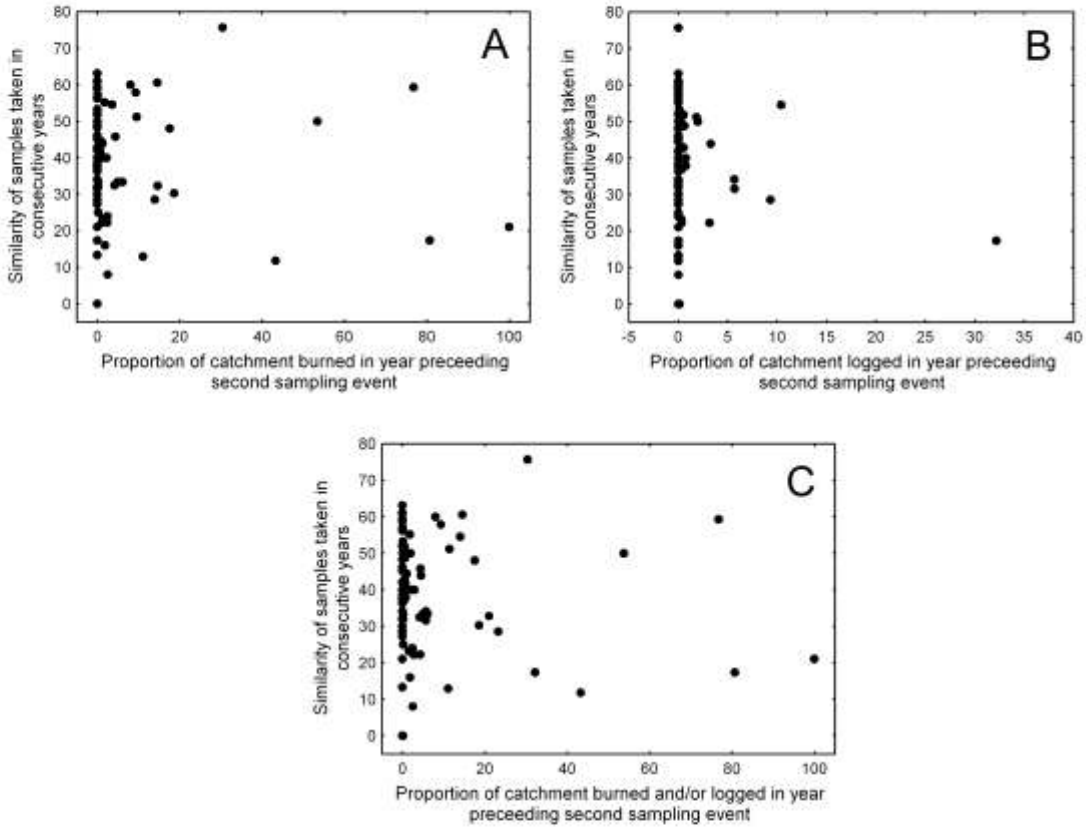


Figure 41. Change in composition of Jarrah forest invertebrate communities (species data only) between consecutive years (2005 to 2006, 2006 to 2007 and 2007 to 2008) as indicated by the Bray-Curtis similarity index, versus cumulative proportion of catchment affected by burning and/or logging over the same period. A = Burning, B = Logging, C = Logging plus burning.

Karri Forest streams

Ordinations

Figures 42 and 43 are graphs of 3D nMDS ordinations of the community data using either all taxa or just those taxa identified to species, with symbols scaled to proportion of catchment affected by logging or burning in the previous one (%1yr) or five years (%5yr). For the species only dataset (Figure 42), some plots shows a degree of separation of samples with minimal proportions of catchment affected from those with larger areas affected, but there is little suggestion of a consistent gradient. The effect was strongest for %1yr Log where sites in catchments with logging tended to occur towards the lower part of the plot away from most of the sites in catchments with no logging in the previous year. When all taxa are included there is not so much of a separation of samples according to logging or burning history.

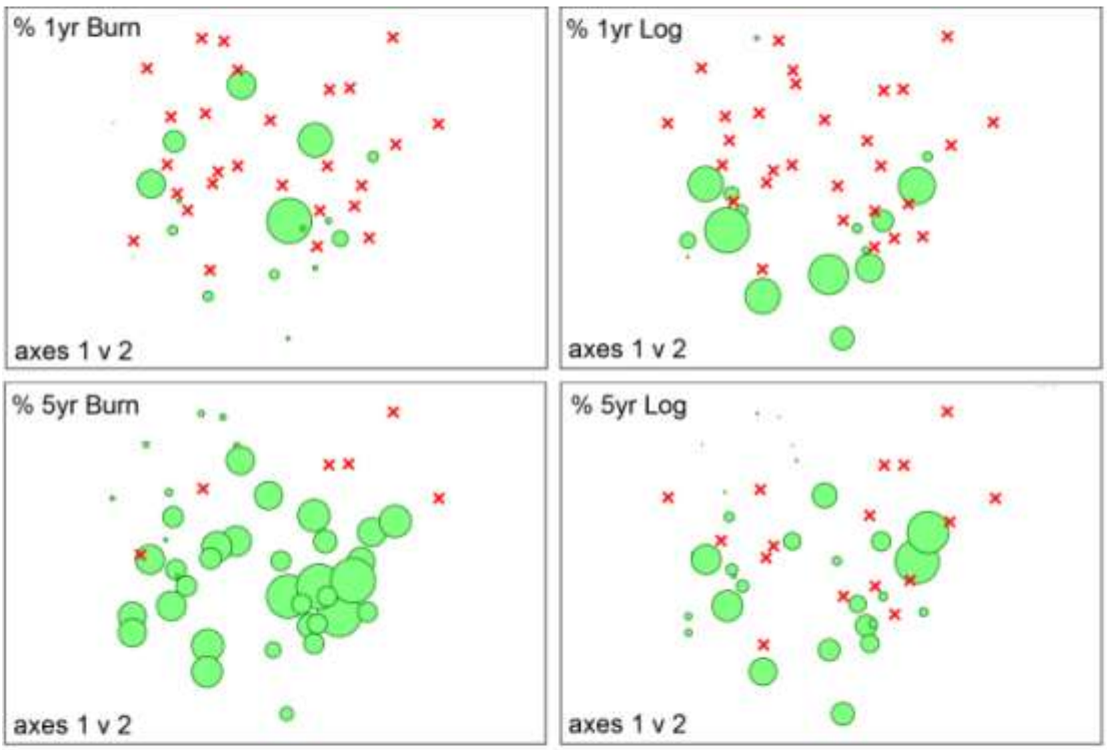


Figure 42. 3D nMDS ordination of all samples from Karri forest, using only taxa identified to species level and with symbols scaled to proportion of catchment history affected in previous 1 or 5 years (red crosses are those samples from catchments without burning or logging). Axes shown are those most strongly correlated with the respective catchment history variable. Note scales of symbols are different for each catchment history variable. Stress = 0.18.

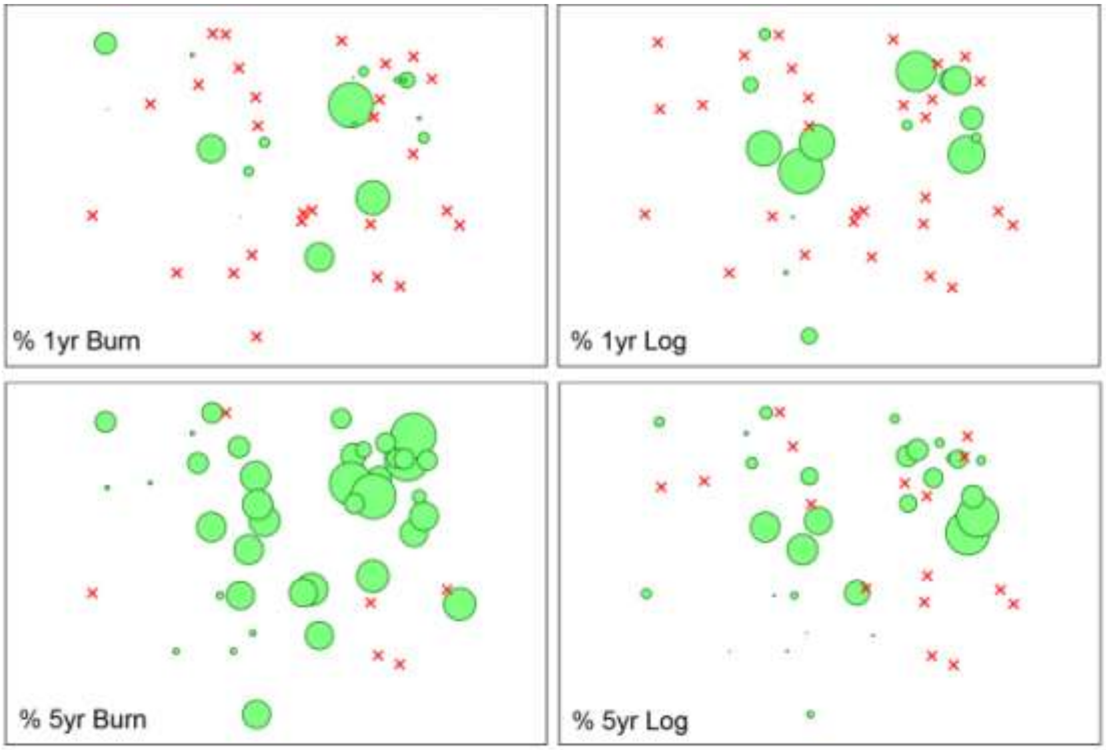


Figure 43. nMDS ordination of samples from Karri forest, using all taxa identified to at least family level and with symbols scaled to proportion of catchment history affected in previous 1 or 5 years (red crosses represent those samples in catchments with 0% affected by logging or fire). Axes shown are 1 versus 2 as those were most strongly correlated with the respective catchment history variables. Stress = 0.18.

Distance-based linear modelling

In the DistLM analyses of species only data, the only significant relationships between community composition and catchment history were for %1yrLog and %1yrBurn versus the species only data in 2008 ($p<0.05$, $r^2 = 0.17$ and 0.18 respectively). The combined r^2 was only 0.23 so the relationship was not strong. Most of the four catchment history variables are also very strongly skewed, with many zero values which even a transformation cannot solve. For this reason the results of these analyses should be viewed with caution. For the larger dataset (all taxa identified to at least family), there were no significant relationships between catchment history and community composition, although for %1yrBurn the relationship was only marginally non-significant ($p=0.06$, $r^2 = 0.15$).

Permanova

Tables 26 and 27 show the results of Permanova analyses for years and catchment variables where there were > 3 samples within each treatment, for species only data and for all taxa respectively. For the five year data there were only 1 or 2 sites with no burning, so this test was run as a contrast between ≤ and > 20% burning in the catchment. The five year logging tests were run as a contrast between ≤ or > 1% logging in the catchment. These analyses suggested no significant differences in community composition between sites in these categories of catchment logging or burning, except that %1yrBurn was only marginally not significant in 2005 (p=0.053) for the species only data.

Table 26. Results of Permanova analyses of differences in community composition (species only data) between sites in Karri forest catchments with contrasting proportions of burning or logging.

Catchment history variable	**Year**	**Contrast**	**p**
% 1yr Burn	2005	no burning (n=6) v some burning (n=6)	n.s. (p=0.05)
	2006	no burning (n=6) v some burning (n=5)	n.s. (p=0.90)
	2007	no burning (n=6) v some burning (n=4)	n.s. (p=0.82)
% 1 yr Log	2005	no logging (n=8) v some logging (n=4)	n.s. (p=0.20)
	2007	no logging (n=7) v some logging (n=5)	n.s. (p=0.17)
	2008	no logging (n=6) v some logging (n=5)	n.s. (p=0.12)
% 5yr Burn	2005	≤ 20% burning (n=7) versus > 20% burning (n=5)	n.s. (p=0.60)
	2006	≤ 20% burning (n=7) versus > 20% burning (n=5)	n.s. (p=0.94)
	2007	≤ 20% burning (n=5) versus > 20% burning (n=7)	n.s. (p=0.31)
	2008	≤ 20% burning (n=7) versus > 20% burning (n=5)	n.s. (p=0.63)
% 5yr Log	2005	≤ 1% logging (n=7) versus > 1% logging (n=5)	n.s. (p=0.73)
	2006	≤ 1% logging (n=5) versus > 1% logging (n=6)	n.s. (p=0.87)
	2007	≤ 1% logging (n=6) versus > 1% logging (n=6)	n.s. (p=0.33)
	2008	≤ 1% logging (n=7) versus > 1% logging (n=4)	n.s. (p=0.18)

Table 27. Results of Permanova analyses of differences in community composition (all taxa identified to at least family level) between sites in Karri forest catchments with contrasting proportions of burning or logging.

Catchment history variable	**Year**	**Contrast**	**p**
% 1yr Burn	2005	no burning (n=6) v some burning (n=6)	n.s. (p=0.10)
	2006	no burning (n=6) v some burning (n=5)	n.s. (p=0.92)
	2007	no burning (n=6) v some burning (n=4)	n.s. (p=0.82)
% 1 yr Log	2005	no logging (n=8) v some logging (n=4)	n.s. (p=0.30)
	2007	no logging (n=7) v some logging (n=5)	n.s. (p=0.25)
	2008	no logging (n=6) v some logging (n=5)	n.s. (p=0.20)
% 5yr Burn	2005	≤ 20% burning (n=7) versus > 20% burning (n=5)	n.s. (p=0.79)
	2006	≤ 20% burning (n=5) versus > 20% burning (n=6)	n.s. (p=0.96)
	2007	≤ 20% burning (n=6) versus > 20% burning (n=6)	n.s. (p=0.15)
	2008	≤ 20% burning (n=7) versus > 20% burning (n=4)	n.s. (p=0.60)
% 5yr Log	2005	≤ 1% logging (n=7) versus > 1% logging (n=5)	n.s. (p=0.74)
	2006	≤ 1% logging (n=6) versus > 1% logging (n=5)	n.s. (p=0.85)
	2007	≤ 1% logging (n=7) versus > 1% logging (n=5)	n.s. (p=0.46)
	2008	≤ 1% logging (n=6) versus > 1% logging (n=5)	n.s. (p=0.30)

Relationships between community change and catchment history

The change in community composition (for species only and for all taxa) at each site over three years (2005 to 2008, as indicated by the Bray-Curtis similarity index) was graphed against the proportion of the catchment burned and/or logged in the intervening period (Figures 44 and 45). In these plots, the lower the Bray-Curtis index (y-axes) the greater the change in community composition between years, so if community composition changes in proportion to the amount of logging or burning there should be a significant negative relationship between these catchment history variables and Bray-Curtis similarity. The graphs show no significant relationships between change in community composition and the cumulative proportion of the catchment burned or logged in the intervening period. However, only 2 sites had > 5% of their catchment logged between 2005 and 2008 so the lack of a relationship is not surprising. Furthermore, the degree of change over the four years is highly variable even where none of the catchment was logged or burned. For logging and burning combined the regression for the species only data was only marginally non-significant ($r^2 = 0.35$, p=0.054), but there was substantial change between 2005 and 2008 even for sites that had no burning or logging.

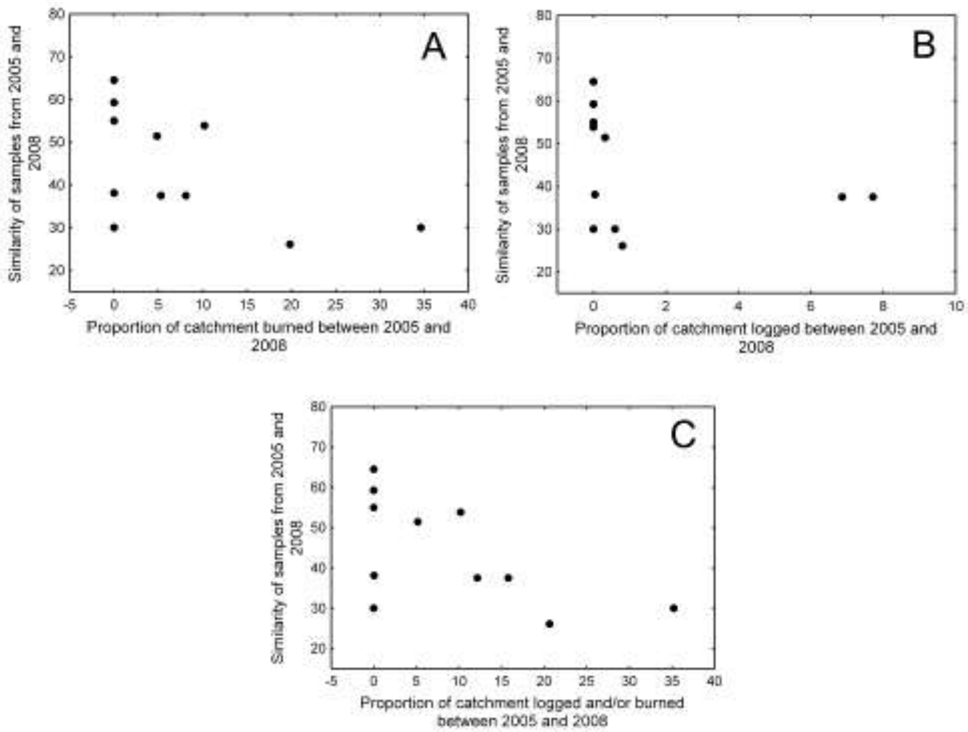


Figure 44. Change in composition of Karri forest invertebrate communities (species only data) between 2005 and 2008, as indicated by the Bray-Curtis similarity index, versus cumulative proportion of catchment affected by burning and/or logging over the same period. A = Burning, B = Logging, C = Logging plus burning.

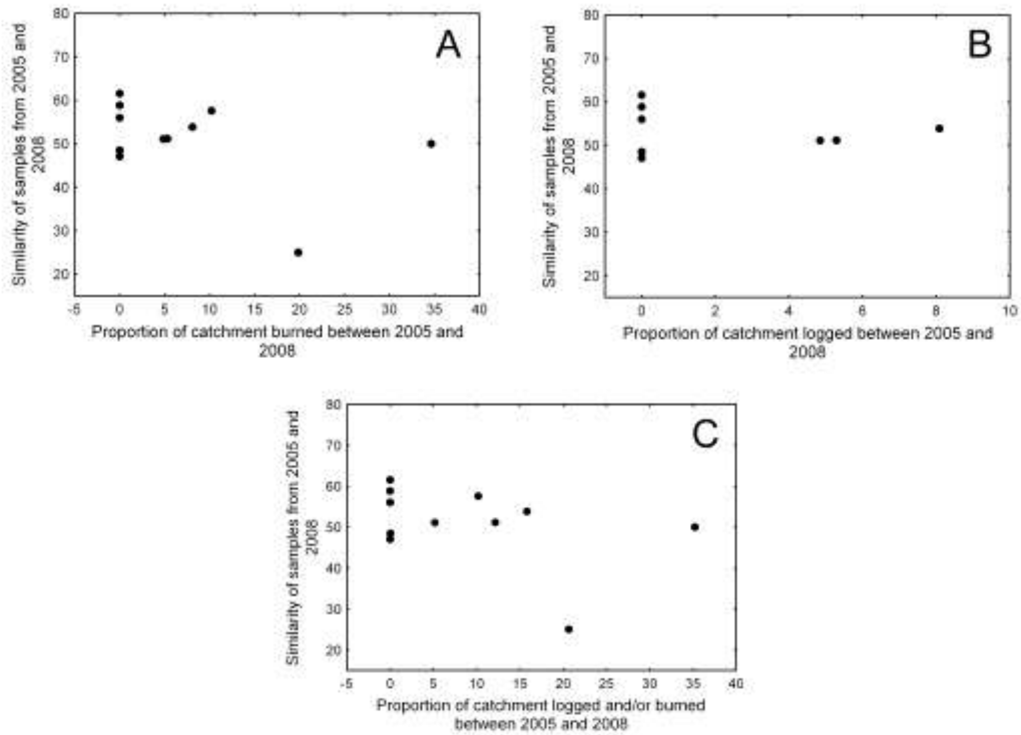


Figure 45. Change in composition of Karri forest invertebrate communities (all taxa identified to at least family) between 2005 and 2008, as indicated by the Bray-Curtis similarity index, versus cumulative proportion of catchment affected by burning and/or logging over the same period. A = Burning, B = Logging, C = Logging plus burning.

Figure 46 shows the change in community composition (for species only data) at each site for all consecutive years. As for the four year period above, there is little in these graphs to suggest that the degree of community change is correlated with the proportion of the catchment burned or logged. It may be significant that only sites with no (or very little) logging or burning in their catchments had Bray-Curtis values > 55. However, the degree of change is highly variable even where there had been no logging or burning during any given year. Furthermore, very few catchments experienced more than 1% logging in any one year or more than 5% burning so detecting a correlation would be difficult.

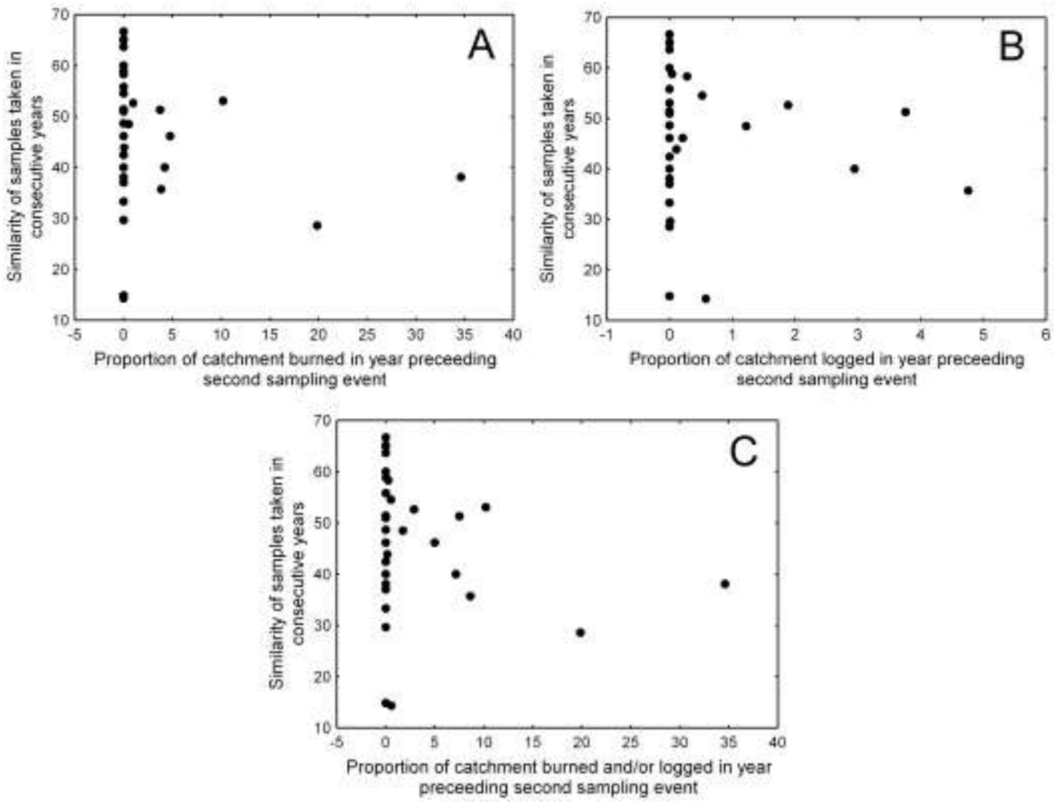


Figure 46. Change in composition of Karri forest invertebrate communities (species data only) between consecutive years (2005 to 2006, 2006 to 2007 and 2007 to 2008) as indicated by the Bray-Curtis similarity index, versus cumulative proportion of catchment affected by burning and/or logging over the same period. A = Burning, B = Logging, C = Logging plus burning.

Dams

The three 'dam' sites (HAR20, MRY42 and SWA34) and three 'reset' sites (HAR21, MRY 43 and SWA35) were compared to 'undisturbed' Jarrah forest sites (the latter being those in catchments which had not been logged or burned during the year prior to sampling).

Figure 47 shows species, chironomid, EPT and family richness for dam, reset and undisturbed (nil) sites. T-tests showed that there were no significances between dam and undisturbed sites for any biodiversity measures. However, low O/E family scores present at the dam sites indicate that fewer families are found than one would expect to find at reference sites. Figure 48 shows all of the dam sites were allocated an AUSRIVAS banding of B indicating these sites are significantly disturbed. There was a significant difference in species richness (p=0.036) between dam and reset sites, with dam sites having less species richness than reset sites. This increase in species richness may be a result of additional species entering the stream via drift from tributaries that join the stream between the two sampling sites. There was a significant difference in species richness (p=0.005), chironomid richness (p=0.029), EPT richness (p=0.019) and family richness (p=0.029) between reset and undisturbed sites. These higher number of species and families found at the reset sites may be due to these sites having a combination of both lotic and lentic species present. This may explain why HAR21 and MRY43 received an AUSRIVAS X banding (enriched). Often sampling points immediately below dams have fauna resembling lentic habitats, due the dam habitat being more like a wetland, rather than a flowing stream. When the water is released from the dam these lentic species are flushed into the stream system. At the reset sites (after lotic species have entered the stream from a tributary) there is a combination of both lotic and lentic species giving rise to a higher species diversity. Therefore information on when water is released from the dam may be a factor to consider when interpreting the biodiversity measures. At the present only limited information has been obtained.

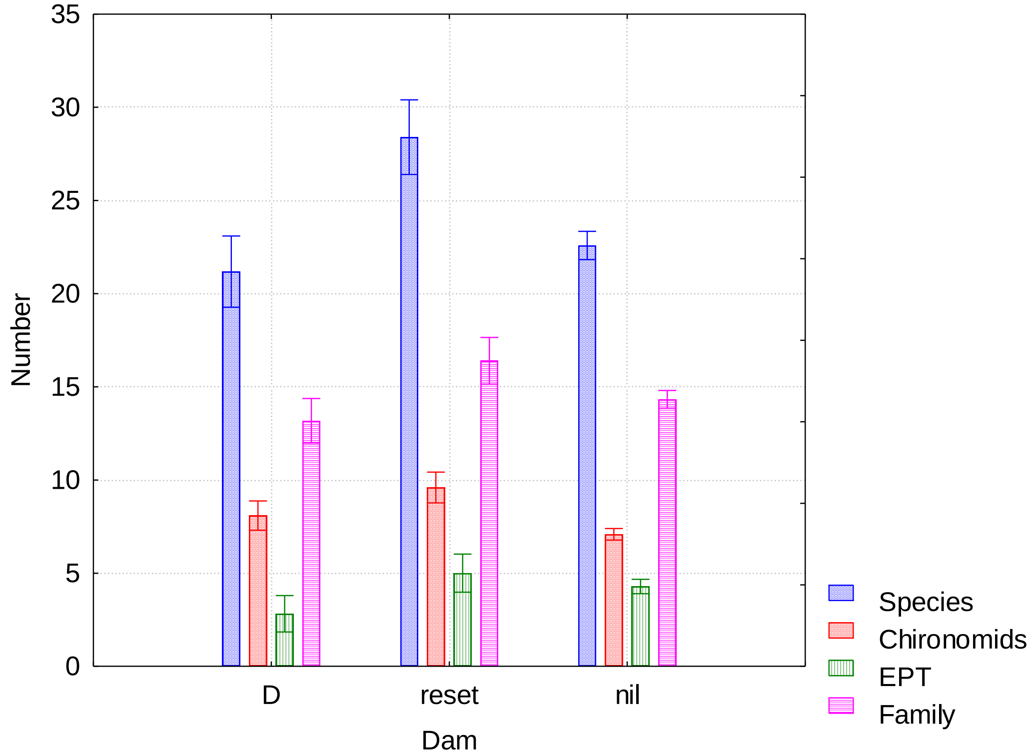


Figure 47. Mean (±SE) species richness, chironomid richness, EPT richness and family richness for dam (D), reset and undisturbed (nil) Jarrah sites.

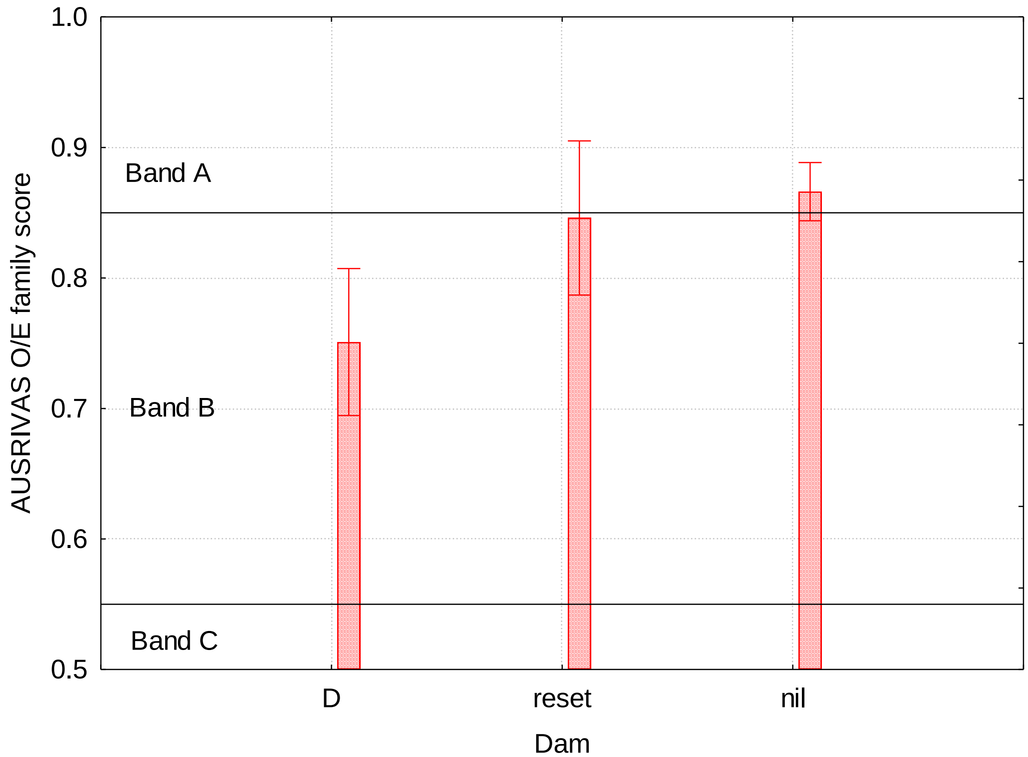


Figure 48. Mean (±SE) AUSRIVAS O/E family scores for dam, reset and undisturbed (nil) Jarrah sites. Lines show the cut off levels for the AUSRIVAS banding system.

Stirling Dam sites (HAR20 and HAR21)

Between 2007 and 2009 dam construction works were undertaken at Stirling Dam (HAR20). This resulted in substantial inputs of sediment to the river, especially at HAR20 (Figure 49). Large amounts of sediment could still been seen 1km downstream at HAR21, especially during 2007. Figure 50 shows the changes in biodiversity measures at the dam and reset sites compared to undisturbed jarrah sites. Figure 51 shows the changes in biodiversity measures along with events which have occurred in the catchment areas since 2000. At both of these sites, all invertebrate richness measures (but not O/E scores at HAR20) were lower in 2007 (after construction works began) than in the previous two years (Figure 50). However, some biodiversity measures were already in decline at HAR21 (but not HAR20) before the construction works, with richness of species, families and chironomids much lower in 2006 than in 2005. The reason for the 2005 to 2006 decline at the reset site may be due to a fire disturbance when 14% of the catchment was burned adjacent to the river between sites HAR20 and HAR21. EPT richness at HAR21 showed no change between 2005 and 2006, but reduced substantially between 2006 and 2007 after the dam works started. EPT richness was generally lower at Jarrah sites in 2007 (probably as a result of the dry winter in 2006) however the increased sedimentation at HAR20 and HAR21 probably exacerbated the decrease at these sites. An increase in sedimentation can clog the gills of many EPTs and fills in the microhabitats between the rocks where EPTs prefer to live

Figure 49. Photographs showing the dam work and increased sedimentation and turbidity in the stream below Stirling Dam (HAR20) in 2007.

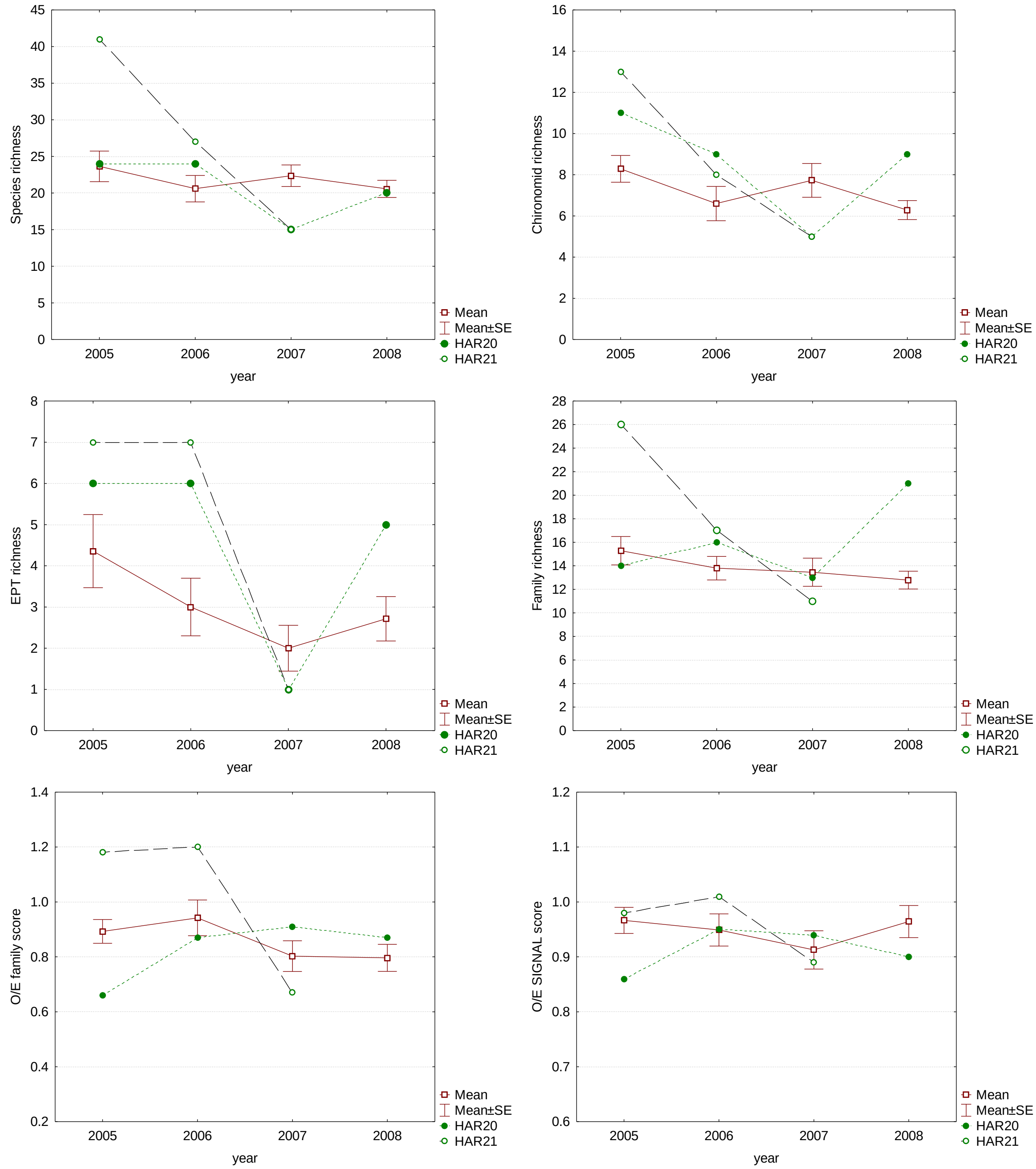


Figure 50. Biodiversity measures for Stirling Dam sites (dam- HAR 20, reset - HAR21) and the means (±SE) for undisturbed Jarrah sites for each year sampled.

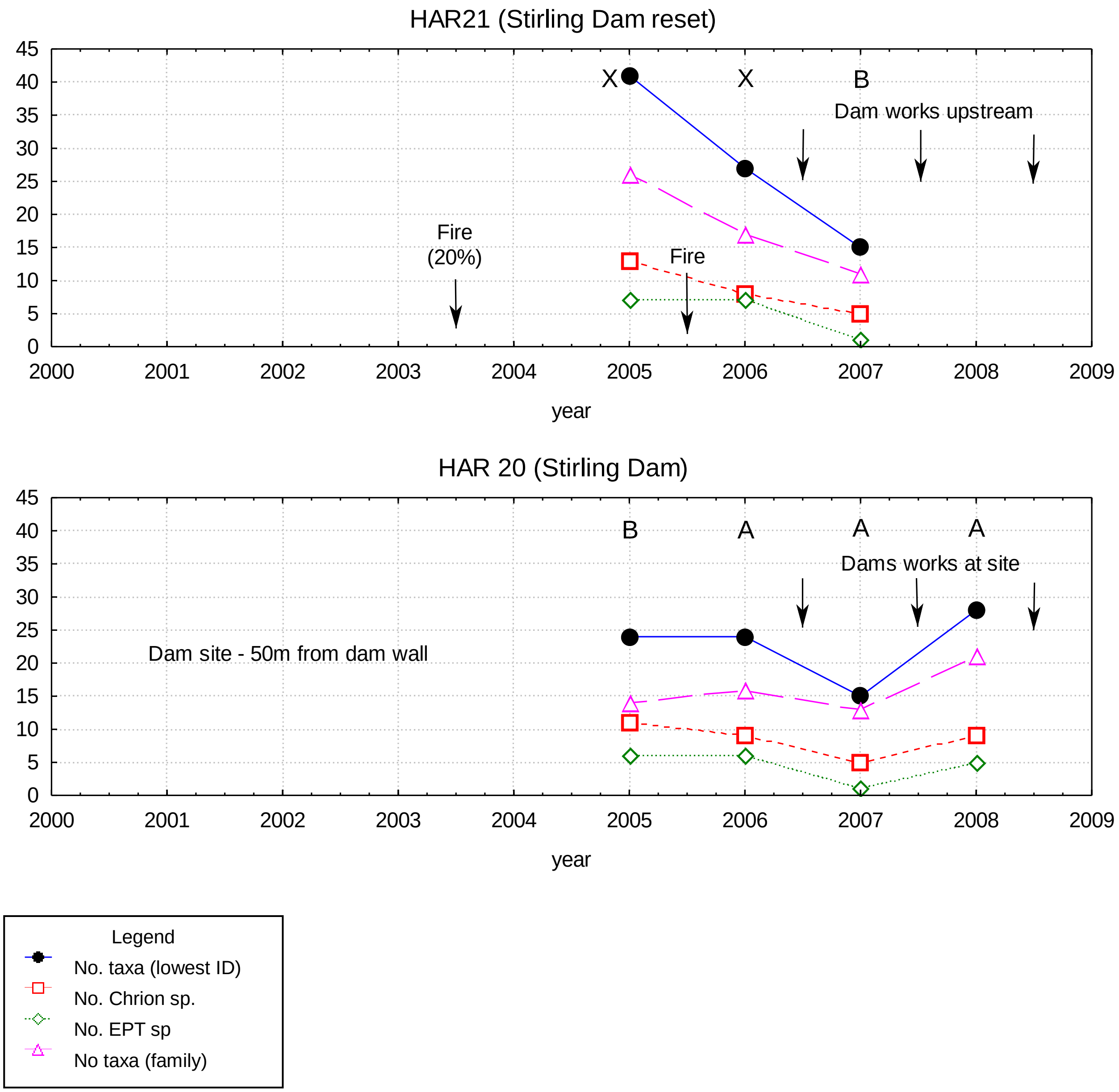


Figure 51. Biodiversity measures plotted with catchment disturbances for the Stirling Dam sites (HAR20 and HAR21). Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets. AUSRIVAS bands are shown above the sampling year

It is interesting to note that HAR21 received the same AUSRIVAS banding (X) in both 2005 and 2006 despite the declines in some biodiversity measures (including family richness) This is because some of the families lost in 2006 were not included in the AUSRIVAS model. Of the 10 taxa present in 2005 and not collected 2006, 7 were not used in the AUSRIVAS model, therefore the loss of these families was not detected by the model. By contrast, in 2007 the site received a B band, indicating that there was a change in the richness of families which are used by the AUSRIVAS model.

Serpentine Dam sites (MRY42 and MRY43)

Figure 52 shows the reset site (MYR43) generally had higher species richness than the dam site (MRY42), largely because of the higher number of EPTs. However, the dam site had higher chironomid richness. At both sites there was generally a decline in biodiversity measures between 2005 and 2006, except chironomids at the reset site. This decline may be partially due to 2006 being a dry year, although these sites did have a larger decline than Jarrah undisturbed sites (Figure 52). MRY43 in 2005 recorded the highest O/E family score (1.21) of any site sampled during the project. This infers that this site has a greater number of families present than the reference sites used in the AUSRIVAS model, giving it an X banding. Species and family richness was high at this site in 2005 (34 and 23 respectively) but decreased in 2006 (29 and 17 respectively) and the banding level dropped to B (slightly impaired) (Figure 53). Samples taken in 2007 and 2008 recorded a slight rebound in these numbers resulting in the site being upgraded to band A (similar to reference) in 2008. Community composition at MRY43 changed substantially between years, with EPT and chironomid richness showing opposite trends. The high species and family richness at MRY43 may be due to both lentic species (flushed from the dam) and lotic species (entering from a tributary) being present. A study on the Serpentine River (Davis *et al.*, 1988) reported similar findings with a high number of taxa found at one site (approximately where MRY43 was located) compared to a site just below the piphead dam (near the MRY42 location). They found the site near MRY43 had a different invertebrate community to other sites located both upstream in a nearby tributary (Gooralong Brook) and further downstream in the Serpentine River.

Changes in biodiversity measures do not seem to be related to logging and fire disturbances in the MRY43 catchment. The last records of logging in the MRY43 catchment were in the 1990's with no logging recorded since 1998. Control burns have been recorded in the catchment area every year since 1998. The largest burn area recorded in the past ten years occurred in 2005 with 7.1ha (10.5%) of the catchment area being burned (Figure 53).

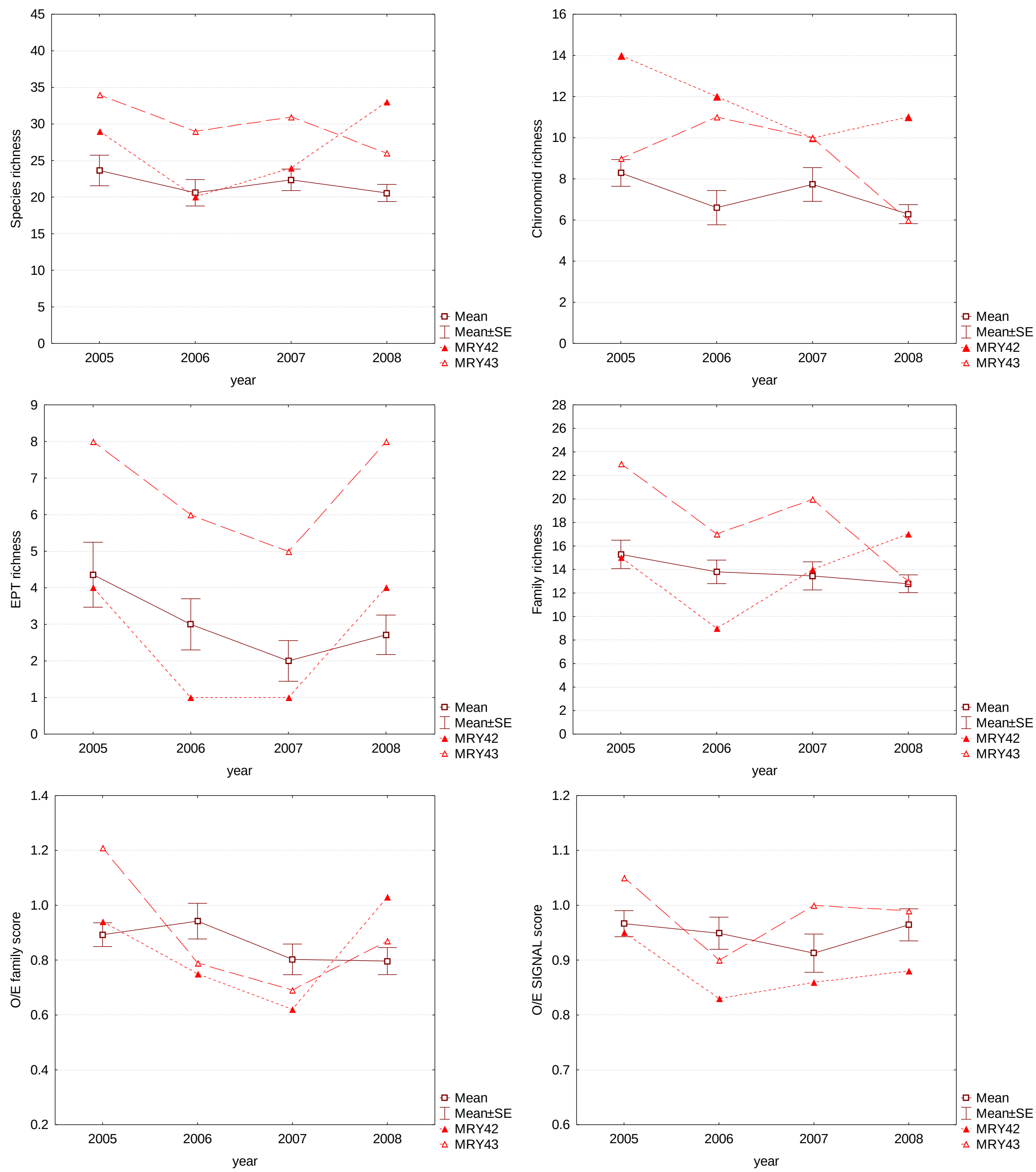


Figure 52. Biodiversity measures for Serpentine Dam (MRY42; reset MRY43) and the means (±SE) for undisturbed Jarrah sites for each year sampled.

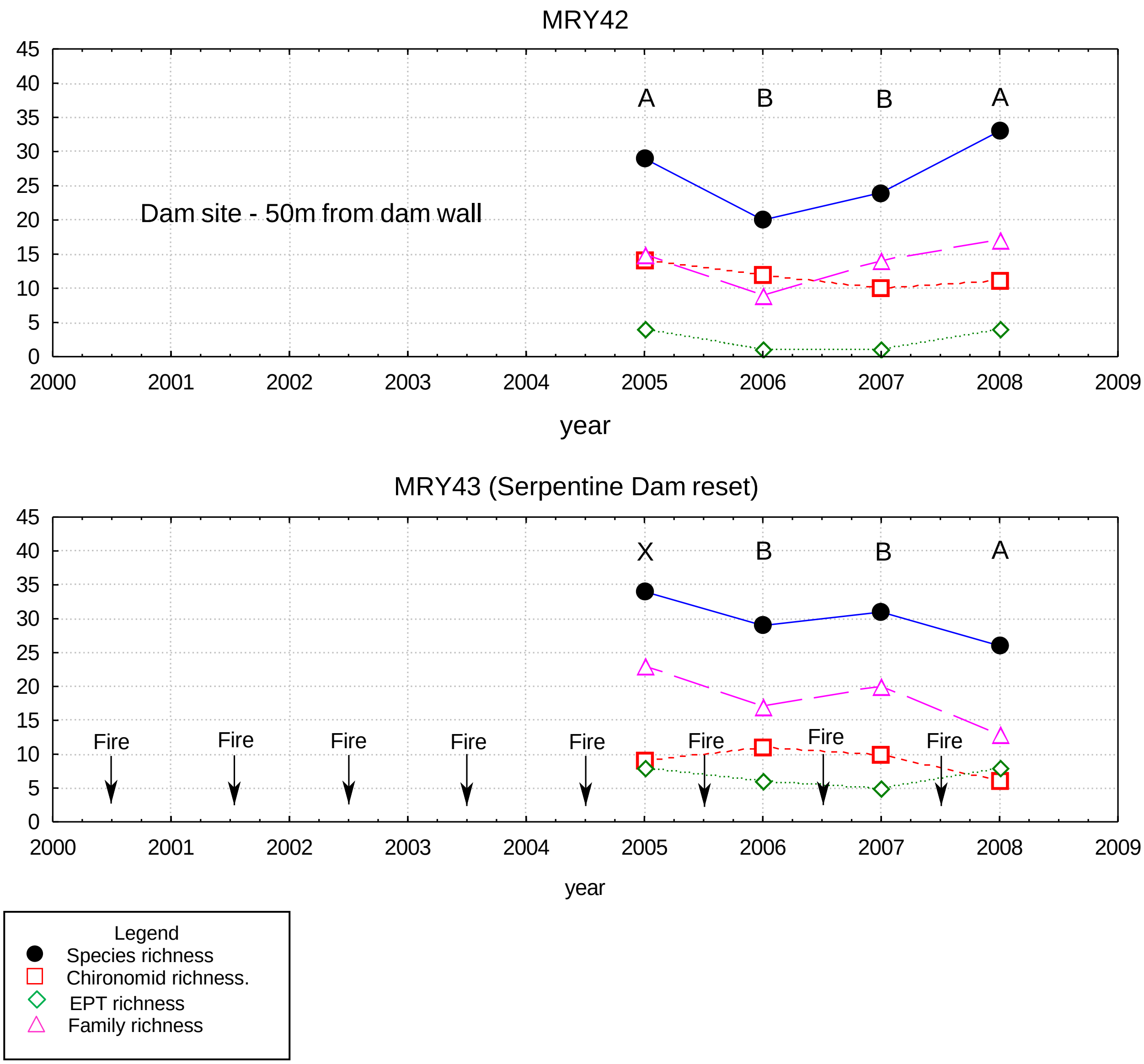


Figure 53. Biodiversity measures plotted with catchment disturbances for the Serpentine Dam sites (MRY 42 and MRY43). Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets. AUSRIVAS bands are shown above the sampling year

Canning Reservoir sites (SWA34 and SWA35)

The Canning Reservoir sites were added to the project in 2006 to increase the number of sites below dams. The dam site (SWA34) had lower species, chironomid, EPT and family richness than the reset site (SWA35) (Figure 54). Even though the reset site often had a higher number of species and chironomids than the undisturbed sites, the number of families was lower. This is reflected in the low AUSRIVAS scores (O/E family and O/E SIGNAL) for this site. As a result SWA35 received a C band (severely impaired) in 2006. The dam site (SWA34) received a C band in 2007 and 2008 (Figure 55).

The dam site (SWA34) seemed to be impaired and had the lowest richness for species (6 in 2007), chironomids (2 in 2006) and O/E SIGNAL score (0.65 in 2007). The O/E family score (0.28) in 2007 was near the boundary (0.24) of band D (extremely impaired). In 2007 SWA34 had a reduction in species, EPT and families and an increase in chironomids (Figure 54). The large decrease in the O/E SIGNAL score at this time indicates a decrease in sensitive families present. The cause of this rapid decrease in 2007 is uncertain, but it may be due to a higher flow rate. Measurements from gauging station near SWA35 showed stream discharge rates were higher in September 2007 (319.4ML) compared to 2006 (44.0ML) and 2008 (40.72ML). The Canning Reservoir is not a winter supply dam so water should not be released from the dam at this time. Therefore the increased flow is probably a result of increased rainfall and runoff entering the stream. Even though there was no flow at the time of sampling the water level was slightly higher in 2007 (Figure 56) with below detection concentrations (<0.01µg.$L^{-1)}$ for NH_3, NO_3, soluble reactive phosphorus and total P and low total N concentration of 0.06µg.L^{-1} (reduced from 0.58µg.L^{-1} in 2005)(Appendix 2). There was also a decrease in alkalinity and increase in colour compared to 2005 samples. Changes in the invertebrate community in 2007 may be a result of changes to the physical condition in the river. A study by Storey *et al* (1991) on invertebrates assemblages downstream of the Canning Dam, found differences in the fauna were associated with differences in the physical conditions between the reaches.

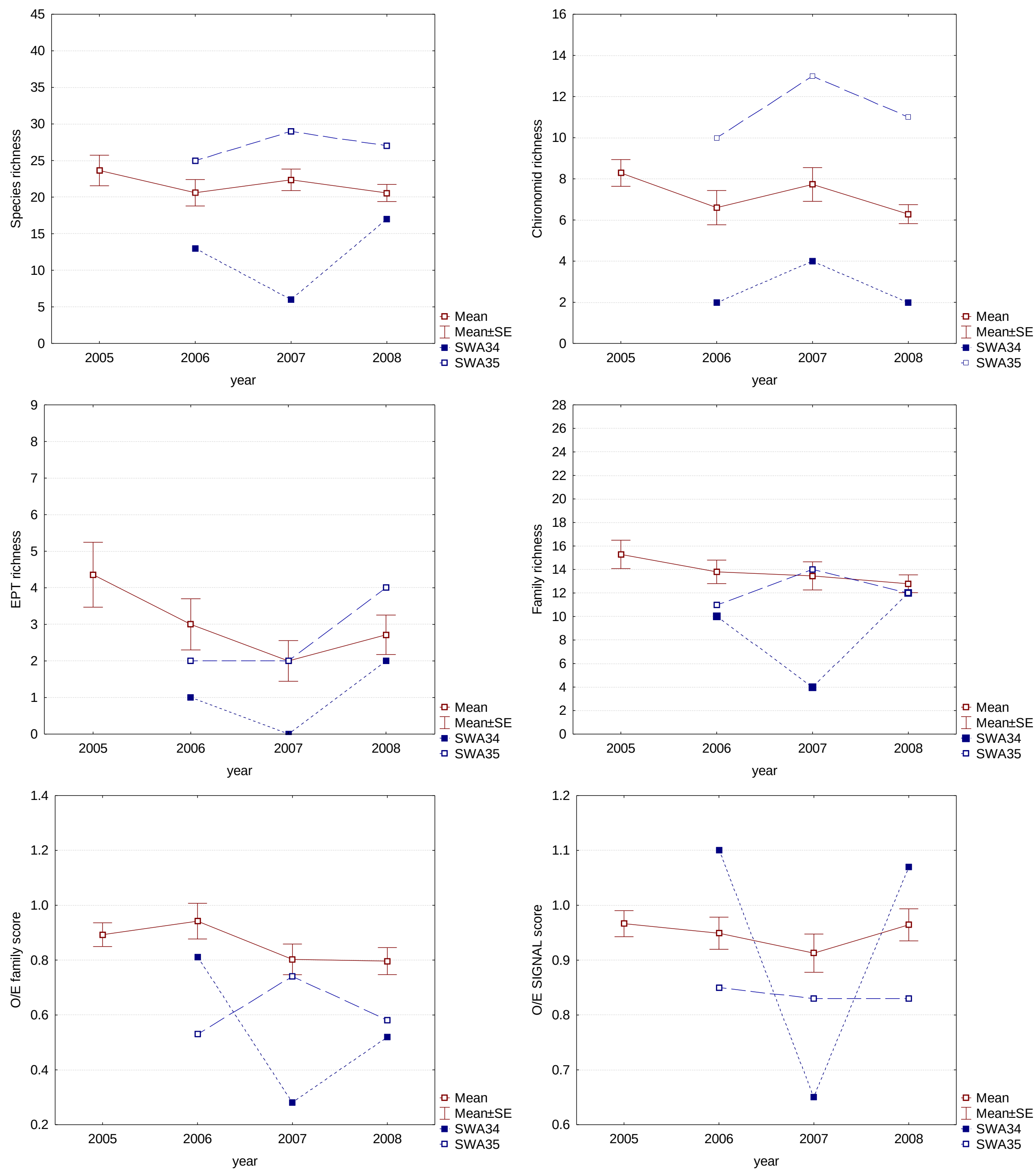


Figure 54. Biodiversity measures for Canning Reservoir (SWA34; reset SWA35) and the means (±SE) for undisturbed sites Jarrah for each year sampled.

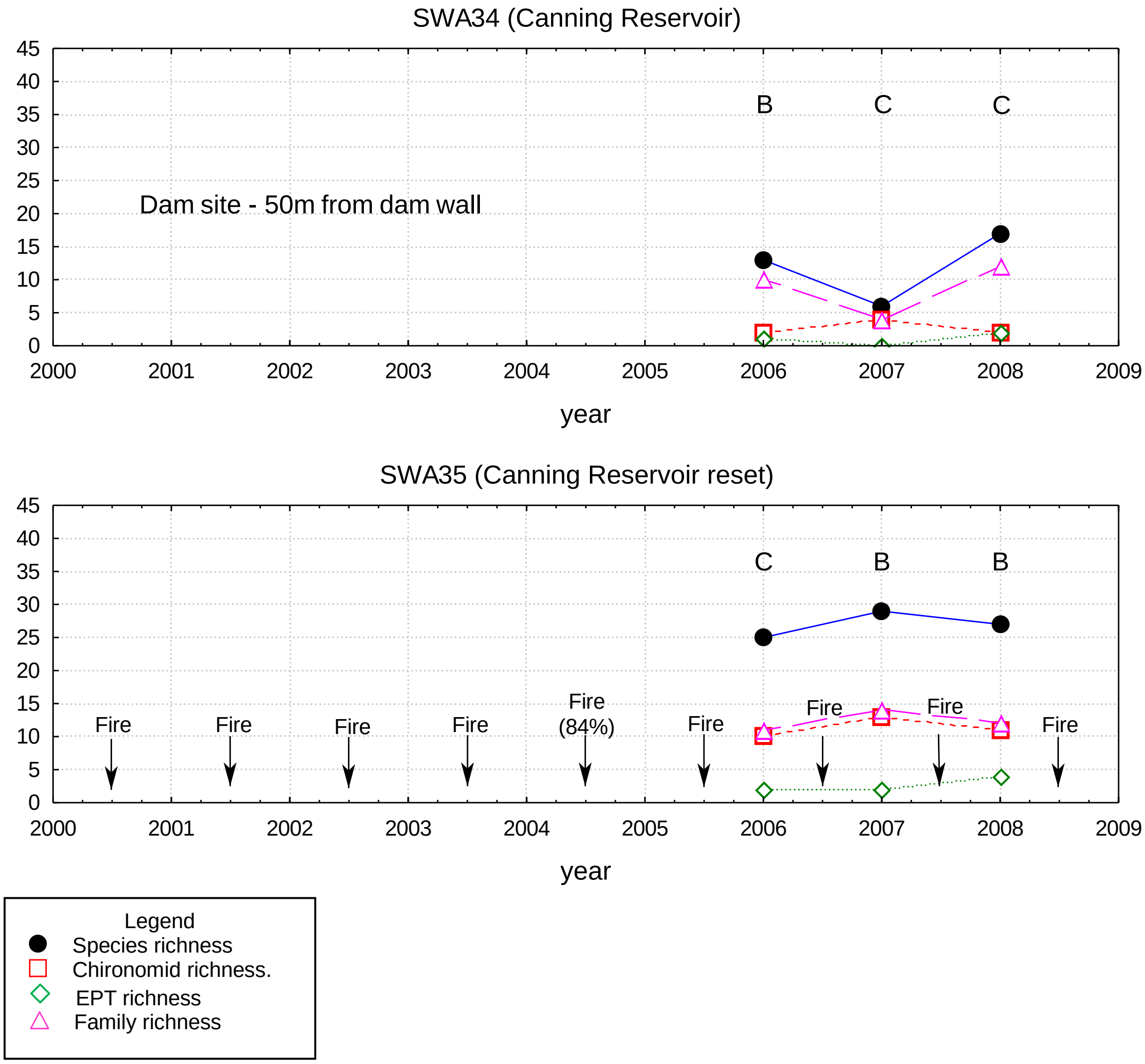


Figure 55. Biodiversity measures plotted with catchment disturbances for the Canning Reservoir sites (MRY 42 and MRY43). Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets. AUSRIVAS bands are shown above the sampling year

A.  B 

C. 

Figure 56. Photographs of SWA34 for A) 2006, B) 2007 and C) 2008.

Wildfires

Two sites; SWA24 (Little Darkin) and DEN26 (Quickup), both experienced wildfires in the 2004/2005 season, just prior to the first sampling occasion. On these occasions the fire occurred at the sites rather than just within in the catchment. These sites were specifically chosen to examine the effect of wildfires on the biodiversity in the streams. Both sites are within the Jarrah forest so biodiversity measures for these sites were compared to the mean values for undisturbed Jarrah sites. Photographs showing the sampling site for SWA24 and DEN26 from 2005 to 2008 are shown in Figures 57 and 58 respectively.

Figure 57. Photographs of the sampling site at SWA 24 (Little Darkin) from 2005 – 2008.
A) 2005, B) 2006, C) 2007 D) 2008

Figure 58 Photographs of the sampling site at DEN26 (QuickUp) from 2005 – 2008.
A) 2005, B) 2006, C) 2007 D) 2008

Figure 59 shows that at both sites species and family richness were well below the means for undisturbed sites for 2005. DEN 26 had similar or higher richness than the undisturbed sites in 2006, 2007 and 2008. SWA 24 still had low richness in 2007 but was higher than the mean richness in 2008. These results suggest recovery from the effects of wildfires over periods of 3 to 4 years. In 2005, both sites had a higher than average level of chironomids and lower EPT richness. Chironomids would be expected to increase in richness and abundance if there were greater amounts of fine sediments and fine organic matter in the stream after the fire. The same conditions, plus other potential effects of a reduced riparian cover, such as reduced litter input (coarse organic matter) and elevated temperatures, may have reduced EPT richness. In 2006 chironomid richness declined at both sites, with richness at DEN26 being below undisturbed sites. At DEN26 chironomid richness was slightly lower than undisturbed sites in 2007, but was similar in 2008. At SWA 24 chironomid richness was similar to the undisturbed sites in 2007 and 2008. EPT richness at SWA24 declined in 2006 and further declined in 2007, when no EPT were present. However in 2008 EPT richness was similar to undisturbed sites. EPT richness at DEN26 was lower than undisturbed sites in 2006, 2007 and 2008, although richness was higher in 2006 and 2008, than 2007. This reduction in EPT richness in 2007 and rebound in 2008 was also seen in the undisturbed sites.

A few environmental variables were slightly higher in 2005 at these sites, compared to the following years. Both sites had higher flows, but many sites in 2005 had higher flows this year so it is uncertain whether the increase in flow is due to the catchment being burned or just seasonal variation. DEN26 also had higher levels for alkalinity and colour and a lower conductivity, but SWA24 only had slightly higher NO_3 concentrations (Appendix 2). It is possible that the increased runoff and flow has resulted in the differences in the variables for 2005.

The AUSRIVAS bands allocated to DEN26 and SWA24 varied between years (Figure 60). At DEN26 there was little variation in the O/E scores (O/E SIGNAL, 0.95±0.1 and O/E Family, 0.84±0.1), and the scores were near to the boundary of bands A and B (lower boundary for Band A is 0.85) which resulted in the banding switching back and forth between the A and B bands. This may be due to the natural temporal variation rather than the wildfire impact at DEN26, however, as the other biodiversity measures were lower for 2005 and 2006 there was probably a short term impact on species composition at the site due to the wildfire. The wildfire seemed to have a greater impact at SWA24 than DEN26 with all biodiversity measures (except chironomids richness) below mean levels for 2005, 2006 and 2007. This wildfire may have had a greater impact due to the fires intensity and also the time of the fire before sampling. It can be seen from the photographs (Figures 57 and 58) that the surrounding habitat is more scorched and shows no signs of regrowth at SWA24 compared to DEN26. In 2008 species and family richness at SWA24, were higher than the average range for undisturbed sites and was allocated of an AUSRIVAS A Band (Undisturbed). It would seem that within 5 years both sites have recovered to similar biodiversity measures to other undisturbed Jarrah sites. Further sampling will help provide a better indication of the recovery time of these sites after the wildfire.

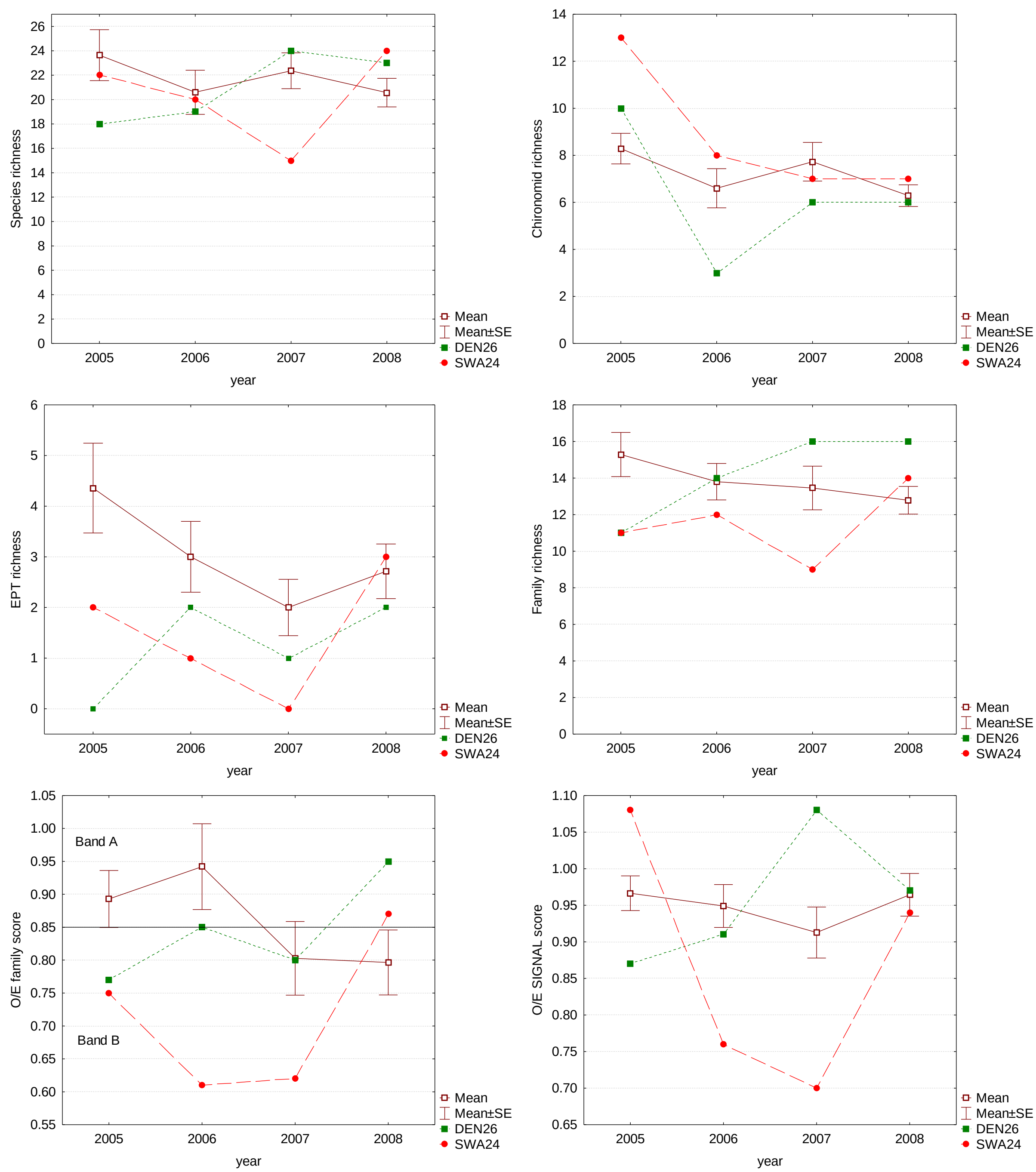


Figure 59. Biodiversity measures for wildfire impacted sites (DEN26 and SWA24) compared to other Jarrah undisturbed sites.

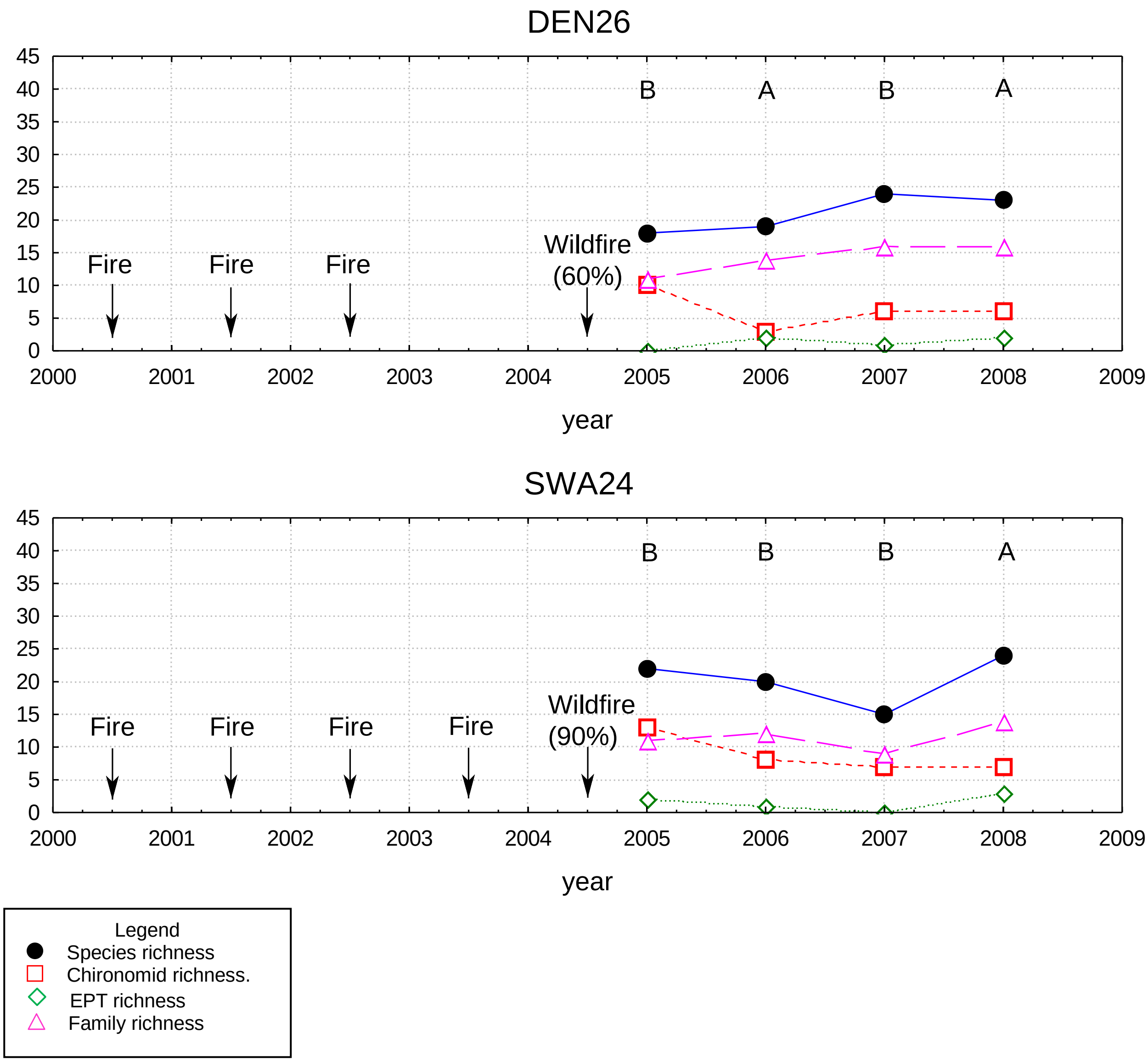


Figure 60. Biodiversity measures plotted with catchment disturbances for sites affected by wildfire (DEN26 and SWA24). Arrows indicate events which have occurred at the site since 2000. Disturbances >20% of catchment are shown in brackets. AUSRIVAS bands are shown above the sampling year

Dieback

The presence of dieback in forest areas may affect the hydrology in the catchment and consequently the forest streams. Other effects on streams could be increased sedimentation and consequences of reduced riparian cover (e.g. altered organic matter input and increased light and therefore algal production).

The record of dieback for each catchment is shown in Table 28. Dieback has not been recorded from 11 catchment areas, although some of these have not been fully interpreted. Table 29 shows the number of catchments for each forest type with dieback recorded.

Table 28. Dieback records for each catchment. All areas shown are in hectares.

Catchment	Total Area (Ha)	Area of Public Land	Dieback status as at 02.12.08				Dieback present (%Catchment)
			Dieback present	Dieback free	Uninterpret able	Not interpreted	
BLA06	55,241	49,488	18,848	28,950	893	796	34.1
BLA43	10,015	10,015	2,058	7,927	30	0	20.6
BLA51	6,431	4,063	193	3,863	5	2	3.0
BLA52	400	400	21	379	0	0	5.3
BLA53	1,523	1,523	435	1,088	0	0	28.6
BLA54	2,409	2,409	1,392	1,017	0	0	57.8
BLA55	4,739	4,162	1,183	2,957	2	19	25.0
BLA56	4,724	4,724	542	4,182	0	0	11.5
BUS05	4,694	1,587	369	1,025	11	182	7.9
BUS26	551	551	61	490	0	0	11.1
COL36	425	425	48	378	0	0	11.2
COL37	419	419	0	419	0	0	0.0
COL38	81	81	0	80	0	0	0.6
DEN09	3,827	1,106	0	630	0	476	0.0
DEN26	718	664	0	0	0	664	0.0
DON03	15,679	15,558	4,154	6,882	4,493	30	26.5
DON14	1,398	1,183	242	600	336	5	17.3
DON15	2,422	2,422	71	2,267	81	2	2.9
DON16	3,308	3,308	746	2,003	559	0	22.6
FRA17	221	221	0	218	0	3	0.0
FRA18	2,346	1,437	3	977	9	447	0.1
HAR01	2,798	2,798	1,268	1,530	0	0	45.3
HAR21	185	84	0	79	0	4	0.0
KEN11	2,861	2,861	274	452	0	2,135	20.9
MYR09	1,698	1,698	934	762	1	0	55.0
MYR33	1,756	1,756	1,341	415	0	0	76.4
MYR41	3,510	3,510	479	3,001	30	0	13.7
MRY43	6,788	5,681	2,742	2,388	287	264	40.4
MYR44	2,576	2,576	121	2,449	6	0	4.7
MYR45	2,463	2,421	0	2,396	0	25	0.0
SHA21	768	768	0	480	288	0	0.0
SHA22	2,244	2,244	256	1,710	137	141	11.4
SHA23	148	148	47	89	0	12	31.7
SHA24	1,767	1,767	992	381	394	0	56.1
SWA04	1,396	1,347	683	583	81	0	48.9
SWA24	2,977	2,977	98	2,823	56	0	3.3
SWA31	24,567	20,482	0	16,266	0	4,216	0.0
SWA32	28,329	28,329	1,426	26,692	211	0	5.0
SWA33	14,113	14,113	124	13,785	203	1	0.9
SWA35	7,557	6,249	925	5,141	56	128	12.2
WAR01	1,130	941	0	754	183	3	0.0
WAR02	2,705	2,039	85	1,920	1	33	3.1
WAR05	5,795	4,974	6	4,339	27	601	0.1
WAR15	9,200	4,058	1,213	1,144	1,275	425	13.2
WAR16	497	497	175	278	44	0	35.1
WAR17	3,439	3,439	201	3,121	118	0	5.8
WAR18	3,681	3,581	108	3,453	18	2	2.9
WAR19	919	919	0	919	0	0	0.0

Dieback status is courtesy of FMB using FMIS, note that catchment areas may be slightly different (<5ha) due to different GIS systems used to calculate areas.

Table 29: The number of catchments within the Jarrah and Karri forests with Dieback recorded. Excludes the dam sites.

Forest type	Dieback		
	No Record	Present	Total
Karri	3	8	11
Jarrah	9	28	37
Total	12	36	48

The impact of dieback presence in the catchment on biodiversity measures was analysed by using repeated measures ANOVA's (within factor being year) (Table 30). The only significant effect of dieback was for O/E SIGNAL scores (p=0.022) in the Jarrah forest. Figure 61 shows Jarrah sites with dieback had a higher SIGNAL score indicating the greater presence of sensitive families at these sites. This result should be viewed with some caution as SIGNAL values used in the AUSRIVAS model are for eastern Australian families and some Western Australian families are more tolerant.

Table 30. Repeated measures ANOVA between Dieback and invertebrate measures, grouped by forest type. Bold and * denotes significant difference. DF for dieback = 1, site = 3

		Jarrah (n=37)				**Karri** (n=11)			
		SS	MS	F	p	SS	MS	F	p
Species Richness	Dieback	4.20	4.20	0.029	0.866	3.60	3.60	0.020	0.890
	Year	6.99	2.33	0.118	0.949	23.43	7.81	0.457	0.715
	Year *Dieback	78.99	26.33	1.332	0.273	48.23	16.08	0.941	0.436
		SS	MS	F	p	SS	MS	F	p
Chironomid Richness	Dieback	8.13	8.13	0.586	0.453	4.29	4.29	0.260	0.624
	Year	43.00	14.33	2.528	0.066	82.65	27.55	5.854	**0.004***
	Year *Dieback	4.62	1.54	0.272	0.846	12.25	4.08	0.867	0.472
		SS	MS	F	p	SS	MS	F	p
EPT Richness	Dieback	88.34	88.34	2.563	0.126	0.63	0.63	0.013	0.912
	Year	10.12	3.37	1.030	0.386	9.08	3.03	0.854	0.478
	Year *Dieback	13.31	4.44	1.355	0.266	9.48	3.16	0.891	0.460
		SS	MS	F	p	SS	MS	F	p
Family Richness	Dieback	1.34	1.34	0.031	0.863	0.85	0.85	0.021	0.887
	Year	12.17	4.06	0.648	0.588	19.60	6.53	0.906	0.441
	Year*Dieback	35.60	11.87	1.895	0.141	43.86	14.62	2.028	0.116
		SS	MS	F	p	SS	MS	F	p
O/E family	Dieback	0.22	0.22	2.000	0.173	0.01	0.01	0.161	0.699
	Year	0.09	0.03	1.898	0.140	0.01	0.00	0.247	0.863
	Year *Dieback	0.04	0.01	0.772	0.515	0.03	0.01	0.505	0.682
		SS	MS	F	p	SS	MS	F	p
O/E SIGNAL	Dieback	0.12	0.12	6.273	**0.022***	0.01	0.01	0.388	0.551
	Year	0.01	0.00	0.331	0.803	0.02	0.01	2.620	0.074
	Year *Dieback	0.02	0.01	1.362	0.264	0.01	0.00	0.712	0.555

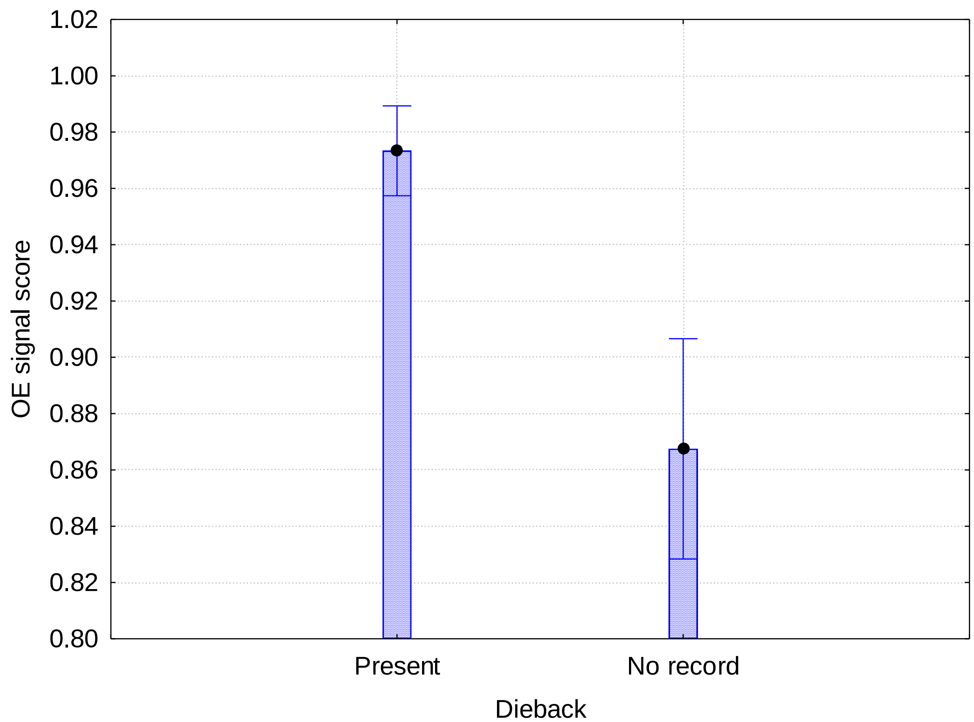


Figure 61. O/E SIGNAL scores for sites with and without dieback present in the Jarrah forest.

There were significant correlations between the proportion of Jarrah forest catchments affected by dieback and all of the biodiversity measures, except for chironomid richness. No significant correlations were found in the Karri forest (Table 31, Figure 62). The significant correlations are not strong, but all are positive (Figure 63). The dieback may be influencing invertebrate communities by increasing the amount of debris, runoff and sediment entering the streams, though it is interesting that the community changes to one that contains a greater proportion of "sensitive" species.

At this stage in the project, the effect of fire or logging in the catchments with or without dieback has not been examined. Such data would help to interpret biological changes at particular sites, but it should be noted that there will be insufficient replication within each subcategory of disturbance to generalise about biological responses to dieback using factorial techniques such as ANOVA.

Table 31. Correlations between the proportions of the catchment with dieback recorded and forest types. R values with bold * denoting a significant value (p<0.05).

	Dieback (% catchment)		
	Both forest types	Jarrah	Karri
Species richness	.3085 **p=.000 ***	.4456 **p=.000***	-.1131 p=.454
Chironomid. richness	.1237 p=.112	.1661 p=.070	-.0045 p=.976
EPT richness	.4062 **p=.000***	.6621 **p=.000***	-.2305 p=.123
Family richness	.3529 **p=.000***	.4836 **p=.000***	-.0581 p=.701
O/E50Signal	.3422 **p=.000***	.4152 **p=.000***	.1618 p=.283
O/E50family	.2818 **p=.000***	.4070 **p=.000***	-.1885 p=.210

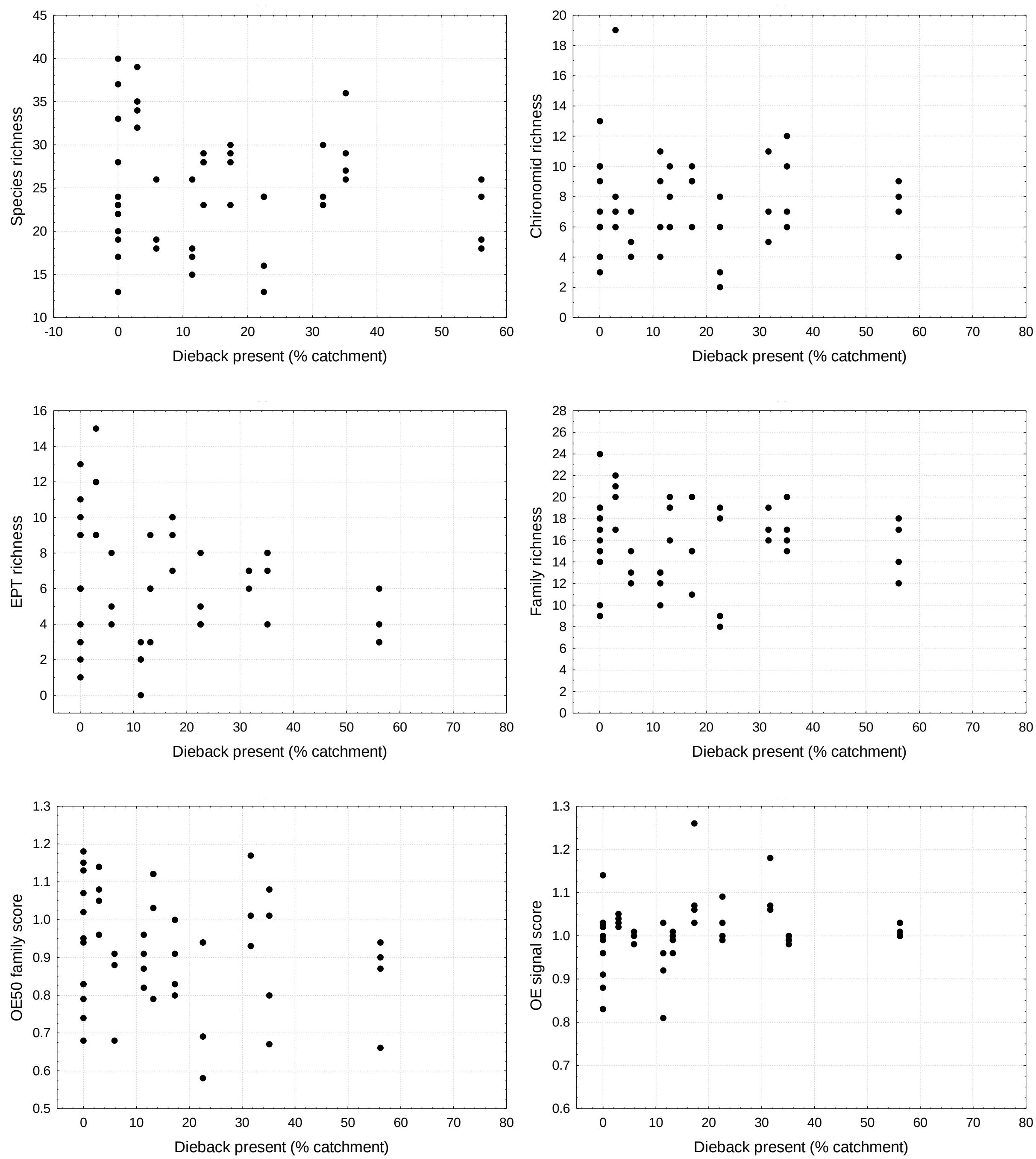


Figure 62. Biodiversity measures plotted against the proportion of the catchment (%) recorded with Dieback for Karri forests.

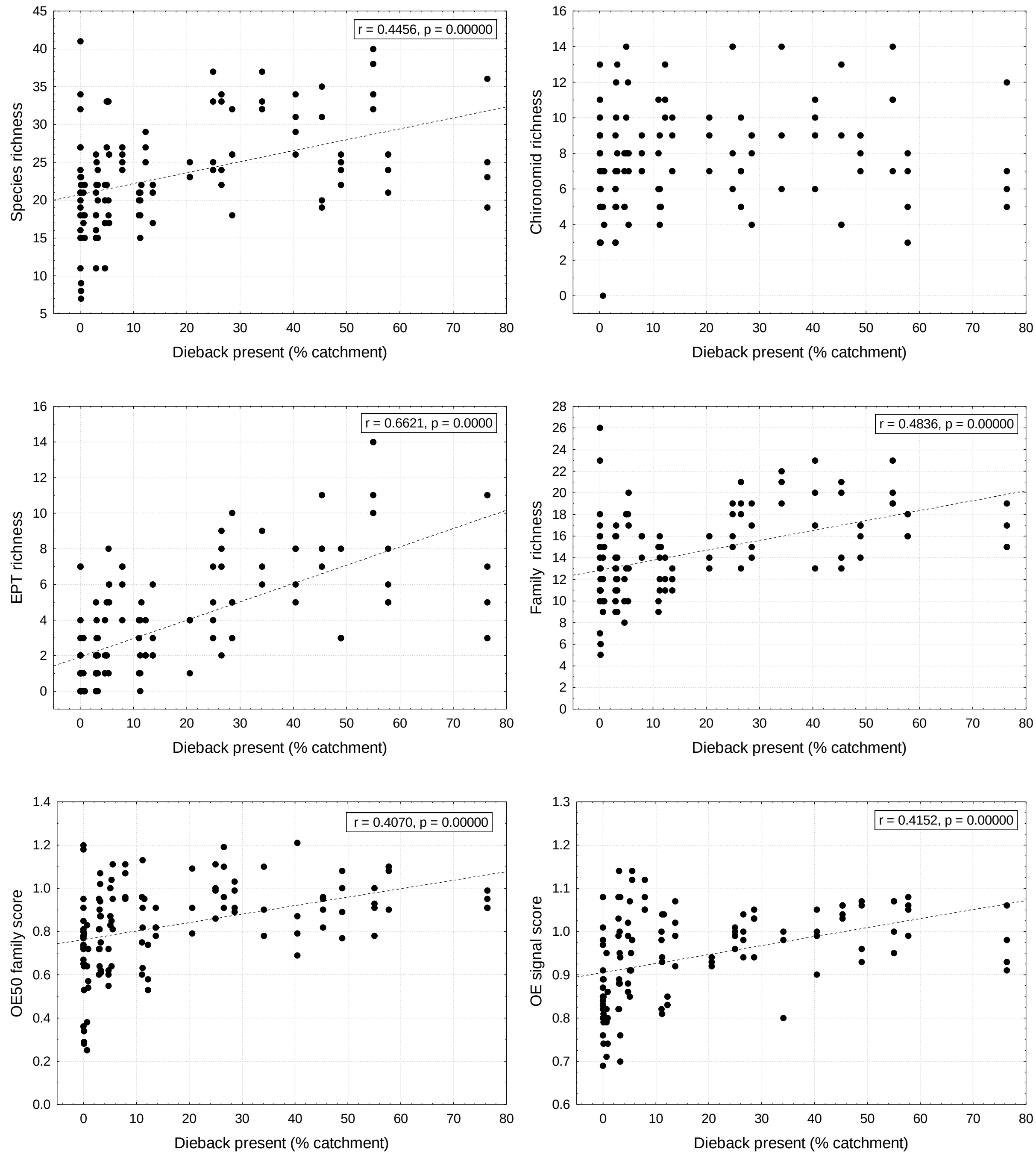


Figure 63. Biodiversity measures plotted against the proportion of the catchment (%) recorded with Dieback for Jarrah forests. Lines of fit show significant correlations (p<0.05).

SUMMARY

Invertebrates

The invertebrate communities inhabiting south-west forest streams were diverse, with over 310 taxa collected from 84 families and an additional 10 orders. Within many sites there was substantial variation in the biodiversity measures and the AUSRIVAS scores and bands between years. However, AUSRIVAS scores generally changed by only one band and often switched back and forth between bands over time. Some of the temporal variation in the biodiversity measures may be related to rainfall related flow regimes. Biodiversity measures were generally low in 2007, following the particularly dry year in 2006 (10 sites were dry and others would have had shortened hydroperiods). The lower richness in 2007 may have been the result of reduced survival and reproduction in the dry 2006 season and subsequent low recruitment in 2007. Another study being carried out in the northern Jarrah forest (Aquatic Research Laboratory, 2009) also found a decrease in species richness in 2007 and has described a historical change in the macroinvertebrate composition since 1984, which is likely to be reflecting a change from perennial to seasonal flows. Invertebrate biodiversity was also higher in streams with higher maximum flow and lower conductivities which may reflect local rainfall and runoff. The eastern-most streams had higher salinities and particularly low invertebrate diversity.

Forest types

There was a difference in invertebrate communities between the Jarrah and Karri forests, with Karri forests generally having a higher number of EPTs. Differences between forest types were not consistent between years. Community analysis showed that there is a latitudinal gradient in invertebrate community composition, with southern Jarrah forest sites having similar invertebrate communities to those present in Karri forest.

Biodiversity measures and Disturbances

Seven sites (14% of total) were rated as severely impaired by the AUSRIVAS models (they received a C band for at least one sampling occasion). All of these sites occurred within the Jarrah forest and had a history of varying catchment disturbance. At these sites, impairment did not seem to be related to any single factor, but may be due to a combination of factors occurring simultaneously or repeatedly in the catchment.

Effects of fire and logging on invertebrate communities were only detected in some years. In Jarrah forest streams, the only significant effect of fire on biodiversity was lower EPT richness in catchments with both fire and logging in 2006. Rainfall was particularly low in 2006, with ten sites being dry when visited, and it may be that low rainfall exacerbated the effects of disturbance in the catchment. Jarrah forest streams with some logging in the catchment (with or without burning) had higher species, EPT, chironomid and family richness in 2008, compared to streams in catchments with no burning or logging in the same year. Sites which were logged (but not burned) also showed a significant an increase in species, EPT, chironomid and family richness in 2008. This implies that logging may have an effect on aquatic invertebrates, however the effect varies annually and may be influenced by other factors occurring in the catchment.

The proportion of Jarrah forest catchments burned was only correlated with change in invertebrate diversity between 2006 and 2007; when there was greater reduction in species and EPT richness in catchments with more burning. The proportion of the catchment logged was not correlated with change in biodiversity measures between any years.

In the Karri forest there were only 12 sites so not all of the disturbance categories were sufficiently represented in all years for formal analysis. The proportion of a catchment affected by fire or logging was also much lower in the Karri forest, with no Karri sites having more than 5% of the catchment logged in any year and only three sites having more than 35% of the catchment burned in any year. In contrast, eleven Jarrah catchments had over 35% of the catchment burned and four sites had over 10% of the catchment logged in any year.

In Karri forest streams, there were no differences in biodiversity measures between catchments with fire (with or without logging) and those without fire in the previous year. In 2008, streams in catchments which were logged in the previous year (with or without burning) were found to have lower EPT richness compared to streams in catchments which were undisturbed. There was insufficient data to determine the effects of logging only (i.e. without burning) in the Karri forest. However, as no fire effect was found in 2008 it is possible that the difference in EPT richness was due to logging alone for this year.

The proportion of the Karri forest catchment burned was negatively correlated with change in EPT richness between 2006 and 2007, but no other correlations were detected for logging or fire in Karri forest streams.

There were no significant correlations between changes in biodiversity measures and the proportion of Jarrah or Karri catchments logged and/or burned over the four year period 2005 to 2008. Time since the last fire or logging event was also uncorrelated with biodiversity measures.

The results to date suggest that EPT taxa are the most sensitive and are proving to be a valuable measure of disturbance at a site. However, similar disturbances may have different effects on EPT taxa depending on variables such as the site's geology, slope and amount of riparian disturbance. For example, a disturbance may increase the amount of runoff and debris entering the stream which may be favourable to EPTs (which prefer flowing water and high detritus levels), but if there is increased sedimentation this will have a negative effect on EPT richness.

Invertebrate community composition and disturbance

In Jarrah forest streams communities from sites with greater proportions of the catchment logged or burned differed in composition from those of sites with less logging or burning, but not in a consistent manner. In an ordination analysis based on invertebrate community composition, communities in more affected catchments were spread around the periphery of samples from less affected catchments, rather than distributed along a composition gradient. This effect was most noticeable for sites whose catchments had burning in the previous year and sites in catchments logged in the previous 5 years. That the differences in community composition between disturbed and undisturbed catchments were not consistent meant that they were not detected by Permanova analyses, other than a marginally significant difference between sites with logging 5 years prior to 2005 and those with no logging. There were no significant correlations between the amount of change in community composition over time (1 and 4 year intervals) and the cumulative proportion of catchment burned and/or logged in the intervening period.

In the Karri forest there was some indication that invertebrate communities in catchments with minimal logging or burning differed from those in catchments with larger areas affected, but, again, there was little suggestion of a consistent gradient. The effect was strongest for logging in the 12 months prior to sampling (%1yr Log), where sites in catchments with logging tended to have somewhat different community composition to sites in catchments with no logging in the previous year, especially when only taxa identified to species are considered.

Permanova analyses suggested that the only significant relationships between community composition and catchment history were for %1yrLog and %1yrBurn in 2008, although the effect was not strong and only significant when taxa not identified to species level were excluded.

There were no significant relationships between change in community composition over 1 or 4 year periods and the cumulative proportion of the catchment burned and/or logged in the intervening periods. However, only 2 Karri sites had > 5% of their catchment logged between 2005 and 2008 so the lack of a relationship is not surprising. Furthermore, the degree of change over four years is highly variable even where none of the catchment was logged or burned.

Dams

There were no significant differences in biodiversity measures between the dam sites and sites in undisturbed catchments. However, low O/E family scores present at the dam sites indicate that fewer of the families included in AUSRIVAS models are found in streams below dams than one would expect to find at reference sites. All of the dam sites were allocated an AUSRIVAS banding of B or C indicating these sites are significantly impaired. The AUSRIVAS scores may therefore be a more sensitive indicator of the effects of dams than the raw biodiversity measures. "Reset" sites generally had higher biodiversity measures than undisturbed sites. The higher species richness at reset sites compared to dam sites may be a result of additional species entering the stream via drift from tributaries that join the stream between the two sampling sites. Two of the reset sites (HAR21 and MRY43) received an AUSRIVAS banding of X (enriched), but both also dropped to a B banding (significantly impaired) at some stage during the project.

Invertebrate communities downstream of the dam wall varied substantially between rivers. The Stirling Dam sites (HAR20 and HAR21) were both affected by the dam works which occurred between 2007 and 2009. A lot of sediment entered the river and greatly reduced the richness of species present, especially EPTs, at these sites in 2007. Below Serpentine Dam (MRY42 and MRY43) invertebrate composition at the reset site changed between years, with chironomid richness showing the opposite trends to EPT richness. Both of the Canning Reservoir sites (SWA34 and SWA35) were severely disturbed, receiving an AUSRIVAS C banding for at least one sampling occasion.

Wildfires

Two sites, SWA24 (Little Darkin) and DEN26 (Quickup), both experienced wildfires in the 2004-2005 season just prior to the first sampling occasion. Even though there are no pre-wildfire measures of invertebrate diversity, richness of species and families at these sites was well below those of undisturbed Jarrah streams for 2005. The effect was greater for SWA24 for which all biodiversity measures (except chironomid richness) were lower than the averages for undisturbed Jarrah sites in 2005, 2006 and 2007. This wildfire may have had a greater impact than the fire at DEN26 due to the fire's intensity and the shorter gap between the fire and the 2005sampling. By 2008 (4 years after the wildfires) both sites had biodiversity measures (except for EPTs) similar to undisturbed Jarrah sites. Continued sampling will provide a longer term trajectory of local fire impacts.

Dieback

Of the biodiversity measures, only O/E Signal differed between catchments with or without dieback in the Jarrah forest. This indicates that a greater proportion of the families present in dieback affected catchments are those considered sensitive to disturbance. However, caution should be used when interpreting the O/E SIGNAL in Western Australia, as the current SIGNAL index is largely based on eastern Australia data and there are suggestions that Western Australian species within some families are more tolerant to disturbance than equivalent eastern Australian species (e.g. to salinity:Pinder *et al.,* 2004).

There was no relationship between the percentage of the catchment recorded with dieback and biodiversity measures in the Karri forest but in the Jarrah forest all measures (except for chironomid richness) were positively correlated with the proportion of the catchment affected by dieback. The dieback may be influencing stream ecosystems by increasing the amount of debris, runoff and sediment entering the streams. There are likely to be interactions between the effects of logging, fire and dieback but these are beyond the scope of the current project.

FUTURE DIRECTIONS

This project was designed to assess stream biodiversity within catchments subject to a range of forest management practices. It is a long term monitoring program focussing on condition in a large number of streams spread across the study area and on changes over time at individual stream reaches. While the project is not a classically designed experimental project, the selection of sites with a range of catchment management histories does allow some analysis of the effects of logging and fire on the fauna. We have investigated some of these approaches in this interim report but others will be investigated.

Alternative approaches to classifying catchment management history may reveal additional linkages between disturbance and biodiversity. At present a site is deemed “undisturbed” if no fire or logging has been recorded in the previous 12 months. The category may include a site which was burned/logged almost 12 months prior to the sampling period and a site which was recently burned/logged, so there may be some time lags that have not been investigated sufficiently.

One option to better characterise catchment disturbance is to incorporate measures of the distance between disturbances and sampling point. For example, a small disturbance close to the sampling site may have an effect equivalent to a large disturbance well upstream of the sampling site. GIS data and maps showing the extent and location of the disturbances within each catchment over time have been produced (Appendix 4), so distance data can easily be extracted. There may also be scope to better describe multiple disturbances through time, through incorporation of time lags and production of indices that incorporate frequency, magnitude and proximity of disturbance. There is an insufficient number of sites (degrees of freedom) to include additional categorical descriptors of forestry practices (such as harvest type) with the present sampling regime, but some continuous or ordinal variables, such as frequency of disturbance and distance between disturbance and sampling site could be used in regression and modelling. This additional data could also be useful when interpreting temporal patterns at individual sites. Some of these additional variables have already been obtained from GIS datasets from the FMB and FMS (Appendix 3).

The sites sampled for this project were generally well downstream of any logging or burning activity (planned or unplanned). The project was designed to investigate the effectiveness of the forest management plan in protecting stream biodiversity at a landscape level rather than assessing local impacts at the site of logging or burning. The latter has been the subject of a number of other studies in south-western Australia (Growns and Davies, 1991, Growns and Davis, 1994a, Trayler and Davis, 1998, Horwitz, 1997). Nonetheless, there is scope for this or future projects to determine how far downstream any impacts extend. This would involve sampling at the point of logging or fire and at a series of sites downstream, perhaps to below a major stream confluence – as is done for the sites in the present study for examining impacts of flow regulation through dams.

Additional analytical techniques that could be investigated include models that partition variation into spatial, temporal, environmental and disturbance components and that can handle a large number of variables (e.g. Anderson and Gribble, 1998).

There are limited historical data on aquatic fauna in the south west forest streams. Studies carried out in the northern Jarrah forest have shown that aquatic invertebrate composition has changed since the 1980's (Aquatic Research Laboratory, 2009). This work suggested that these changes reflect transition from perennial to seasonal flows. No studies on historical changes in the aquatic fauna have been carried out in the South West and Warren regions. Several studies (Growns and Davies, 1991, Growns and Davis, 1994a, Trayler and Davis, 1998) were carried out in the Warren region in the 1990's and re-sampling these sites would provide information whether invertebrate community composition has changed in the southern forest areas. Many of the sampling sites for the current project were selected because they were used during the First National Assessment of River Health during the 1990s (Halse *et al.*, 2001a). The final report will assess changes in biodiversity between these periods where possible (e.g. AusRivas and richness and composition of selected taxa for some sites).

Post 2013

Rainfall in the south-west is expected to continue to decline in coming decades as a result of climate change (Bari *et al.*, 2005). There is already some indication that altered hydrological regimes in south-west streams have resulted in changed biological communities. This has implications for forest management, particularly with respect to possible interactive effects of forestry, water resource development and climate-change on altered hydrology. Improved understanding of current, and likely further impacts, of climate change would contribute to identification and maintenance of ecological flow regimes, impact assessment, the role of local and regional drought refuges, threatened aquatic species and communities conservation, and long term conservation planning. Individual species and community composition modelling in relation to climate and hydrology (and dependant water chemistry and habitat variables) would be one significant contribution.

Further research into what factors drive change in aquatic community in south west may prove valuable to help explain some of the variation measured within a site over time and between sites. Catchment characteristics (such as slope and size of vegetation buffers) influence the amount of runoff and sedimentation entering the stream (Growns and Davis, 1991, Minshall, 2003) and stream characteristics (such as stream flow period, surface water slope and substrate roughness) influence the flow exposure and sheer water velocities and consequently invertebrates present at the time of sampling (Growns and Davis, 1994b). Fire and harvest activities within the catchment can alter some of these factors, therefore this additional information may assist in explaining some of the variations in aquatic invertebrates observed between sites with similar disturbance areas in the catchment.

This project is the most spatially extensive study of stream aquatic invertebrates of south-western Australia carried out to date. Analysis of this data will help to better understand the distribution and conservation status of individual species. It could also be used for analysis of stream biodiversity patterning in the region to inform conservation planning. Our data could be combined with other datasets (such as those held at University of Western Australia, Edith Cowan University), although inconsistency in nomenclature used for undescribed species will limit aggregation of data for some invertebrate groups. This would extend the work done for selected insect groups by Sutcliffe (2003). To achieve this, further identification will be required for some groups, particularly water mites and crustaceans. At present, only species from these groups are listed as threatened fauna.

Most work on aquatic biodiversity in the south-west forests has focussed on streams, with very little work being undertaken in the many lentic wetlands scattered through the forests, from stream backwaters and floodplains to more isolated swamps, granite outcrop pools and soaks. There is no data on invertebrate biodiversity in the majority of these wetlands, exceptions being a few swamps sampled for the Salinity Action Plan survey or monitoring project (Pinder *et al.*, 2004 and, Cale *et al.*, 2004) or the Avon Baselining project (Jones *et al.*, 2009), such as Goonapping, Kulicup and Dobaderry Swamps and Nalyerin Lake). A survey of these wetlands would provide additional distributional data on invertebrate groups likely to exhibit subregional patterning, such as water mites and microcrustacea but also contribute to broader conservation aims.

Management of Phytophthora dieback is an important aspect of forest management in south-western Australia. There is some indication from this project that dieback may affect aquatic diversity in Jarrah forest streams. Quantification of relationships between dieback and stream ecosystems would require a separate research project.

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APPENDICES

APPENDIX 1.

SCIENCE PROJECT PLAN

Department of Conservation and Land Management

Science Division

Important: Refer to the *Explanatory Notes* (Staff Guideline No. 7) when preparing an SPP.

PART A Title and Location

SPP Number: [allocated by DAA] -
Request No: [allocated by WASPP] -
Concept Plan No: [allocated by DAA] - ??

1. Project Title: Forest Stream Biodiversity Monitoring 2005

2. Science Division Program: Landscape Conservation

3. Staff [Names and estimates of percentage of time]:

   Supervising Scientist: Stuart Halse (5 %)
   Other Scientists: -
   Technical Officers: Ben Smith (60 %), Harley Barron (10 %)
   External Collaborators: -
   Volunteer(s): -

4. a) Output Program: Sustainable Forest Management
   b) Relevant Departmental KRAs: KRA1, KRA3

5. a) IBRA Region(s): Swan Coastal Plain (SWA), Jarrah Forest (JF), Warren (WAR)
   b) NRM Region(s): Swan, South-West, South Coast
   c) CALM Region(s)/District(s): Swan, South-West, Warren
   d) Geocode(s): -

6. Related SPPs: 99/0007

7. Proposed commencement completion dates: 1/07/2005 – ongoing monitoring program

8. Date of submission of this Plan and signature of Supervising Scientist:

   13/12/2005 

9. Nomination of an external scientist capable of providing expert advice on the scientific merit of the SPP: A/Prof Jenny Davis

PART B Endorsements

10. List the relevant Regional Ecologist(s) and Nature Conservation Leader(s) whom you have consulted about the SPP:

Geoff Stoneman, Lachie McCaw, Neil Burrows, Martin Rayner, Alan Danks, Sarah Comer, Kim Williams, John Carter, Dave Mitchell, Mark Garkarklis, Roger Hearn, Karlene Bain.

What opportunities exist for collaboration with other Science Division Programs, other Departmental Staff, Universities, other Government agencies, Industry, traditional land owners and the broader community? Explain how these linkages were investigated/developed.

Discussions have been held with Colin Terry of Water Corporation about tying in with their Wungong Brook work (and sites were added to achieve this); and with Karlene Bain (District Nature Conservation Coordinator, Walpole District) to provide an aquatic component to their studies of impacts of burning in London Block.

11. Biometrician:
Return comments to DAA

12. Animal Ethics Committee: (If applicable)
Return comments to DAA

13. Program Leader, WA Herbarium (If applicable; see Point 22 below):
Return comments to DAA

14. Program Leader:
Program Leader arranges that a copy of the SPP is sent to the nominated external scientist (See No. 8) for a confidential assessment if required
Program Leader to forward to DAA

15. Divisional Administrative Assistant (DAA):
Divisional Admin. Assistant to manage approval process, load approved SPP on WASPP, arrange filing at Directorate, publish in Science Communications, send photocopy of completed SPP to Supervising Scientist, copy cover sheet to Regional Manager, District Manager and relevant Program Leader (for their information)

PART C Relevance and Outcomes

16. Background and literature review:

One of the overall aims of the Forest Management Plan 2004-2013 is to protect soil and water resources in forested areas to which the Plan applies. Key performance indicator (KPI) 20 is the percentage of waterbodies (e.g. stream kilometres, lake hectares) with significant variance of biodiversity from the historic range of variability. The intent of KPI20 is to provide a measure of the success of the Forest Management Plan in protecting the ecological integrity and quality of streams.

The rationale behind this project is that logging and fire frequently cause changes to stream conditions and, consequently, their ecology. Sedimentation and opening up of canopy are usually the greatest causes of impact (see Halse and Blyth 1992), with much of the sediment coming from roads crossing streams.

The project addresses KPI20 by monitoring aquatic macroinvertebrates and measuring various aspects of water physico-chemistry at 40-50 sites in spring each year. The protocol being used is based on AUSRIVAS, and AUSRIVAS models will be used to assess the degree of disturbance in the streams subject to monitoring (Halse *et al*. 2001).

17. Project aim:

The objective of KPI 20 is to assess the success of the implementation of the Forest Management Plan 2004-2013 in protecting the ecological integrity and quality of streams. The specific criteria to be used in assessing success are:

Indicator - *Percentage of water bodies (e.g. stream kilometres) with significant variance of biodiversity from the historic range of variability*
Biodiversity Measure - *The diversity of aquatic macro-invertebrate fauna at a selected number of monitoring sites*
Performance Target - *No sites with fauna significantly different from the reference condition*

18. Anticipated project outcome(s) including benefits to CALM:

Project will monitor whether CALM is meeting FMP commitments with regard to maintaining forest stream biodiversity. It will also provide information on forest stream biodiversity and add to knowledge of the occurrence and distribution of the State's biota.

19. Anticipated users of the knowledge to be gained and technology transfer strategy:

(1) Monitoring results will be used by SFM and the EPA to assess compliance with the FMP.
(2) Information on pattern of aquatic invertebrate occurrence will be used by CALM to examine adequacy of forest reserve system, and to compile lists of Threatened Ecological Communities and Rare or Priority Taxa.
(3) Information on response of stream communities to fire, logging and dams will be used by FPC, SFM and Water Corporation to improve management of forestry activities, burning regimes and water harvesting.
(4) Project results will be disseminated by:
A. circulating progress reports annually to appropriate agency staff
B. formal reporting of results to SFM and the EPA every five years
C. scientific publications as appropriate

20. Milestones [Describe tasks and when they will be completed]:

Annual		
Sep-Oct	Oct-Feb	Mar
Sampling	Identification	Analysis/reporting
Five-yearly		
Analysis and compilation of formal report of results, incorporating AUSRIVAS model outputs and trends in species richness of selected taxa in relation to activities adjacent to the stream sites		

21. References

Halse, S.A. and Blyth, J.D. (1992). Aquatic fauna of the karri forest. In: Research on the Impact of Forest Management in South-West Western Australia. CALM Occasional Paper No. 2/92. July 1992. Department of Conservation and Land Management, Western Australia, pp. 115-138

Halse, S.A., Scanlon, M.D. and Cocking, J.C. (2001). First National Assessment of River Health: Western Australian Program. Milestone Report 5 and Final Report. Unpublished report to Environment Australia. Department of Conservation and Land Management, Perth, 86 pp

PART D Study Design

22. Method [including statistical analysis]:

Monitoring will occur between August and October in channel habitat. This consists of unvegetated river banks and the central portion of the stream. Macroinvertebrates will be collected by 10 m of sweeping with a pond net, the sample will be washed and elutriated and then sub-sampled using a box sampler until 200 animals have been randomly encountered. All macroinvertebrates will be identified to family level and animals of the orders/families Ephemeroptera, Plecoptera, Trichoptera, Hemiptera, Coleoptera, Odonata and Chironomidae identified to species. These groups are amenable to species identification because keys exist and they are either known to be sensitive to water quality change or species-rich. Family level identifications are used in AUSRIVAS models and the species data will be used to examine biodiversity trends in more detail. Overall, methodology will follow that of Halse *et al.* (2001).

Data on site characteristics has been compiled for all sites. Things documented include tenure, forest type (jarrah or karri), logging and fire history, soil type, slope and expected impacts. In addition to macroinvertebrates, water quality data will be collected, including salinity, nutrients, pH, temperature, turbidity and dissolved oxygen.

The distribution of the 46 sites sampled in 2005 is shown in Figure 1 and Table 1 provides a breakdown of forest type, occurrence in CALM regions, land tenure, reason for monitoring and expected impacts. The initial basis for site selection was to examine sites previously sampled during the 1994-1999 AUSRIVAS program, for which some existing data are available. Only sites where discharge was less than 100,000 ML per annum were included. However, the project required a set of sites that are representative of forest conditions and a series of other selection criteria were imposed. These included that ca 75% of sites should be in jarrah forest, 25% in karri; ca 60% of sites should be in areas subject to logging and 40% in unlogged areas; sites should be spread across the forested area; a small number of sites should examine the impact of dams; a small number of sites should be located in areas that experienced wildfire last summer so that the impact of intense burns could be examined; a small number of sites should be in areas to be logged this year or next year so that the impact of logging could be examined. In order to fulfill the above criteria, it was necessary to include a number of sites not sampled during AUSRIVAS.

A small number of sites will be added to the program in 2006, after consultation with DoE and Water Corporation to examine the impact of Yarragadee extraction. This will include sites on St John's Brook, Milyeannup Creek and Poison Gully. There will also be consideration of whether sites on bauxite, and other mining, leases should be included.

The framework for reporting and analysis, as stipulated by SFM, is shown below.
The entities to be measured for the KPI are:

Entity	Target
Aquatic macro-invertebrate diversity	No sites with fauna significantly different from the reference condition.

Required data

Required data	Collection & storage method	Custodians
List of monitoring sites where aquatic macro-invertebrate diversity measured.	Sites selected from: a) within with timber harvesting in their catchments; and b)sites below dams c)sites that fall within the plan area	Science Division
Reference condition for selected monitoring sites	The reference condition for a site is the expected number of macro-invertebrate taxa according to AUSRIVAS models developed by the Department (see background section). Models are available on the AUSRIVAS website (University of Canberra)	Science Division
Aquatic macro-invertebrates collected from selected monitoring sites	Science Division to conduct assessment of sites annually and report prior to mid-term and final reporting of the number of aquatic macro-invertebrates collected.	Science Division

Calculation method

Entity to be measured	Calculation method
Aquatic macro-invertebrates observed and expected (*O/E* score)	*O/E* score: Observed macro-invertebrates score divided by expected macro-invertebrates from AUSRIVAS models based on pristine stream condition
Ecological rating	An ecological rating of undisturbed, marginally disturbed, or disturbed will be assigned to each monitoring site on the basis of the *O/E* score (Halse *et al*. 2001).

Entity measurement, calculation and reporting frequency

Required metric	Measurement frequency	Calculation frequency
Aquatic macro-invertebrates *O/E* score	Annual for selected sites	Five-yearly
Ecological rating		

Presentation of the entities

Metric	Presentation
Aquatic macro-invertebrate *O/E* score and ecological rating	Data will be presented in Table A showing *O/E* score for each monitoring site and ecological rating with text to describe trends and provide analysis for sites where there is a significant difference from the reference condition. Average *O/E* scores associated with various potential perturbations will also be provided.

Table A. Aquatic macro- invertebrate *O/E* score and ecological rating at selected monitoring sites within the area of the Forest Management Plan.

	Observed Macro-invertebrates score divided by expected Macro-invertebrates	Average ecological rating (undisturbed, marginally disturbed or disturbed)
	Yr 1 Yr 2 Yr 3 Yr 4 Yr 5	
Site 1		
Site 2		

Table 1. The number of sites sampled in jarrah and karri forest in 2005 separated according to CALM region, land tenure, reason for on-going sampling or expected impact this year.

	Jarrah	**Karri**
CALM region		
Swan	12	0
South-west	13	1
Warren	9	11
Land tenure		
State Forest	20	8
National/Conservation Park	14	4
Reason for on-going sampling		
Baseline site	8	4
Forestry activity	11	3
Logging impact	6	5
Fire impact	3	0
Dam impact	3	0
Road impact	0	2
Stock impact	1	0
Expected impact this year		
None	22	6
Logging	6	5
Wildfire	2	0
Flow alteration	2	1
Sedimentation	1	2
Eutrophication	1	0

PART E Data Management and Budget

23. Estimated number of vouchered specimens:

Selected specimens will be incorporated into the Woodvale aquatic invertebrate collection. Over time it is expected several hundred specimens will be vouchered in this way, with details stored on a corporate database on the Woodvale server. Type specimens of any new species will be lodged with the Western Australian Museum.

24. Data management [how and where are data being archived/maintained? - see Guideline No 16]:

Data will be incorporated into the MRHI database on the Woodvale server, which is a corporate database for river invertebrate data. All CALM's AUSRIVAS data are held in this database (there has been periodic export to the Commonwealth Government AUSRIVAS database).

25. Data custodian:

Stuart Halse and Ben Smith

26. Budget Estimate [anticipated expenditure]:

$75,000

Consolidated Funds (CALM)

	Year 1 ($)	**Year 2 ($)**	**Year 3 ($)**
FTEs – Scientist	6000	6000	7000
FTEs – Technical	45000	48000	51000
Equipment	4000	4000	4000
Vehicle	7000	7000	7000
Travel	5000	5000	5000
Other	3000	3000	3000
TOTAL	70000	73000	77000

APPENDIX 2.

ENVIRONMENTAL MEASURES RECORDED FOR EACH SAMPLE.

SITE	year	Alkalinity (mg/L)	Colour (TCU)	NH3 (mg/L)	NO3 (mg/L)	N Total (mg/L)	P SR (mg/L)	P Total (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	pH	Temperature (°C)	DO (%)	Min flow (cm/sec)	Max flow (cm/sec)
BLA06	2006	20	19	0.02	<0.01	0.13	<0.01	<0.01	1.5	556	6.55	17.3	99.1	0	112.1
BLA06	2007	5	7	<0.01	<0.01	0.09	<0.01	<0.01	0.5	497	6.83	14.9	92.3	0	142.9
BLA06	2008	15	3	0.15	<0.01	0.36	<0.01	0.01	0.2	659	6.58	15.7	103.9	0	33.1
BLA43	2006	10	26	0.01	<0.01	0.12	<0.01	<0.01	0.6	293	7.16	14.9	113.5	0	44
BLA43	2007	5	11	<0.01	<0.01	0.04	<0.01	<0.01	0.5	313	6.76	14.3	96.4	0	49.1
BLA43	2008	10	8	0.03	<0.01	0.18	<0.01	0.01	0.2	328	6.54	15.2	98	7.2	28.4
BLA51	2005	15	60	0.01	0.01	0.37	<0.01	0.02	1.9	163.2	6.73	11.1	80.5	5.8	33.1
BLA51	2006	30	19	0.01	<0.01	0.31	<0.01	<0.01	0.2	196.4	6.72	14.4	70.8	0	14
BLA51	2007	30	15	0.01	0.01	0.27	<0.01	<0.01	0.2	3820	6.57	24	117.9	0	0
BLA51	2008	10	5	0.05	<0.01	0.44	<0.01	<0.01	0.2	4890	6.55	8	83.1	0	9.5
BLA52	2005	10	21	<0.01	<0.01	0.07	<0.01	0.01	1.3	258	6.49	18.3	105.7	10.8	51.8
BLA52	2007	10	3	<0.01	<0.01	<0.02	<0.01	<0.01	0.2	328	6.69	16.8	100.8	0	23.1
BLA52	2008	10	4	0.1	<0.01	0.25	<0.01	<0.01	0.2	338	6.53	16.5	103.5	0	55.4
BLA53	2005	10	2.5	<0.01	<0.01	0.04	<0.01	0.03	3.2	377	6	13.3	105	0	33.7
BLA53	2006	5	3	0.01	<0.01	0.04	<0.01	<0.01	0.2	420	6.09	15.8	108.8	0	0
BLA53	2007	5	1	<0.01	<0.01	0.01	<0.01	<0.01	0.2	431	5.96	14.8	92.1	0	113.1
BLA53	2008	5	1	0.23	<0.01	0.28	<0.01	0.01	0.2	431	5.83	15.6	89.4	0	24.7
BLA54	2005	5	23	0.01	<0.01	0.1	<0.01	0.02	2.4	327	6.18	14.3	115	7.4	54.4
BLA54	2006	5	16	0.01	0.01	0.12	<0.01	<0.01	1.8	411	6.09	14.7	105.9	0	35.6
BLA54	2007	5	7	<0.01	<0.01	0.02	<0.01	<0.01	2.8	385	6.31	13.8	101	0	47
BLA54	2008	5	1	0.05	<0.01	0.16	<0.01	0.02	0.2	470	5.79	10.7	96.4	5.6	87.4
BLA55	2005	30	19	<0.01	0.01	0.19	<0.01	0.01	1.4	541	7.4	15.5	115.8	0	84.6
BLA55	2006	25	12	0.01	0.01	0.17	<0.01	<0.01	1.1	796	6.65	13.6	81.8	0	0
BLA55	2007	20	10	<0.01	0.01	0.09	<0.01	<0.01	0.7	657	6.62	11.5	89.5	0	20.1
BLA55	2008	15	10	0.15	0.01	0.32	<0.01	<0.01	0.2	819	6.71	17.9	101.8	0	62.9
BLA56	2008	5	36	0.15	0.01	0.28	<0.01	0.01	0.2	288	5	20.9	71.3	0	0
BUS05	2005	20	19	0.03	0.03	0.32	<0.01	0.02	1.5	380	7.06	13.9	110.6	0	110.1
BUS05	2006	20	9	0.03	0.07	0.38	<0.01	<0.01	4.3	400	6.73	15.2	109.9	0	69.9
BUS05	2007	20	18	0.03	0.1	0.32	<0.01	<0.01	0.6	395	6.88	14.1	94.8	0	46.3
BUS05	2008	10	12	0.12	0.05	0.36	<0.01	<0.01	0.2	430	6.76	13.8	98.1	0	3
BUS26	2005	15	9	<0.01	<0.01	0.08	<0.01	0.01	1.1	234	6.82	15.5	84.9	0	37.8
BUS26	2007	5	4	<0.01	<0.01	0.05	<0.01	<0.01	0.2	376	6.1	17.2	127.2	0	9.9
BUS26	2008	5	14	0.04	<0.01	0.14	<0.01	0.01	0.2	470	6.36	13.9	90.1	5.6	32.2
COL36	2005	10	140	0.02	<0.01	0.41	<0.01	0.01	1.2	304	5.76	13.5	70.7	3.7	33.5
COL36	2006	5	82	0.02	0.01	1.3	<0.01	0.05	30	281	5.34	14.7	72.3	0	25.5
COL36	2007	5	220	0.03	0.02	0.68	<0.01	<0.01	3.9	290	5.42	17.9	128.3	0	0
COL36	2008	5	110	0.03	<0.01	0.51	<0.01	0.01	1.3	357	5.46	12	83.6	0	5.6

SITE	year	Alkalinity (mg/L)	Colour (TCU)	NH3 (mg/L)	NO3 (mg/L)	N Total (mg/L)	P SR (mg/L)	P Total (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	pH	Temperature (°C)	DO (%)	Min flow (cm/sec)	Max flow (cm/sec)
COL37	2005	30	63	0.01	0.01	0.43	<0.01	0.02	41	154	7.19	8.7	89.4	5.5	32
COL37	2008	25	140	0.03	0.02	0.98	<0.01	0.02	0.9	173.5	6.04	13.5	30.8	0	0
COL38	2005	15	44	<0.01	<0.01	0.18	<0.01	0.01	1.6	110.8	6.72	14.2	83.2	0	33.3
COL38	2006	15	42	0.03	0.02	0.45	<0.01	<0.01	3.2	178	6.19	17.3	68.1	0	0
COL38	2007	15	58	0.02	0.01	0.41	<0.01	<0.01	1.5	174.2	6.47	19.2	71.6	0	0
COL38	2008	20	59	0.06	<0.01	0.5	<0.01	0.01	0.2	148.8	6.47	15.4	93.9	0	0
DEN09	2005	45	79	<0.01	<0.01	0.84	<0.01	0.01	1.9	3280	7.19	14.4	103.7	8.2	52.2
DEN09	2008	60	44	0.83	<0.01	1.9	<0.01	<0.01	0.2	12560	6.72	16.3	61.3	0	0
DEN26	2005	20	730	0.11	0.01	0.97	<0.01	<0.01	1.3	504	5.1	13.4	99.8	3.8	68.6
DEN26	2006	1	5	0.05	0.01	0.41	<0.01	<0.01	15	1318	4.54	12.5	76	0	20.3
DEN26	2007	5	15	0.02	0.01	0.14	<0.01	<0.01	2.1	1893	5.39	13.3	63.6	0	0
DEN26	2008	5	27	0.63	<0.01	0.86	<0.01	0.01	0.2	1630	5	17.1	69.1	0	5
DON03	2005	10	28	<0.01	<0.01	0.08	<0.01	0.01	1.5	250	7.2	12.6	108.3	7.4	82
DON03	2006	15	130	0.01	0.01	0.19	<0.01	<0.01	3.9	264	7.1	13.4	108.9	0	20
DON03	2007	10	25	<0.01	<0.01	0.09	<0.01	<0.01	1	273	6.54	12.3	98.6	0	20.6
DON03	2008	10	30	0.26	0.01	0.44	<0.01	0.01	0.2	305	6.48	16.2	91.2	0	0
DON14	2005	10	16	<0.01	0.01	0.12	<0.01	0.01	2.4	309	7.13	10.6	98.7	8	60.9
DON14	2006	15	29	0.01	0.04	0.15	<0.01	<0.01	2.3	326	7.34	10.8	114.5	0	85.7
DON14	2007	10	16	0.01	0.02	0.07	<0.01	<0.01	0.9	357	6.64	11.4	95.6	0	0
DON14	2008	10	28	0.07	0.03	0.21	<0.01	0.01	0.2	322	5.53	14.5	97.2	5.3	88.6
DON15	2005	5	44	<0.01	<0.01	0.15	<0.01	0.01	0.9	195.3	6.6	11.1	103.3	0	41
DON15	2006	25	100	0.05	<0.01	1.6	<0.01	0.03	24	198.7	7.64	14.8	115.3	0	37.9
DON15	2007	5	24	<0.01	<0.01	0.07	<0.01	<0.01	2.3	228	6.64	14.3	98.3	0	0
DON15	2008	10	39	0.05	<0.01	0.19	<0.01	<0.01	0.2	220	6.49	15.7	97.9	9.3	39.4
DON16	2005	15	21	<0.01	<0.01	0.15	<0.01	0.02	4.9	245	7.34	10.3	98.8	0	46
DON16	2006	20	22	0.07	0.03	0.27	<0.01	<0.01	6.1	280	6.59	11.3	67.6	0	0
DON16	2007	15	15	0.01	<0.01	0.12	<0.01	<0.01	2.9	226	6.5	10.9	90	0	59.8
DON16	2008	15	27	0.05	0.01	0.24	<0.01	<0.01	0.2	264	6.97	12.7	87.9	0	41.6
FRA17	2005	5	490	0.03	<0.01	0.41	<0.01	0.01	0.3	282	4.34	12.6	99.1	0	80.6
FRA17	2006	1	360	0.04	0.04	0.69	<0.01	<0.01	1.4	352	4.18	12.6	108	3.3	46.9
FRA17	2007	<0.5	460	0.05	0.05	0.68	<0.1*	<0.01	1.2	398	4.26	13.7	89.3	0	11.1
FRA17	2008	5	550	0.2	0.05	0.95	<0.01	<0.01	0.6	363	4.09	13	92.5	0	21
FRA18	2005	35	62	<0.01	<0.01	0.42	<0.01	0.01	0.6	2420	6.92	15.2	96.1	0	47.7
FRA18	2007	30	50	0.02	0.01	0.46	<0.01	<0.01	7.6	3400	6.83	24.7	103.5	0	0
FRA18	2008	20	130	0.36	<0.01	1.1	<0.01	<0.01	1.1	3040	6.29	16.7	49	0	0
HAR01	2005	10	8	<0.01	<0.01	0.05	<0.01	0.01	2.3	244	6.74	10.6	89.4	0	72.4
HAR01	2006	5	9	0.01	<0.01	0.05	<0.01	<0.01	0.2	193	6.24	10	87.5	21.1	112.5
HAR01	2007	5	4	<0.01	<0.01	<0.02	<0.01	<0.01	0.6	228	6.32	13.2	140.4	0	113

SITE	year	Alkalinity (mg/L)	Colour (TCU)	NH3 (mg/L)	NO3 (mg/L)	N Total (mg/L)	P SR (mg/L)	P Total (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	pH	Temperature (°C)	DO (%)	Min flow (cm/sec)	Max flow (cm/sec)
HAR01	2008	10	5	<0.01	<0.01	0.07	<0.01	<0.01	0.2	270	6.34	11.5	90.1	0	62
HAR20	2005	15	5	<0.01	0.01	0.1	<0.01	0.01	0.4	224	6.99	12.5	99.3	0	34.7
HAR20	2006	15	8	0.01	0.02	0.15	<0.01	<0.01	1.8	174	6.43	12.1	91.8	0	89.1
HAR20	2007	5	7	<0.01	0.02	0.05	<0.01	<0.01	1.1	220	6.57	17.3	163.6	0	66.5
HAR20	2008	15	3	<0.01	0.03	0.13	<0.01	0.01	0.2	243	6.32	17.1	124.7	0	46.9
HAR21	2005	10	12	<0.01	0.01	0.07	<0.01	0.01	0.4	247	7.19	13.2	105.7	0	62.1
HAR21	2006	15	20	0.01	0.03	0.71	<0.01	0.01	1.7	190	6.85	11.6	96.2	0	67.9
HAR21	2007	5	7	<0.01	0.02	0.06	<0.01	<0.01	0.9	211	6.49	12.9	148	0	41.8
KEN11	2005	5	530	0.07	<0.01	0.56	<0.01	0.01	0.4	385	4.97	15	100	0	46.2
KEN11	2006	5	170	0.02	0.01	0.7	<0.01	0.01	9	455	4.99	14.5	110.9	9.4	52.2
KEN11	2008	5	490	0.21	0.05	0.98	<0.01	0.01	1.8	428	4.51	21.4	92	0	27.6
MRY09	2005	10	8	<0.01	<0.01	0.04	<0.01	0.01	0.5	170.8	6.75	13.4	69.6	0	60
MRY09	2006	10	11	<0.01	<0.01	0.1	<0.01	<0.01	17	191.2	6.46	10.6	93.8	0	87.3
MRY09	2007	5	7	<0.01	<0.01	<0.02	<0.01	<0.01	0.2	184.9	6.71	13	148.2	0	85.2
MRY09	2008	10	6	<0.01	<0.01	0.09	<0.01	0.01	0.2	206	7	12.7	97.7	12	67.6
MRY33	2005	10	6	<0.01	<0.01	0.08	<0.01	0.01	0.4	505	6.44	11.3	89.4	0	32.4
MRY33	2006	5	9	0.01	<0.01	1.2	<0.01	<0.01	1.7	181.7	5.31	9.4	86.8	3.1	42.9
MRY33	2007	5	5	<0.01	<0.01	0.02	<0.01	<0.01	0.2	211	6.47	14.7	137.6	0	60.1
MRY33	2008	15	6	<0.01	<0.01	0.08	<0.01	0.01	0.2	292	5.9	11.3	94.4	0	34.1
MRY41	2005	15	14	<0.01	<0.01	0.15	<0.01	0.02	0.7	165.5	6.81	10.2	56.9	0	26.7
MRY41	2006	15	21	<0.01	0.02	0.61	<0.01	<0.01	1.2	80.5	6.47	10.3	90	2.9	4.1
MRY41	2007	25	38	0.02	0.01	0.22	<0.01	<0.01	1.6	238	7.16	15.8	105.8	0	0
MRY41	2008	25	25	<0.01	<0.01	0.26	<0.01	0.01	0.2	248	6.14	12.3	69.1	0	0
MRY42	2005	25	6	0.01	0.01	0.14	<0.01	0.01	2.3	26.4	6.63	12.4	56.6	0	14.6
MRY42	2006	25	39	0.08	0.02	0.62	<0.01	<0.01	12	176	6.37	11.8	66.5	0	22.8
MRY42	2007	25	7	0.03	0.02	0.18	<0.01	<0.01	0.2	266	6.63	19	142.3	0	7.9
MRY42	2008	15	6	0.04	0.02	0.23	<0.01	<0.01	0.7	281	6.52	11.7	76.4	0	4.7
MRY43	2005	15	5	<0.01	0.42	0.53	<0.01	0.01	0.5	256	7.02	13.3	68.5	0	41
MRY43	2006	20	9	0.01	0.15	2.5	<0.01	<0.01	2.8	213	7.11	12.9	90.2	0	32
MRY43	2007	20	4	<0.01	0.19	0.22	<0.01	<0.01	2.1	252	7.46	20.4	160.1	0	48.4
MRY43	2008	10	6	0.01	0.1	0.24	<0.01	0.01	0.2	294	6.61	13	100.2	12.8	113.3
MRY44	2005	10	7	<0.01	<0.01	0.06	<0.01	0.01	0.7	262	6.81	13	72.1	0	0
MRY44	2006	10	20	<0.01	<0.01	0.93	<0.01	0.01	0.2	180.5	6.09	10.4	54.3	0	0
MRY44	2007	15	35	0.01	<0.01	0.45	<0.01	<0.01	1.3	212	6.68	15.4	60.5	0	0
MRY44	2008	25	29	0.01	<0.01	0.25	<0.01	0.01	0.9	232	6.08	7.6	28.4	0	0
MRY45	2005	50	21	0.01	<0.01	0.31	0.01	0.01	2.8	179.7	7.43	10.1	79.6	5.8	32.4
MRY45	2007	45	38	<0.01	<0.01	0.36	<0.01	<0.01	1	249	6.74	17	135.3	0	0
MRY45	2008	30	52	0.03	<0.01	0.49	<0.01	0.01	1.5	209	6.63	13.2	83	0	0

SITE	year	Alkalinity (mg/L)	Colour (TCU)	NH3 (mg/L)	NO3 (mg/L)	N Total (mg/L)	P SR (mg/L)	P Total (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	pH	Temperature (°C)	DO (%)	Min flow (cm/sec)	Max flow (cm/sec)
SHA21	2005	5	18	0.03	<0.01	0.18	<0.01	0.01	0.5	356	4.47	11.2	89.6	8.4	30.4
SHA21	2006	1	19	0.06	0.03	0.5	<0.01	<0.01	97	403	4.36	12.9	75.1	2.9	22.6
SHA21	2007	<0.5	15	0.05	0.01	0.3	<0.01	<0.01	2	492	4.2	19.3	51.6	0	27.6
SHA21	2008	5	25	0.62	0.01	0.75	<0.01	<0.01	0.7	434	3.94	14.4	80.7	0	52.8
SHA22	2005	5	300	0.03	0.01	0.41	<0.01	0.01	1.9	179.1	5.17	11	95.5	0	47.6
SHA22	2006	1	340	0.08	0.03	0.54	0.04	<0.01	6.7	267	4.46	11.1	73.3	0	32.2
SHA22	2007	<0.5	330	0.05	0.05	1	<0.1*	<0.01	0.8	268	4.5	15.7	53.1	0	0
SHA22	2008	5	280	0.33	0.05	0.71	<0.01	0.01	1.9	234	4.15	14.6	86.2	2.3	46.2
SHA23	2005	5	150	0.01	0.01	0.21	<0.01	0.01	1.1	298	6.09	12	97.1	0	48.8
SHA23	2006	5	120	0.02	0.02	0.34	<0.01	<0.01	6.4	367	6.06	13.1	107.2	5.4	36.6
SHA23	2007	5	160	0.05	0.05	0.33	<0.1*	<0.01	2.5	407	6.02	16.3	87.7	0	8.1
SHA24	2005	10	230	0.01	0.01	0.49	<0.01	0.01	1.4	286	6.41	14.9	104	0	61.3
SHA24	2006	5	80	0.02	0.02	0.84	<0.01	<0.01	2.3	497	6.12	17.1	104	0	24
SHA24	2007	5	200	0.05	0.05	0.56	<0.1*	<0.01	1.7	532	5.98	17.2	65	0	0
SHA24	2008	10	330	0.03	0.05	0.89	<0.01	0.01	0.8	316	5.61	15.7	94.8	4.3	40.3
SWA04	2005	15	17	<0.01	0.09	0.15	<0.01	0.01	0.4	167	6.92	13.2	68.1	0	46.2
SWA04	2006	15	5	0.01	0.13	0.35	<0.01	<0.01	1.2	297	6.57	10	86.8	9.6	51.9
SWA04	2007	5	5	<0.01	<0.01	0.05	<0.01	<0.01	0.5	319	6.8	17.6	158.4	4.9	65.8
SWA04	2008	5	5	0.2	0.01	0.24	<0.01	0.01	0.2	403	6.3	13.6	90	0	21.4
SWA24	2005	35	8	0.01	0.08	0.18	<0.01	0.01	0.4	343	7.12	15.2	65.8	0	44.1
SWA24	2006	35	18	0.01	0.03	0.36	<0.01	<0.01	2	519	6.52	11.8	66.8	0	0
SWA24	2007	20	5	<0.01	<0.01	0.09	<0.01	<0.01	0.2	329	7.18	18	162	0	13.5
SWA24	2008	15	3	0.02	0.01	0.15	0.01	0.01	2.7	302	6.26	14.1	77.4	0	0
SWA31	2005	25	31	<0.01	<0.01	0.4	<0.01	<0.01	1.8	3780	6.49	9.2	62.3	0	14.6
SWA31	2006	20	18	0.02	0.01	0.81	<0.01	<0.01	0.6	5300	6.49	13.7	73.4	4.1	21.3
SWA31	2007	50	20	<0.01	<0.01	0.26	<0.01	<0.01	0.2	4430	6.68	13.6	127.3	0	0
SWA31	2008	15	15	1.1	<0.01	1.3	<0.01	<0.01	0.2	4010	6.38	10.4	87.2	0	53
SWA32	2005	15	12	<0.01	<0.01	0.08	<0.01	0.01	0.5	345	6.54	12.1	57.6	0	46.9
SWA32	2007	15	14	<0.01	<0.01	0.09	<0.01	<0.01	0.5	401	6.59	15	129	0	60.1
SWA32	2008	20	13	0.32	<0.01	0.49	<0.01	<0.01	0.2	485	5.96	12.7	88.2	0	53.3
SWA33	2005	20	98	<0.01	<0.01	0.34	<0.01	0.01	3.9	118.4	6.57	10.5	51.9	0	33.7
SWA33	2007	20	130	0.04	0.01	0.88	<0.01	<0.01	3.1	172.8	6.35	19.1	61.7	0	0
SWA33	2008	30	120	0.14	0.01	0.95	<0.01	0.02	1.6	171.3	5.9	9.5	45.6	0	0
SWA34	2006	20	21	0.01	0.03	0.58	<0.01	0.03	1.7	201	5.99	12	40.7	0	0
SWA34	2007	15	26	<0.01	<0.01	0.06	<0.01	<0.01	1.7	197.6	5.92	12.7	54	0	0
SWA34	2008	15	16	0.2	<0.01	0.41	<0.01	0.01	3.1	290	5.78	10.6	23.8	0	0
SWA35	2006	20	88	0.01	0.01	1.1	<0.01	<0.01	10	167	6.66	14.3	79	0	0
SWA35	2007	15	11	0.01	0.01	0.13	<0.01	<0.01	1.8	263	7.02	17.7	155.3	0	35.6

SITE	year	Alkalinity (mg/L)	Colour (TCU)	NH3 (mg/L)	NO3 (mg/L)	N Total (mg/L)	P SR (mg/L)	P Total (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	pH	Temperature (°C)	DO (%)	Min flow (cm/sec)	Max flow (cm/sec)
SWA35	2008	10	7	0.51	0.01	0.64	<0.01	0.01	0.2	283	6.19	13.8	83.7	0	25.4
WAR01	2005	15	66	0.01	0.1	0.21	<0.01	0.01	2.1	223	6.59	13	100.4	10.8	53.4
WAR01	2006	15	43	0.02	0.33	2.1	<0.01	0.04	4	223	7.5	16.2	103	0	28.9
WAR01	2007	15	66	0.04	0.39	0.66	<0.01	<0.01	1.2	259	6.8	14.8	93.5	0	0
WAR01	2008	5	79	0.05	0.19	0.72	<0.01	0.02	0.2	244	6.36	16.6	90.9	0	124.5
WAR02	2005	70	68	<0.01	<0.01	0.5	<0.01	0.01	2.8	991	7.58	10	95.8	4.9	57
WAR02	2006	135	110	0.02	0.01	0.45	<0.01	<0.01	4.4	6550	7.42	18.6	82.1	0	0
WAR02	2007	85	61	0.01	0.02	0.42	<0.01	<0.01	0.742	1646	7.15	19.2	63.6	0	7.7
WAR02	2008	65	80	0.05	<0.01	0.84	<0.01	<0.01	0.2	2550	7.3	10.9	93	4.5	23.6
WAR05	2005	125	74	0.01	<0.01	0.36	<0.01	0.01	0.6	4110	7.49	12.6	103.5	0	14.6
WAR05	2006	340	42	0.01	0.01	0.34	<0.01	<0.01	30	10800	7.28	15.2	35.8	0	0
WAR05	2007	310	46	0.08	0.03	1.4	<0.01	<0.01	5.8	23700	7.24	18.1	35.5	0	0
WAR05	2008	70	39	0.19	0.01	0.98	<0.01	<0.01	0.2	18680	7.46	16.7	36	0	0
WAR15	2005	40	11	<0.01	0.15	0.35	<0.01	0.01	0.5	460	7.49	13.9	104.3	8.4	55.4
WAR15	2006	40	40	0.01	0.12	0.62	<0.01	<0.01	5	443	7.57	16	109.6	0	31
WAR15	2007	45	9	<0.01	0.06	0.16	<0.01	0.01	0.2	521	7.53	17.5	104.4	0	25
WAR15	2008	20	9	0.04	0.19	0.46	<0.01	<0.01	0.2	469	7.21	19	77	0	103.6
WAR16	2005	15	13	<0.01	<0.01	0.09	<0.01	0.01	1.3	259	6.96	12.2	95.4	0	30.1
WAR16	2006	25	24	0.05	0.04	0.19	<0.01	<0.01	4.5	373	6.88	14.7	100.6	0	55.8
WAR16	2007	20	23	0.03	0.04	0.18	<0.01	<0.01	1.4	433	6.95	13.7	92.4	0	50
WAR16	2008	15	26	0.07	0.01	0.27	<0.01	<0.01	0.2	349	6.41	16.8	91.9	0	7.8
WAR17	2005	10	75	<0.01	<0.01	0.3	<0.01	0.01	2.5	291	7.05	9.7	102.3	16.6	72.4
WAR17	2007	50	190	0.08	0.02	0.68	<0.01	<0.01	13	482	6.58	11.1	62.6	0	0
WAR17	2008	30	190	0.1	0.02	1	<0.01	0.01	1.7	374	6.56	17.4	66.5	0	9.1
WAR18	2005	35	110	<0.01	<0.01	0.72	<0.01	0.01	2	563	7.1	10.1	92.5	6.4	44.1
WAR18	2006	320	91	0.01	<0.01	0.26	<0.01	<0.01	1.4	18890	7.21	15.3	41.3	0	0
WAR18	2007	310	62	0.02	0.01	2.8	<0.01	<0.01	0.5	8410	6.96	23.9	29.4	0	0
WAR18	2008	55	47	0.51	0.01	1.2	<0.01	0.01	0.2	4670	7.02	18.5	60.4	0	0
WAR19	2005	40	35	<0.01	<0.01	0.21	<0.01	<0.01	0.4	2600	6.65	21.4	71.5	0	6.6
mean		25	65	0.09	0.05	0.43	0.02	0.01	2.9	1152	6.39	14.2	89.9	1.4	34.2
max		340	730	1.1	0.42	2.8	0.04	0.05	97	23700	7.64	24.7	163.6	21.1	142.9
min		<0.5	1	<0.01	<0.01	<0.02	<0.01	<0.01	0.2	26	3.94	7.6	23.8	0	0

APPENDIX 3. ADDITIONAL CATCHMENT HISTORY

This data has been provided by the Forest Management Branch, DEC using the Forest Management Information System (FMIS).

Table A2.1. Tenures within the catchment areas.

Catchment	Total Area (ha)	Tenure as proposed in the FMP 2004-2013		
		DEC Land (ha)	Other Public Land (ha)	Private Land (ha)
BLA06	55,241	49,312	175	5,753
BLA43	10,015	10,015	0	0
BLA51	6,431	4,048	15	2,367
BLA52	400	400	0	0
BLA53	1,523	1,523	0	0
BLA54	2,409	2,409	0	0
BLA55	4,739	4,126	36	578
BLA56	4,724	4,724	0	0
BUS05	4,694	1,529	58	3,107
BUS26	551	551	0	0
COL36	425	425	0	0
COL37	419	417	2	0
COL38	81	81	0	0
DEN09	3,827	926	179	2,721
DEN26	718	664	0	54
DON03	15,679	15,558	0	121
DON14	1,398	1,183	0	215
DON15	2,422	2,422	0	0
DON16	3,308	3,308	0	0
FRA17	221	221	0	0
FRA18	2,346	1,437	0	910
HAR01	2,798	2,798	0	0
HAR21	185	79	5	101
KEN11	2,861	2,861	0	0
MYR09	1,698	1,698	0	0
MYR33	1,756	1,756	0	0
MYR41	3,510	3,510	0	0
MRY43	6,788	5,609	71	1,107
MYR44	2,576	2,576	0	0
MYR45	2,463	2,421	0	41
SHA21	768	768	0	0
SHA22	2,244	2,244	0	0
SHA23	148	148	0	0
SHA24	1,767	1,767	0	0
SWA04	1,396	1,342	5	49
SWA24	2,977	2,977	0	0
SWA31	24,567	16,456	4,027	4,084
SWA32	28,329	28,327	2	0
SWA33	14,113	14,113	0	0
SWA35	7,557	6,205	44	1,308
WAR01	1,130	939	1	189
WAR02	2,705	2,039	0	666
WAR05	5,795	4,974	0	821
WAR15	9,200	3,533	525	5,142
WAR16	497	497	0	0
WAR17	3,439	3,439	0	0
WAR18	3,681	3,581	0	99
WAR19	919	919	0	0

Table A2.2. Harvest frequency for the catchments. All areas are in hectares (ha).

Catchment	Total Area (ha)	Area of Public Land	Frequency of Harvest as at 31.12 08				
			1	2	3	4+	No record
BLA06	55,241	49,488	18,416	24,516	5,848	639	68
BLA43	10,015	10,015	1,792	12	0	0	8,211
BLA51	6,431	4,063	699	1,616	1,375	373	0
BLA52	400	400	0	0	0	0	400
BLA53	1,523	1,523	1,267	77	0	0	178
BLA54	2,409	2,409	351	1,380	678	0	0
BLA55	4,739	4,162	1,682	2,392	50	0	37
BLA56	4,724	4,724	2,393	1,207	30	0	1,094
BUS05	4,694	1,587	952	185	35	8	406
BUS26	551	551	1	359	170	21	0
COL36	425	425	110	312	4	0	0
COL37	419	419	0	346	73	0	0
COL38	81	81	0	35	45	0	0
DEN09	3,827	1,106	878	0	0	0	228
DEN26	718	664	491	1	0	0	172
DON03	15,679	15,558	7,558	6,408	458	0	1,134
DON14	1,398	1,183	344	839	0	0	0
DON15	2,422	2,422	821	32	0	0	1,569
DON16	3,308	3,308	2,449	764	93	2	0
FRA17	221	221	0	0	0	0	221
FRA18	2,346	1,437	669	0	0	0	768
HAR01	2,798	2,798	752	1,610	375	15	45
HAR21	185	84	50	10	0	0	24
KEN11	2,861	2,861	539	0	0	0	2,321
MYR09	1,698	1,698	401	1,030	216	50	0
MYR33	1,756	1,756	180	963	583	30	0
MYR41	3,510	3,510	1,202	1,201	1,073	19	14
MRY43	6,788	5,681	823	1,793	2,458	383	224
MYR44	2,576	2,576	27	736	1,803	9	0
MYR45	2,463	2,421	2,084	317	0	0	21
SHA21	768	768	488	40	0	0	239
SHA22	2,244	2,244	962	117	10	0	1,156
SHA23	148	148	65	10	0	0	73
SHA24	1,767	1,767	1,201	424	84	0	58
SWA04	1,396	1,347	350	663	298	36	0
SWA24	2,977	2,977	1,115	1,184	577	10	90
SWA31	24,567	20,482	14,633	1,207	0	0	4,643
SWA32	28,329	28,329	14,103	10,495	803	67	2,862
SWA33	14,113	14,113	7,581	2,978	703	0	2,850
SWA35	7,557	6,249	319	3,035	2,673	80	143
WAR01	1,130	941	432	508	0	0	0
WAR02	2,705	2,039	1,043	956	40	0	0
WAR05	5,795	4,974	2,071	2,505	306	0	91
WAR15	9,200	4,058	1,426	1,527	487	2	618
WAR16	497	497	258	240	0	0	0
WAR17	3,439	3,439	2,421	200	0	0	818
WAR18	3,681	3,581	887	2,132	516	0	46
WAR19	919	919	571	0	0	0	348

Table A2.3. Harvest intensity. All areas are in hectares (ha).

Catchment	Total Area (ha)	Area of Public Land	Intensity of harvest (at 31.12.08)*			
			cleared, mined	gap, mixed, clear-felled	other silvic objective	no silvic record
BLA06	55,241	49,488	66	3,135	16,664	29,623
BLA43	10,015	10,015	47	24	1,495	8,450
BLA51	6,431	4,063	2	168	1,689	2,204
BLA52	400	400	0	0	0	400
BLA53	1,523	1,523	0	0	19	1,504
BLA54	2,409	2,409	2	0	985	1,422
BLA55	4,739	4,162	1	452	986	2,723
BLA56	4,724	4,724	21	0	2,127	2,576
BUS05	4,694	1,587	0	0	107	1,479
BUS26	551	551	0	0	124	427
COL36	425	425	0	87	229	110
COL37	419	419	0	0	163	256
COL38	81	81	0	0	45	35
DEN09	3,827	1,106	0	0	0	1,106
DEN26	718	664	0	0	0	664
DON03	15,679	15,558	47	4,955	1,712	8,844
DON14	1,398	1,183	4	702	142	334
DON15	2,422	2,422	0	32	0	2,391
DON16	3,308	3,308	0	293	418	2,597
FRA17	221	221	0	0	0	221
FRA18	2,346	1,437	0	31	0	1,405
HAR01	2,798	2,798	0	0	1,196	1,601
HAR21	185	84	0	0	3	81
KEN11	2,861	2,861	0	0	0	2,861
MYR09	1,698	1,698	85	11	633	968
MYR33	1,756	1,756	0	0	57	1,698
MYR41	3,510	3,510	0	101	1,754	1,655
MRY43	6,788	5,681	54	0	0	5,626
MYR44	2,576	2,576	0	132	1,795	649
MYR45	2,463	2,421	0	4	86	2,331
SHA21	768	768	0	515	0	252
SHA22	2,244	2,244	0	664	13	1,567
SHA23	148	148	0	37	0	111
SHA24	1,767	1,767	10	538	5	1,213
SWA04	1,396	1,347	0	0	612	735
SWA24	2,977	2,977	0	173	1,080	1,724
SWA31	24,567	20,482	0	0	0	20,482
SWA32	28,329	28,329	2	1,097	5,927	21,303
SWA33	14,113	14,113	0	264	343	13,506
SWA35	7,557	6,249	0	2	257	5,990
WAR01	1,130	941	3	278	419	241
WAR02	2,705	2,039	1	128	0	1,910
WAR05	5,795	4,974	0	0	0	4,974
WAR15	9,200	4,058	65	1,080	967	1,947
WAR16	497	497	5	235	0	258
WAR17	3,439	3,439	14	2,525	5	895
WAR18	3,681	3,581	0	8	2,464	1,109
WAR19	919	919	0	0	0	919

APPENDIX APPENDIX 4. SITE DESCRIPTIONS

A summary of the information collected for each catchment. Below is a brief decription of the terminology and data used.

Latitude and **Longitude** – given in decimal degrees.
Area of catchment area (ha) –area of catchment upstream of the sampling location determined using GIS mapping.
Average Annual Rainfall (mm) – An estimated mean annual rainfall calculated from using the site location and isohyets (mm)
Discharge category – the mean annual discharge in megalitres per annum (1=10-100ML/a; 2=100-1000; 3= 1000-10,000; 4= 10^4-10^5; 5= 10^5-10^6)
Forest type – The main forest type within the catchment (Jarrah or Karri)
Dieback Present (% catchment) – the proportion of the catchment recorded with Dieback. Dieback records are courtesy of Forest Management Branch using the Forest Management Information System (FMIS) and are the Dieback status up to 02/12/2008.
Species Richness - Total number of taxa, according to the lowest level they were identified to (species-level for Ephemeroptera, Plecoptera, Trichoptera, Hemiptera, Coleoptera, Odonata and Chironomidae and family-level for all other groups). Note that all earthworms were grouped into one “family”, and all trombidioid and oribatid mites were counted as one “family”.
Chironomid Richness - Number of species from within the family Chironomidae.
EPT Richness - Number of species from within Ephemeroptera, Plecoptera and Trichoptera.
Family Richness - Total number of families. Note that all earthworms were grouped into one “family”, all trombidioid and oribatid mites were counted as one “family”, and chironomid sub-families were treated as separate “families”.

Determination of disturbance categories and areas.

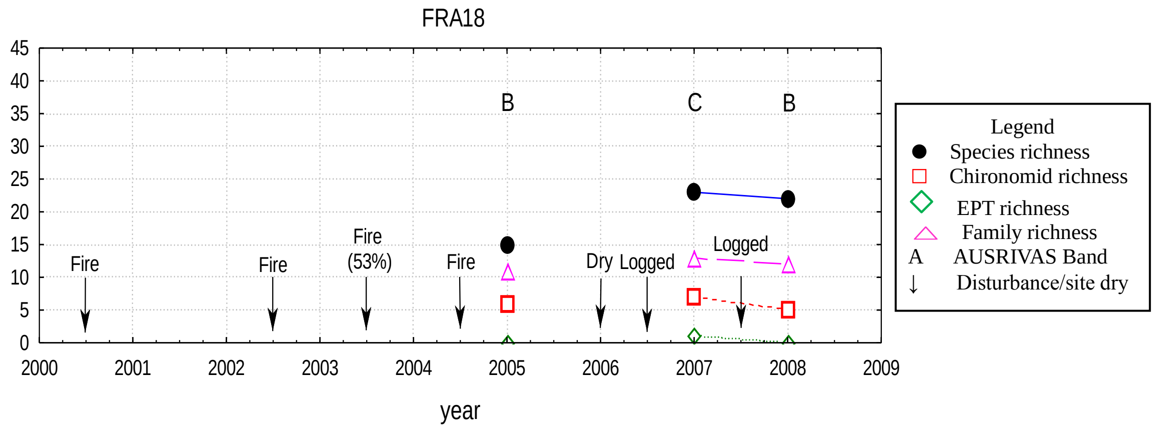
A geographic information system (ArcGIS, ESRI) was used to determine and measure the area of the catchments burned and logged. GIS data on fire and harvest areas were provided by the Fire Management Services (FMS) and the Forest Management Branch (FMB) within the Department of Environment and Conservation. This data was clipped to the catchment area upstream of the sampling location and was used to calculate the area (ha) of disturbance (“Fire” or “Logging”) which had occurred in the catchment area. Categories included “Fire” for areas burned, “Logged” for areas harvested, “F+L” for areas both burned and harvested, ‘Nil’, for sites where no disturbance had been recorded for the previous 12 months in the catchment or observed at the time of sampling, ‘Dam’, for sites located immediately downstream of a dam wall and “reset” for the sites situated downstream of the “Dam” sites after several tributaries had entered the river.

Fire data from FMS is reported in “fire seasons” from July to June inclusive. As sampling for this project occurs in spring fire data is allocated from the previous fire season records. For example; a sample taken in spring 2005 will be allocated the fire data from the 2004/2005 season. No fires have been reported as “winter” since 2004 in the FMB data set suggesting minimal fire activity occurs between June and the sampling occasion. Any recent fire activity at a site is recorded while in the field, so any fire disturbance occurring between end June and the sampling time should be included in the dataset.

Logging data from FMB is reported in calendar years. Logging data for a sampling occasion is allocated the previous year’s logging data For example; a sample taken in spring 2005 will be allocated the 2004 harvest data. This may mean that harvest activities that occur from the beginning of the year which would impact the site may not be included. It is noted at the sampling occasion whether logging activity has occurred at the site, however logging further away in the upper catchment area may not be detected.

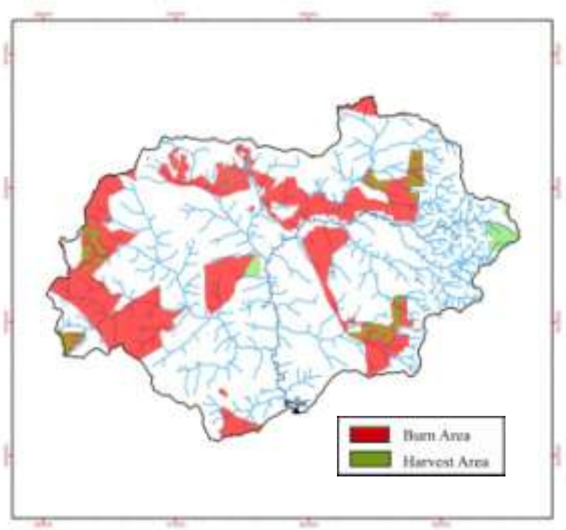
Graphics:

The top graph (example below) shows the biodiversity measures (species richness, chironomid richness, EPT richness and family richness) along with any disturbances occurring within the catchment area since 2000. Arrows indicate if a disturbance (Fire, logged or F+L) has occurred or the site was dry at the time of sampling. If greater than 20% of the catchment was affected then this is shown in brackets. Letters above the sampling occasions show the AUSRIVAS banding allocated to the site (X; enriched, A; undisturbed, B; significantly impaired, C; severely impaired).



The three graphics at the bottom on the page (example below) show the areas within the catchment which have been affected by fire of logging over three time periods.

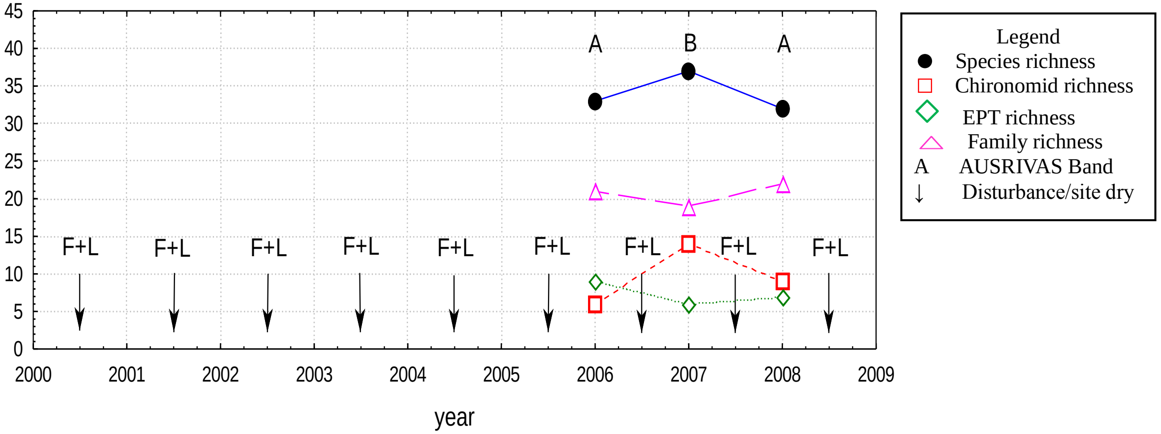
1. Disturbance areas for the previous 1 year – areas burnt or logged for previous year only (2007-2008 season for fires and 2007 for logging).
2. Disturbance areas for the previous five years – the accumulation of all areas burnt or logged over five years. Fire data from 2003-2004 season to 2007-2008 season and logging from 2003 to 2007)
3. Disturbance areas for previous ten years - the accumulation of all areas burnt or logged over ten years. Fire data from 1998-1999 season to 2007-2008 season and logging from 1998 to 2007)

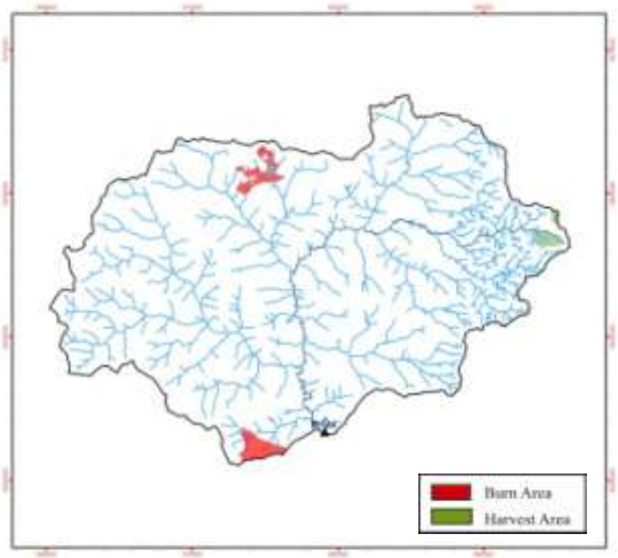


Disturbance areas for the previous 5 years

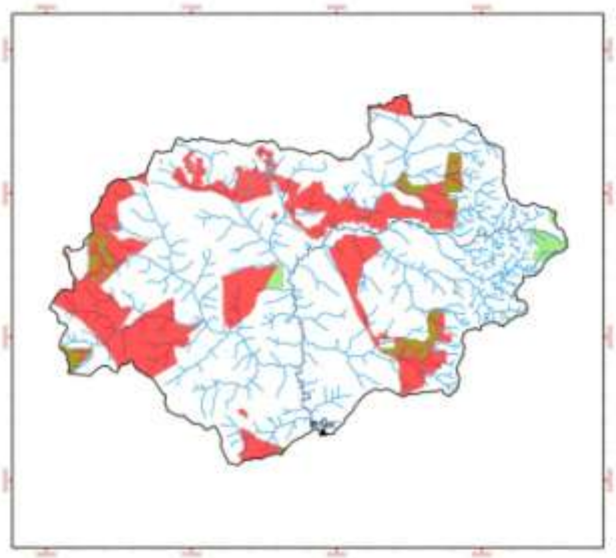
BLA06 ST JOHN BROOK

Latitude:	-33.9433
Longitude:	115.6911
Area of catchment (ha):	55,244
Average Annual Rainfall (mm):	975
Discharge category:	4
Forest type	Jarrah
Tenure at sampling point	Conservation park
Year of Last Burn:	2008
Year of Last Harvest:	2007
Dieback Present (% catchment)	34

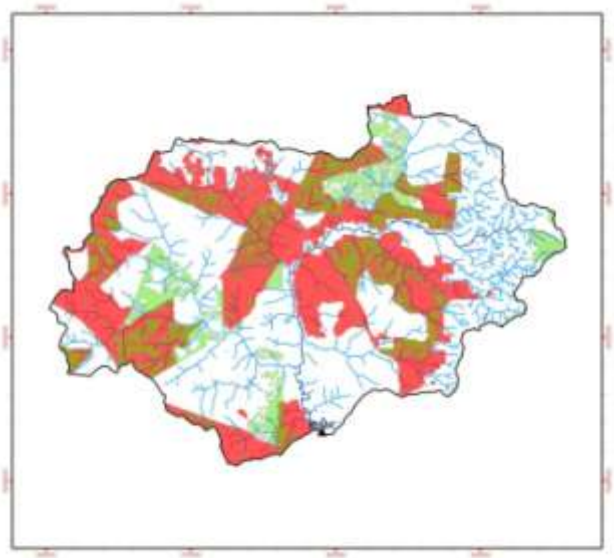




Disturbance areas for the previous 1 year.



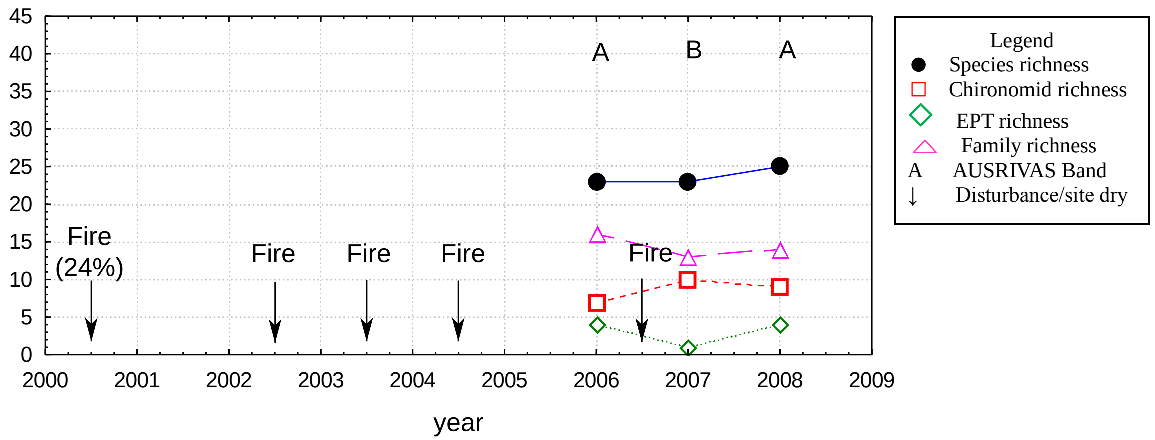
Disturbance areas for the previous 5 years

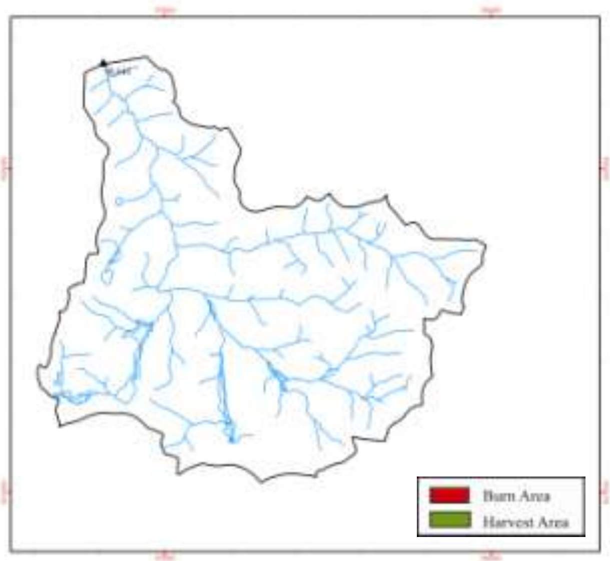


Disturbance areas for the previous 10 years.

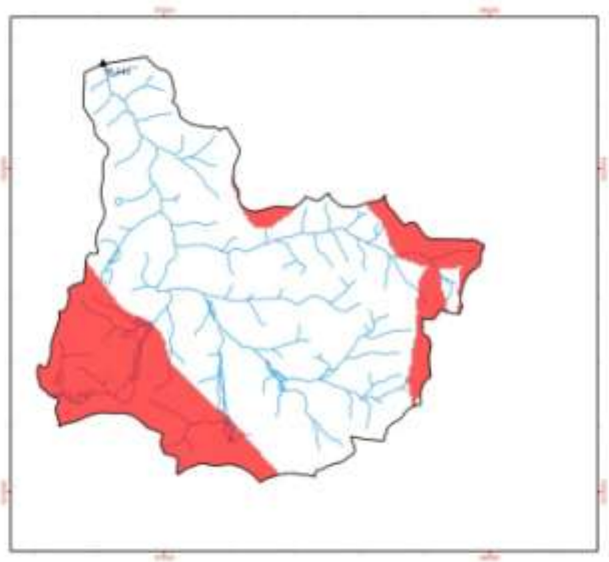
BLA43 BLACKWOOD RD MILYEANNUP

Latitude:	-34.1233
Longitude:	115.5698
Area of catchment (ha):	10,011
Average Annual Rainfall (mm):	1000
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2007
Year of Last Harvest:	1990's
Dieback Present (% catchment)	20

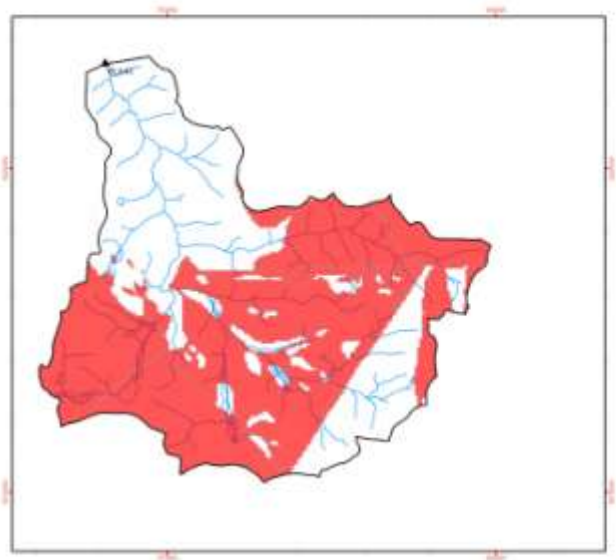




Disturbance areas for the previous 1 year.



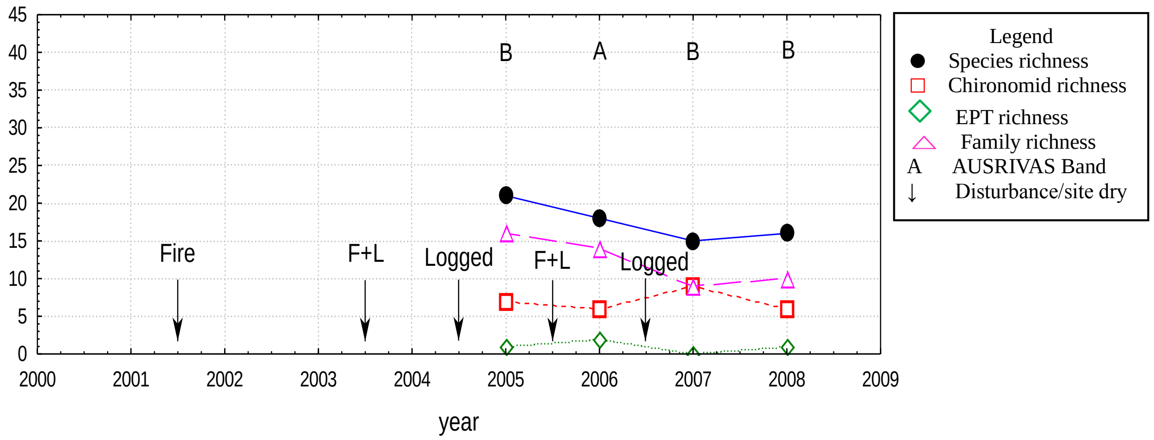
Disturbance areas for the previous 5 years

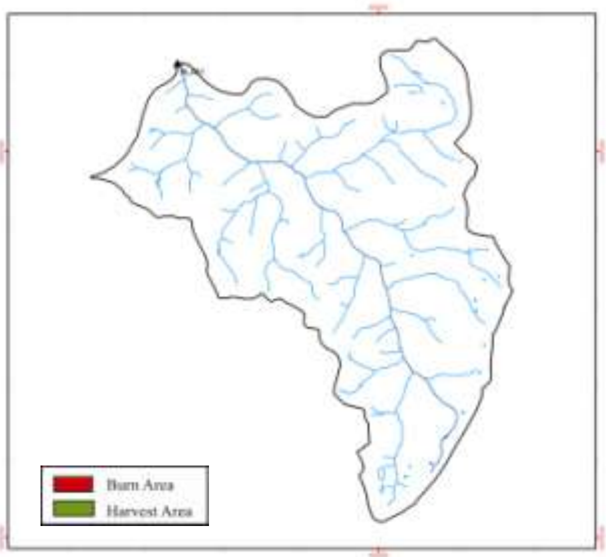


Disturbance areas for the previous 10 years.

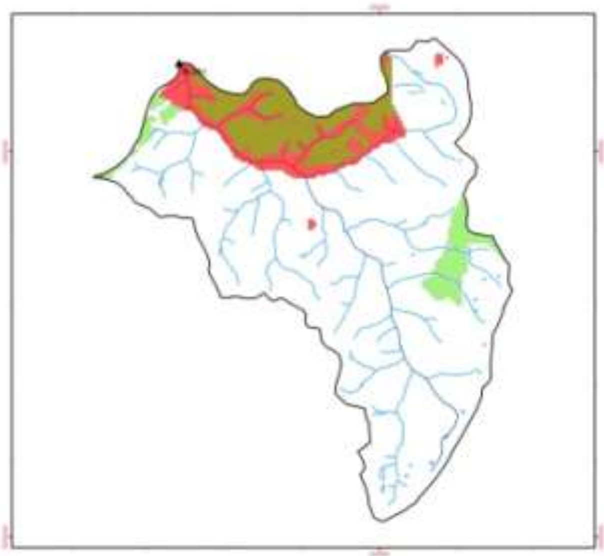
BLA51 BALINGUP BROOK

Latitude:	-33.777
Longitude:	116.188
Area of catchment (ha):	6,432
Average Annual Rainfall (mm):	825
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	2006
Dieback Present (% catchment)	2

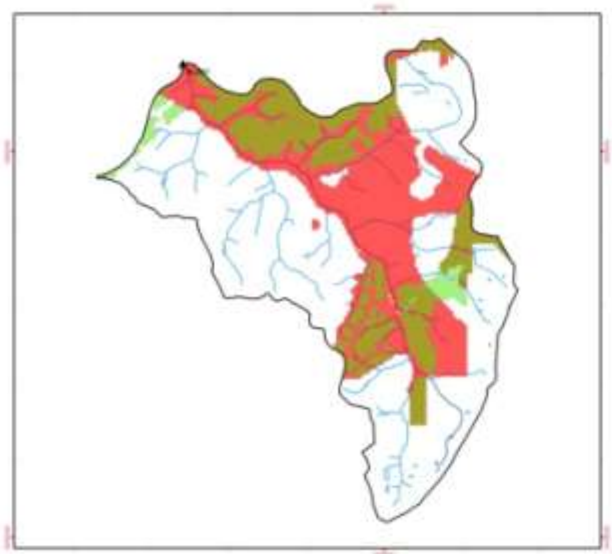




Disturbance areas for the previous 1 year.



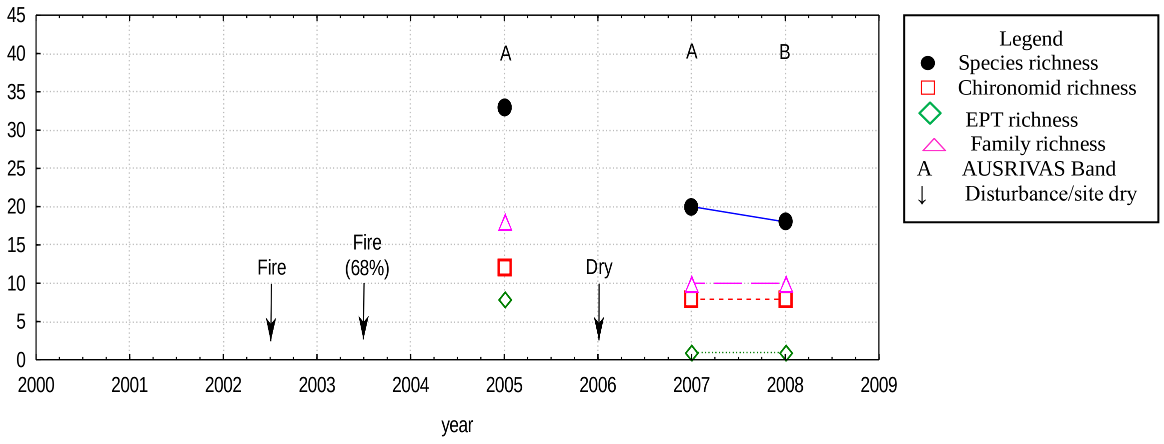
Disturbance areas for the previous 5 years

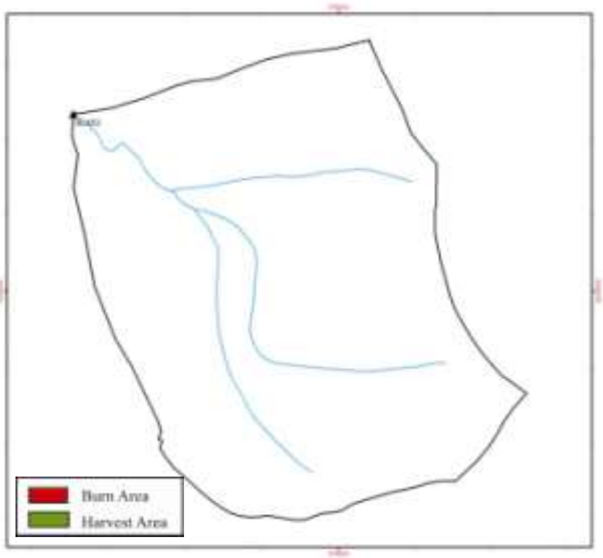


Disturbance areas for the previous 10 years.

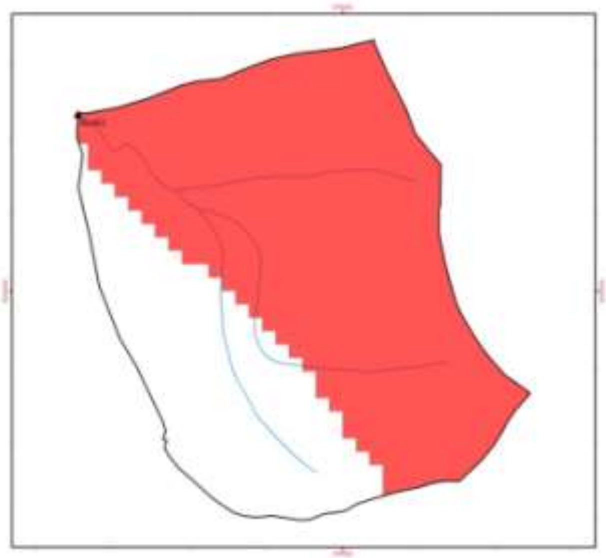
BLA52 DARRADUP ROAD

Latitude:	-34.1450
Longitude:	115.6400
Area of catchment (ha):	401
Average Annual Rainfall (mm):	1025
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2004
Year of Last Harvest:	NR
Dieback Present (% catchment)	5

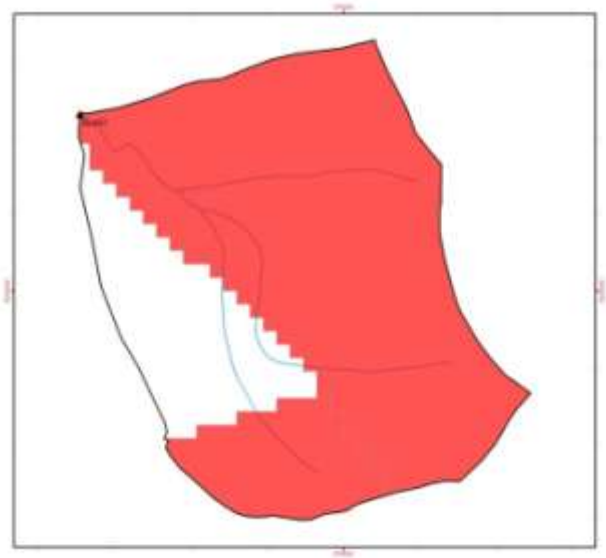




Disturbance areas for the previous 1 year.



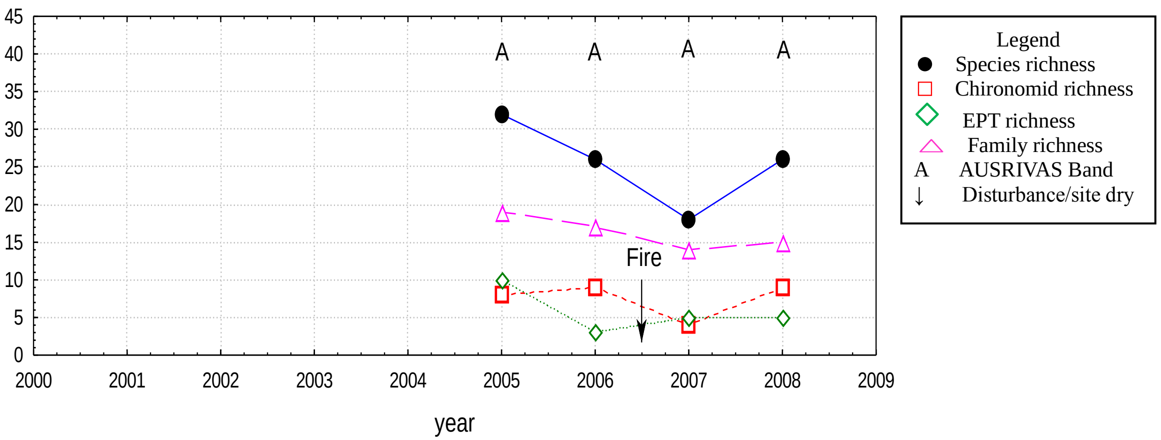
Disturbance areas for the previous 5 years

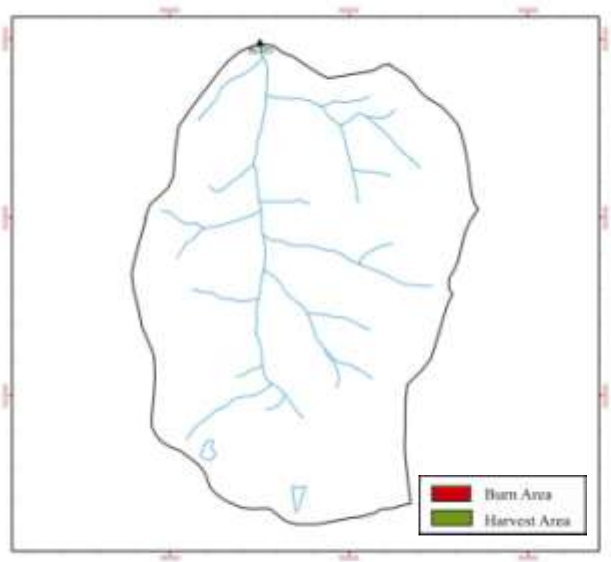


Disturbance areas for the previous 10 years.

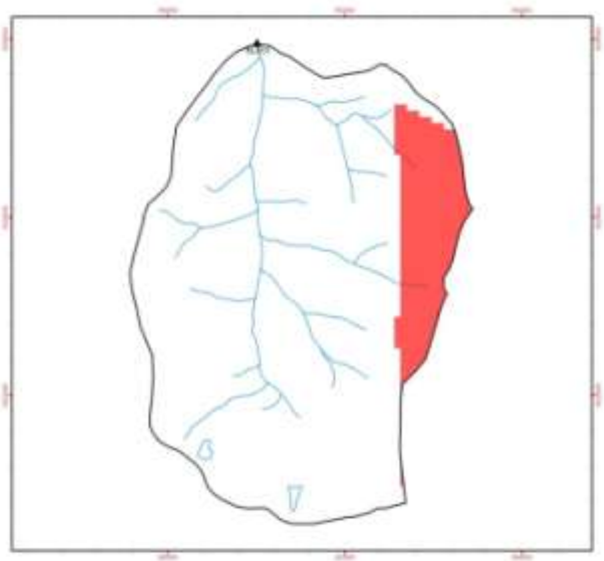
BLA53 BLACKWOOD RD WEST

Latitude:	-34.0966
Longitude:	115.3850
Area of catchment (ha):	1,525
Average Annual Rainfall (mm):	1050
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2007
Year of Last Harvest:	
Dieback Present (% catchment)	28

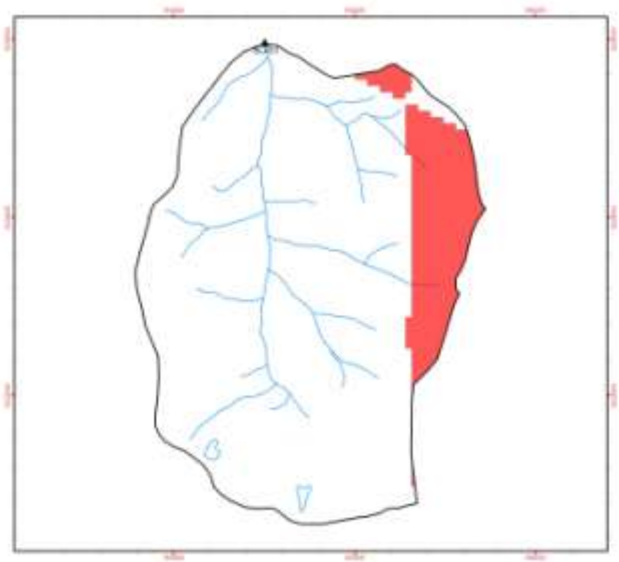




Disturbance areas for the previous 1 year.



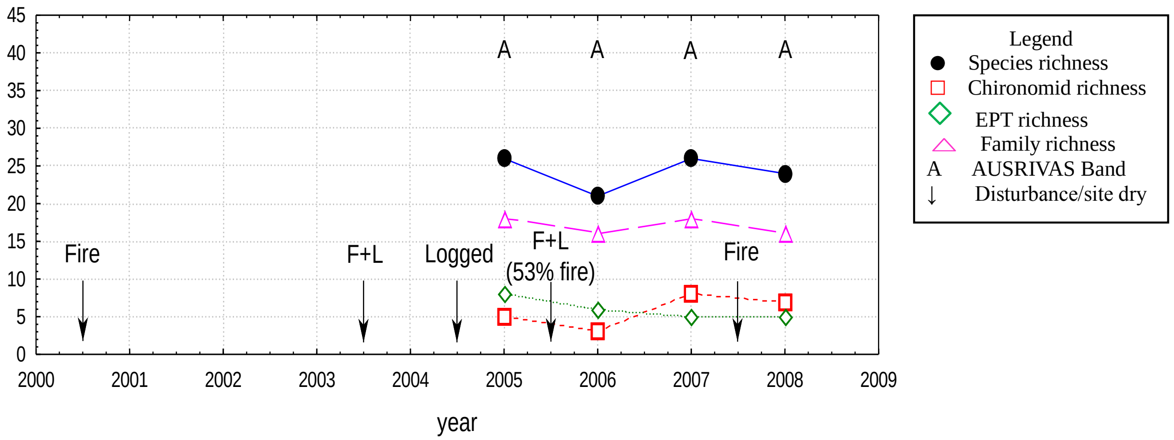
Disturbance areas for the previous 5 years

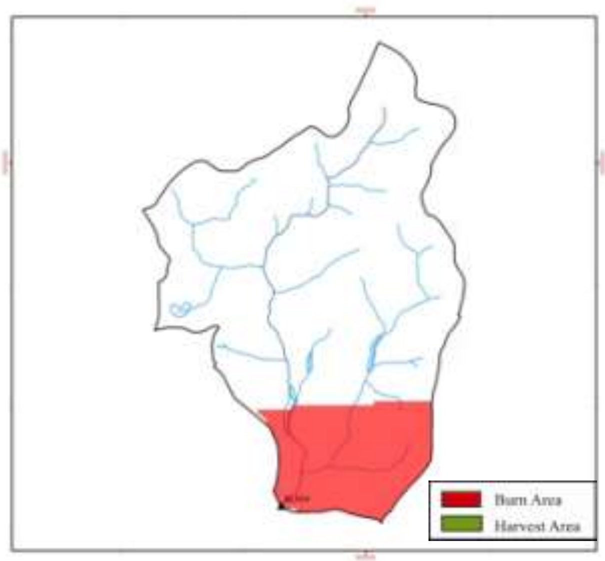


Disturbance areas for the previous 10 years.

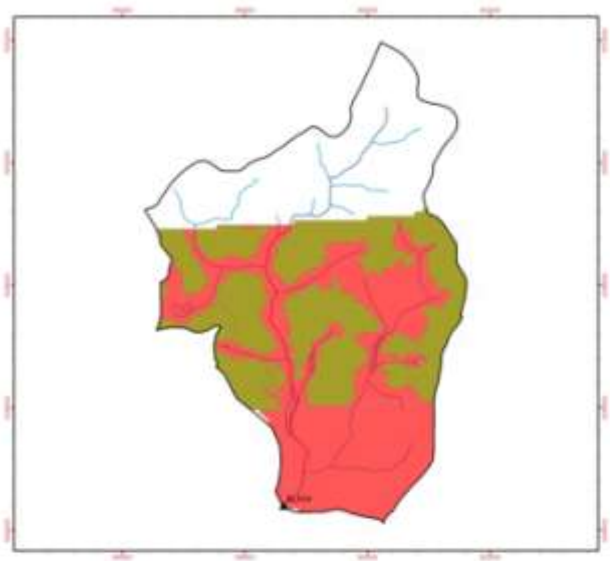
BLA54 ROSA BROOK LAWSON RD

Latitude:	-33.9315
Longitude:	115.4706
Area of catchment (ha):	2,409
Average Annual Rainfall (mm):	975
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	2005
Dieback Present (% catchment)	57

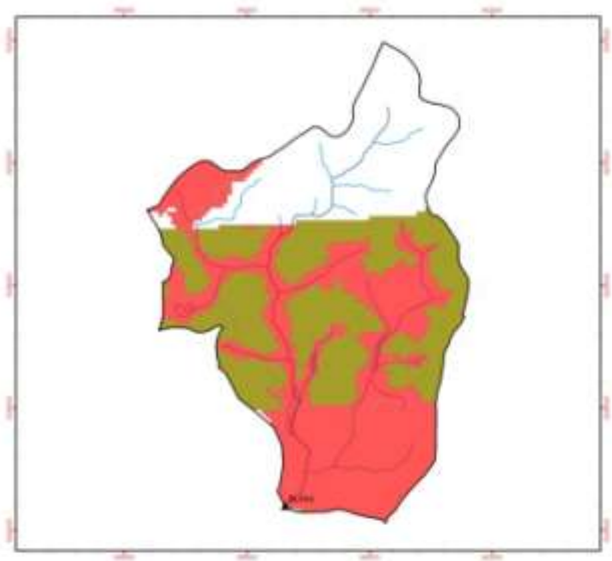




Disturbance areas for the previous 1 year.



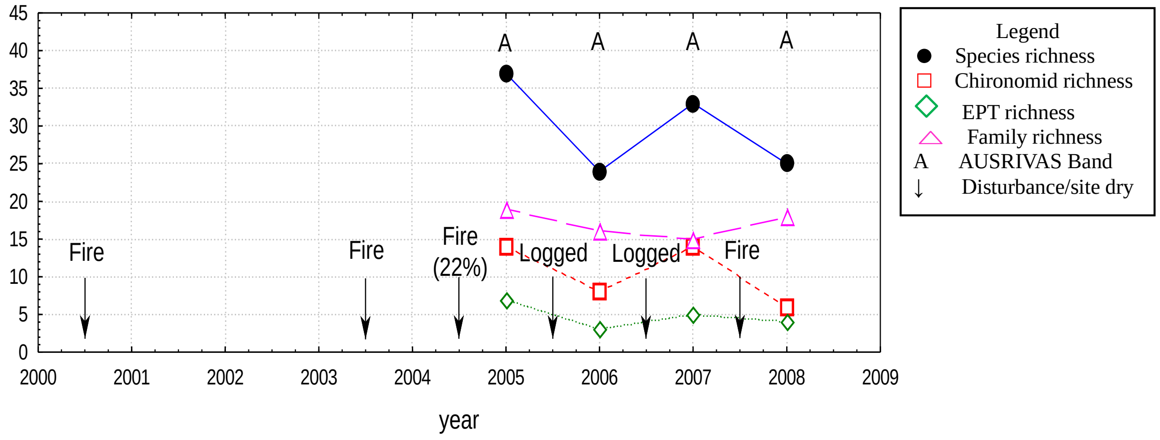
Disturbance areas for the previous 5 years

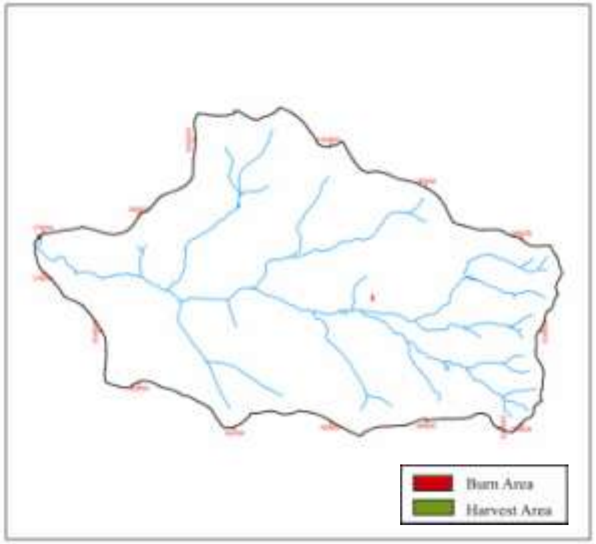


Disturbance areas for the previous 10 years.

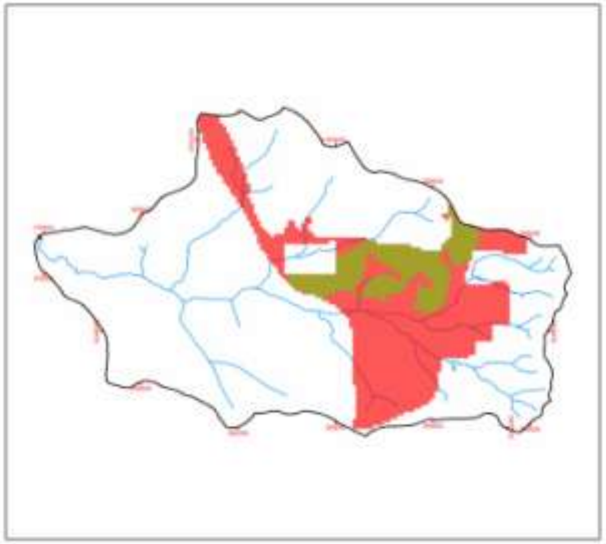
BLA55 ROCKY GULLY

Latitude:	-33.8834
Longitude:	115.6797
Area of catchment (ha):	4,741
Average Annual Rainfall (mm):	975
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	Other crown reserves/freehold
Year of Last Burn:	2008
Year of Last Harvest:	2006
Dieback Present (% catchment)	24

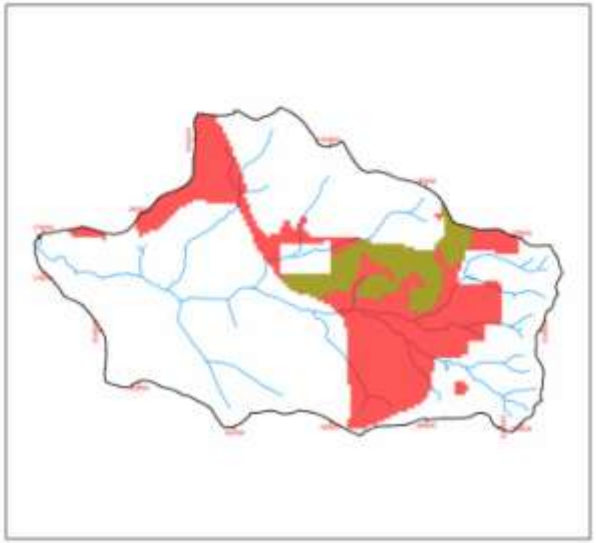




Disturbance areas for the previous 1 year.



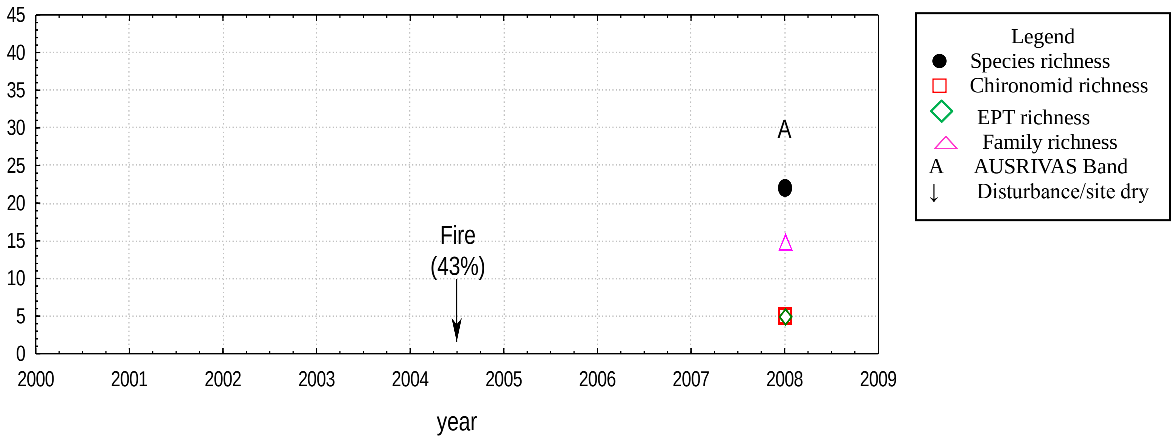
Disturbance areas for the previous 5 years



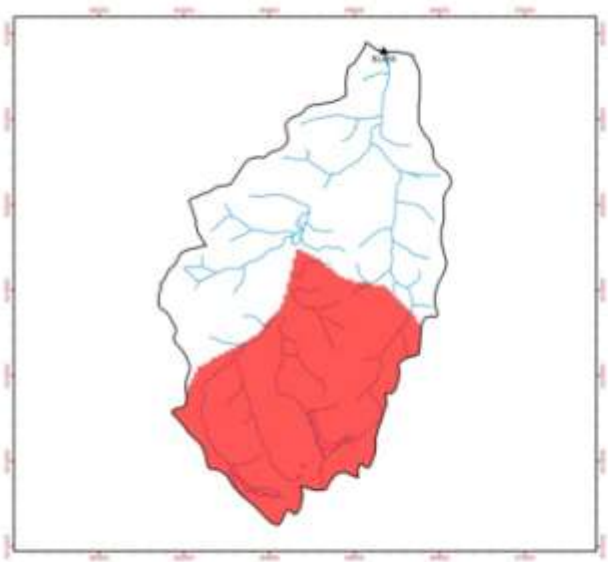
Disturbance areas for the previous 10 years.

BLA56 POISON GULLY

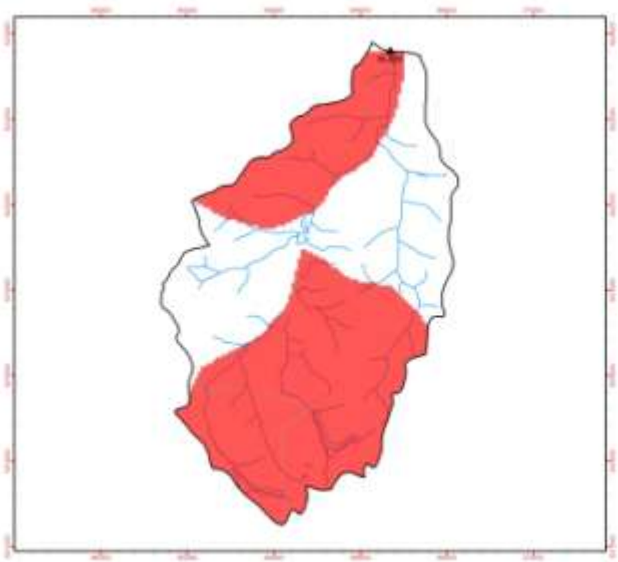
Latitude:	-34.1199
Longitude:	115.5545
Area of catchment (ha):	4,730
Average Annual Rainfall (mm):	975
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2005
Year of Last Harvest:	1990's
Dieback Present (% catchment)	11



Disturbance areas for the previous 1 year.



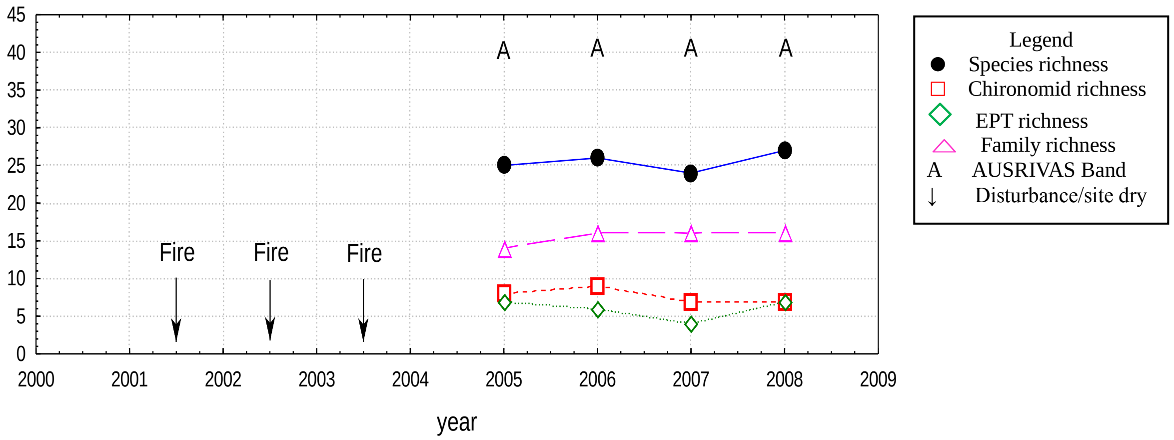
Disturbance areas for the previous 5 years

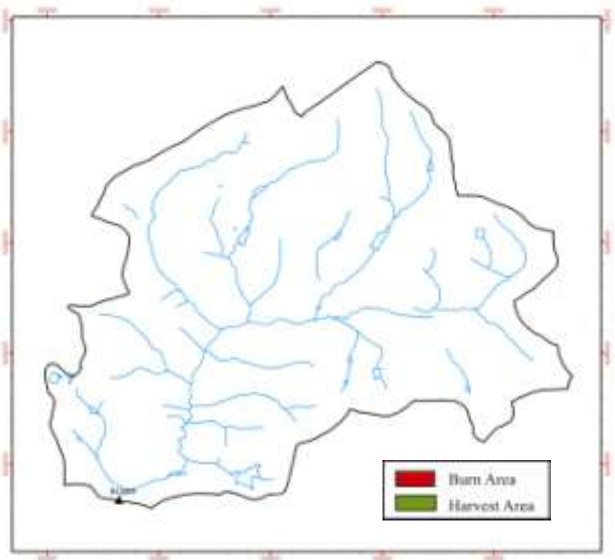


Disturbance areas for the previous 10 years.

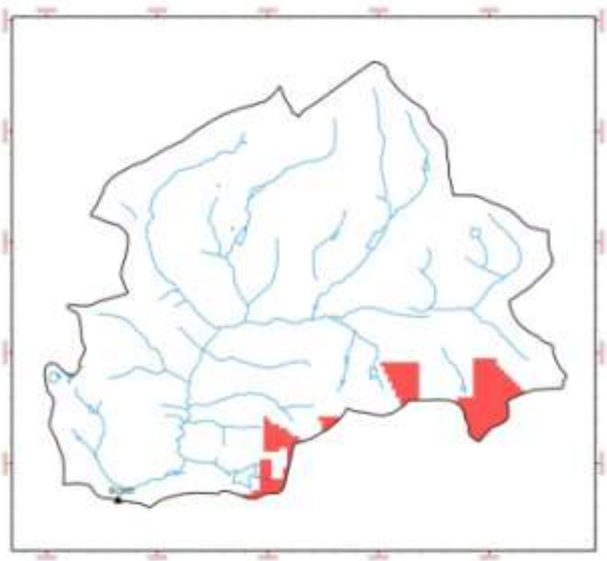
BUS05 BRAMLEY BROOK

Latitude:	-33.9350
Longitude:	115.0672
Area of catchment (ha):	4,689
Average Annual Rainfall (mm):	1100
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2004
Year of Last Harvest:	1980"s
Dieback Present (% catchment)	7

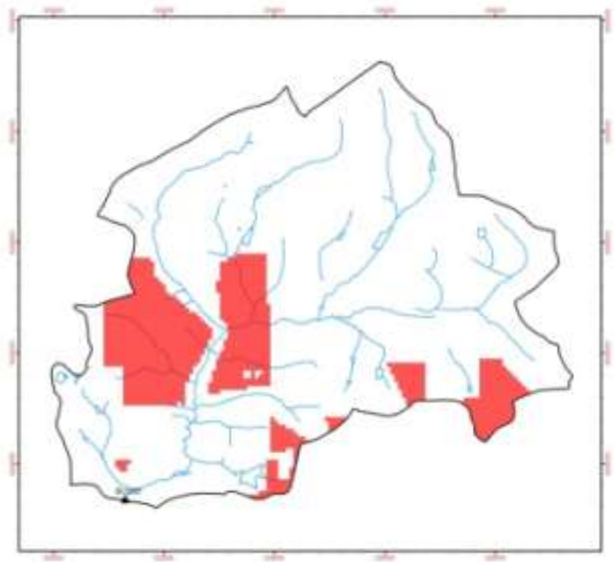




Disturbance areas for the previous 1 year.



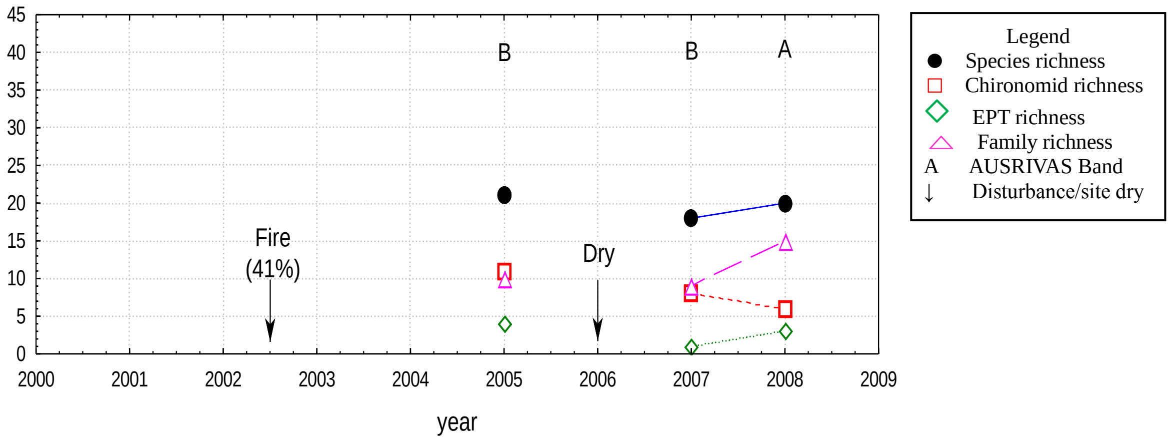
Disturbance areas for the previous 5 years

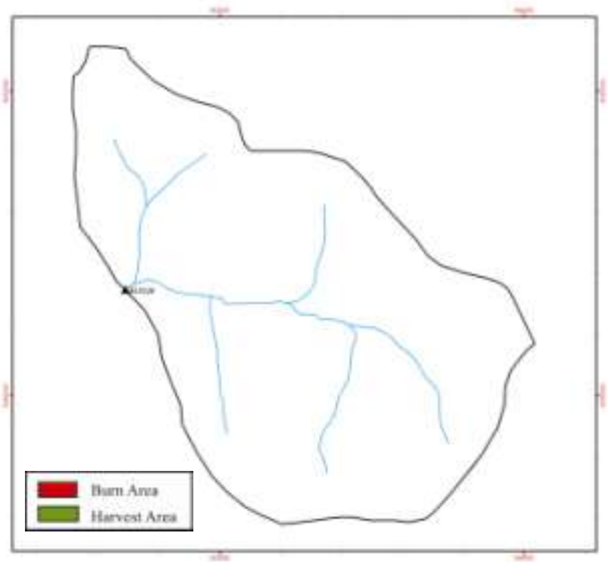


Disturbance areas for the previous 10 years.

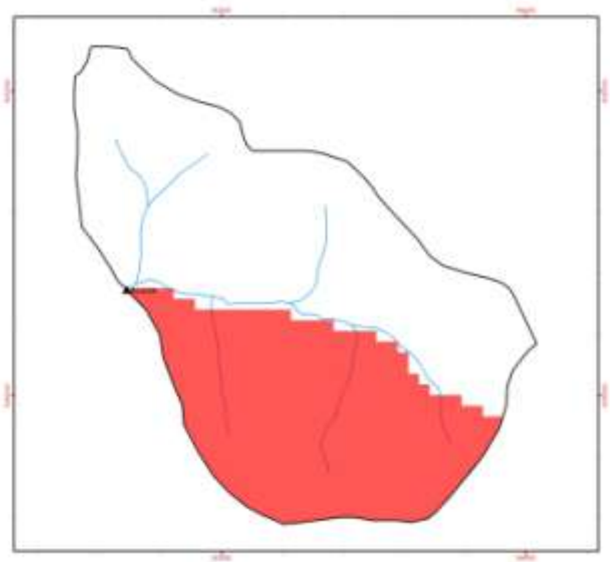
BUS26 CAMP GULLY ROAD

Latitude:	-33.6069
Longitude:	115.7215
Area of catchment (ha):	550
Average Annual Rainfall (mm):	950
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2003
Year of Last Harvest:	1980"s
Dieback Present (% catchment)	11

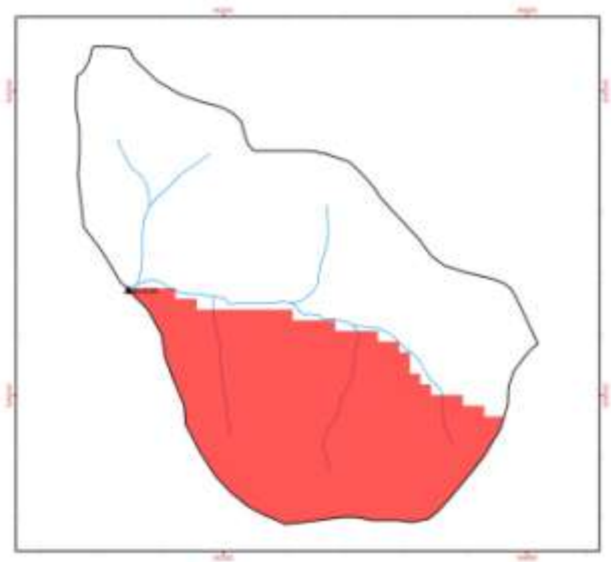




Disturbance areas for the previous 1 year.



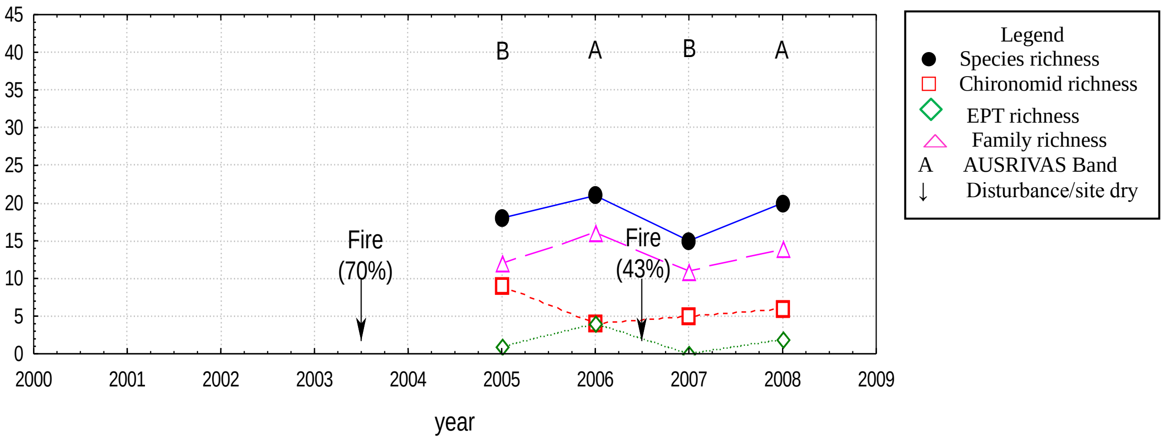
Disturbance areas for the previous 5 years

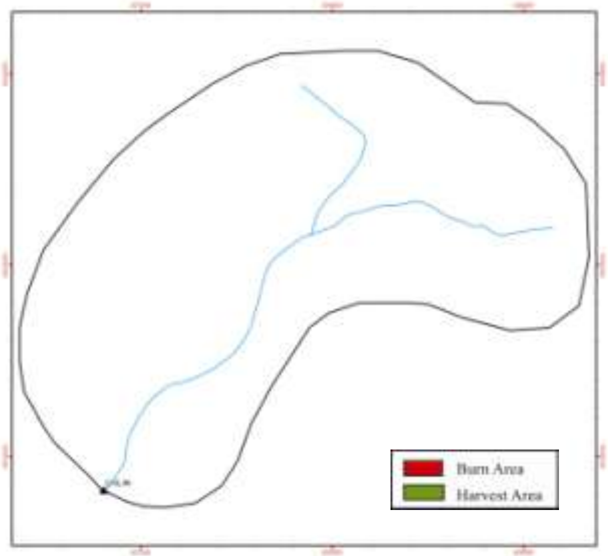


Disturbance areas for the previous 10 years.

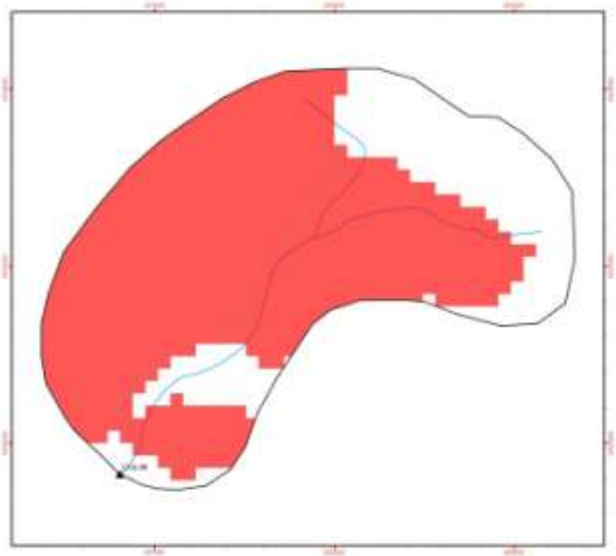
COL36 TREES ROAD

Latitude:	-33.1499
Longitude:	116.2151
Area of catchment (ha):	425
Average Annual Rainfall (mm):	975
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2007
Year of Last Harvest:	1990's
Dieback Present (% catchment)	11

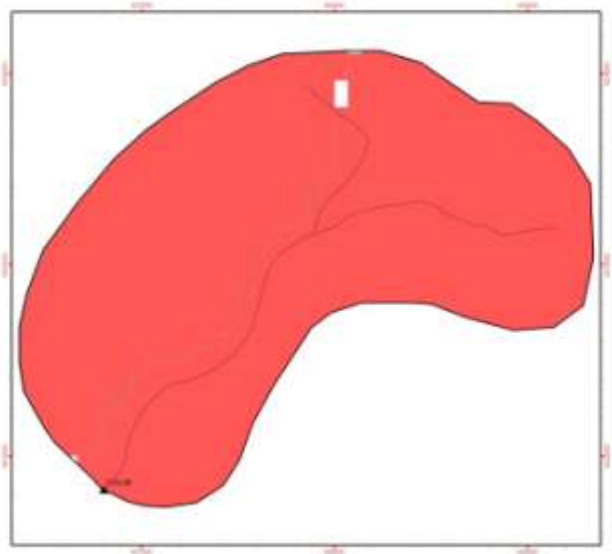




Disturbance areas for the previous 1 year.



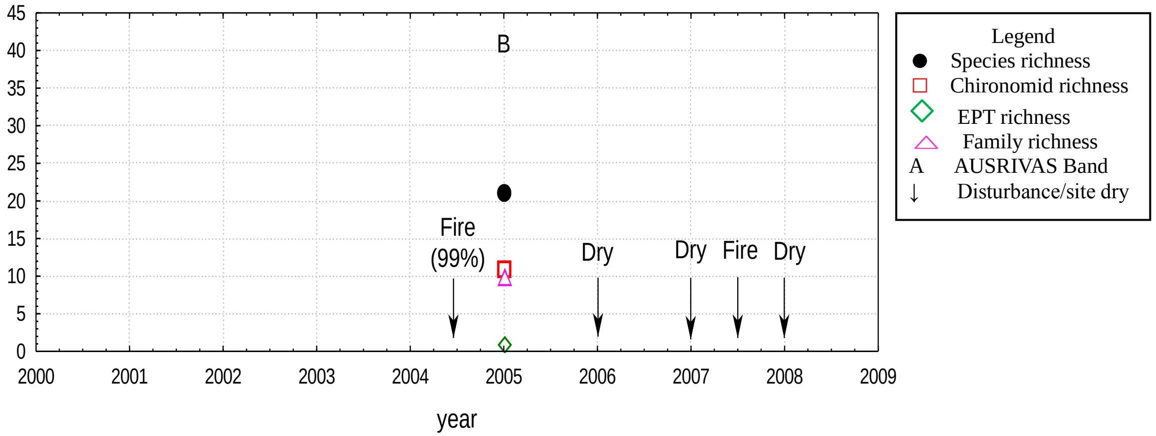
Disturbance areas for the previous 5 years

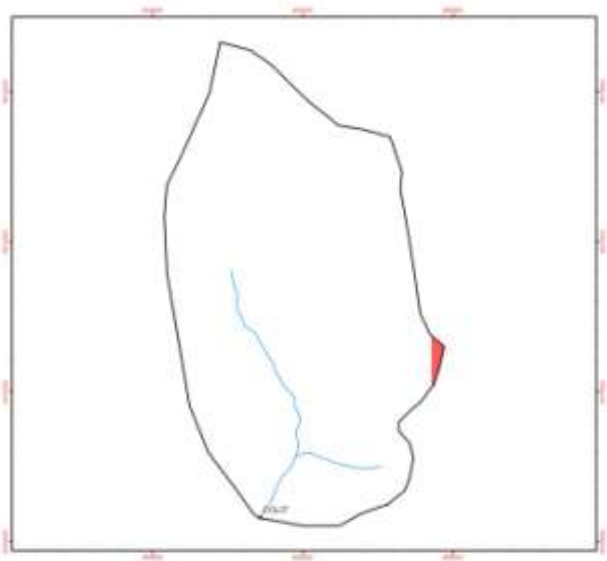


Disturbance areas for the previous 10 years.

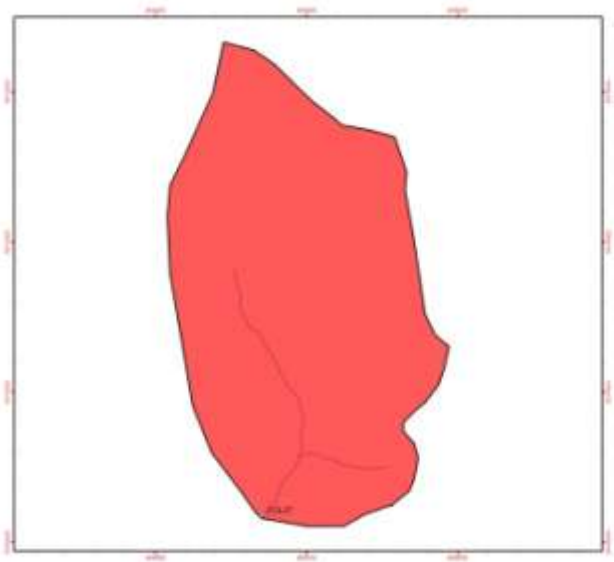
COL37 ERNIE ROAD

Latitude:	-33.3468
Longitude:	116.5134
Area of catchment (ha):	420
Average Annual Rainfall (mm):	675
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	1980"s
Dieback Present (% catchment)	0

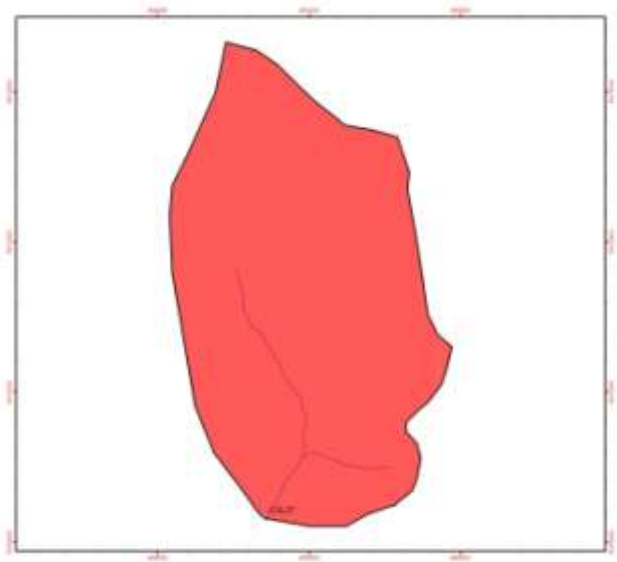




Disturbance areas for the previous 1 year.



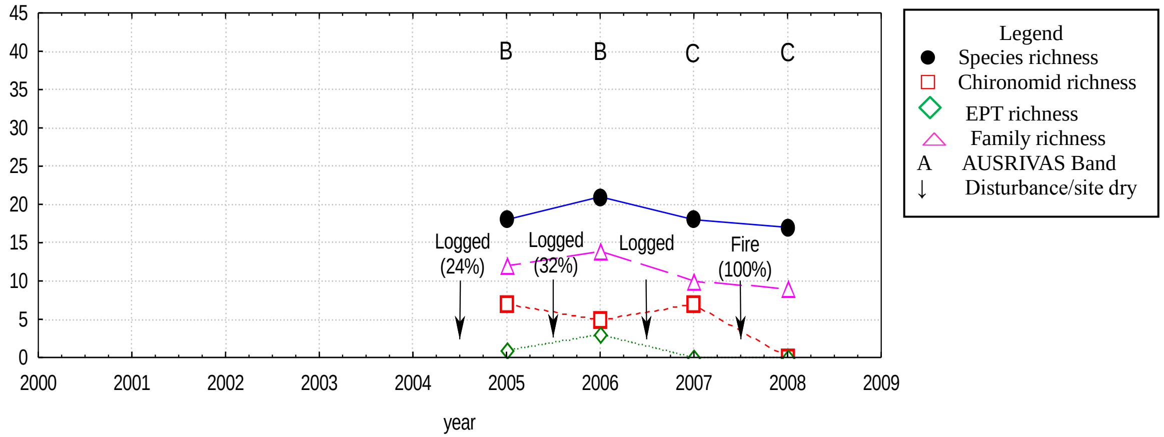
Disturbance areas for the previous 5 years



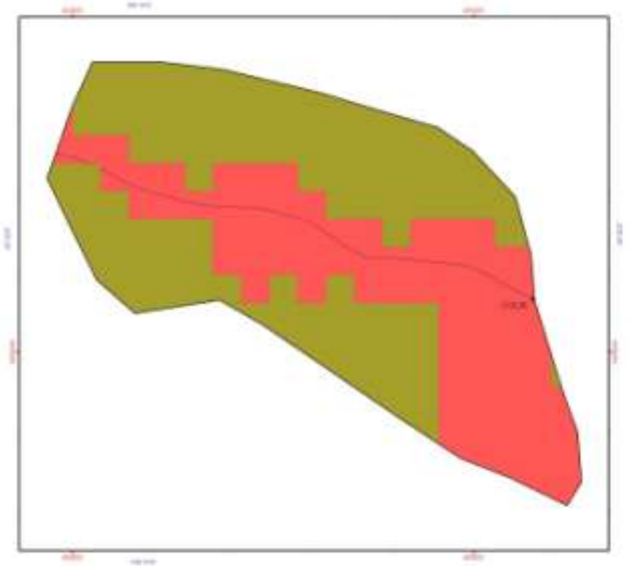
Disturbance areas for the previous 10 years.

COL38 ROSEWOOD ROAD

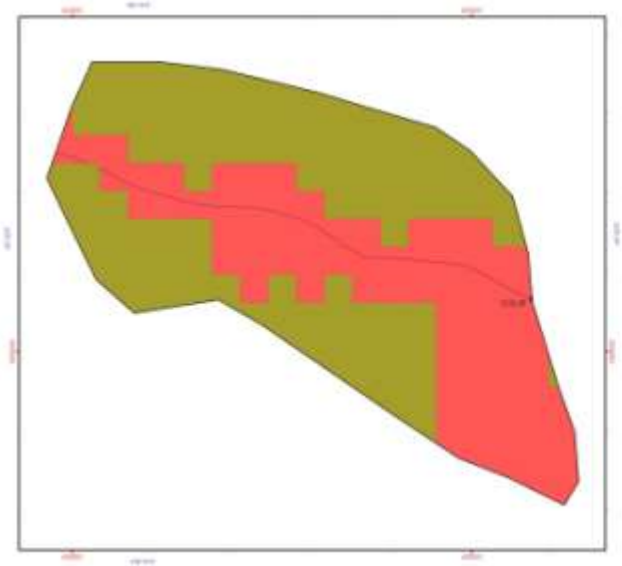
Latitude:	-33.5347
Longitude:	116.1940
Area of catchment (ha):	81
Average Annual Rainfall (mm):	850
Discharge category:	1
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	2006
Dieback Present (% catchment)	0



Disturbance areas for the previous 1 year.



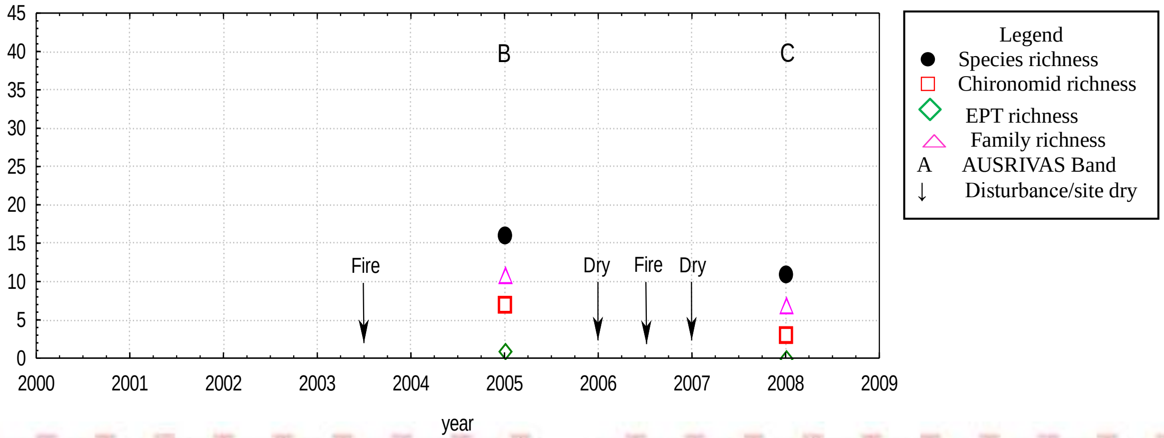
Disturbance areas for the previous 5 years



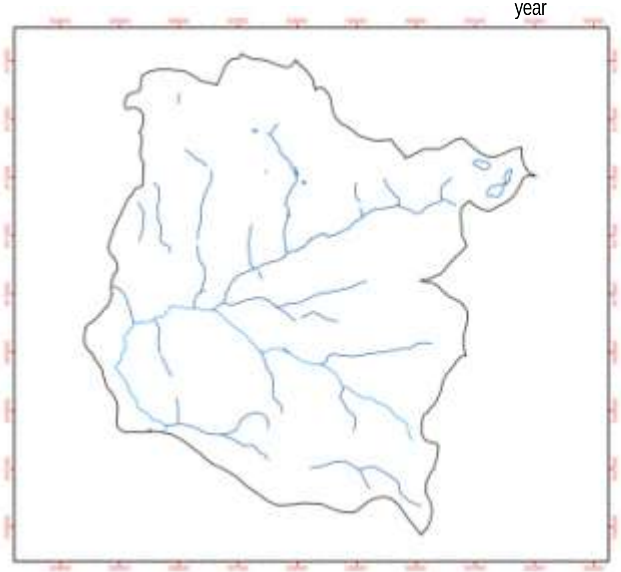
Disturbance areas for the previous 10 years.

DEN09 UPPER DENMARK

Latitude:	-34.6328
Longitude:	117.2783
Area of catchment (ha):	3,832
Average Annual Rainfall (mm):	750
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2007
Year of Last Harvest:	1960's
Dieback Present (% catchment)	0



Disturbance areas for the previous 1 year.

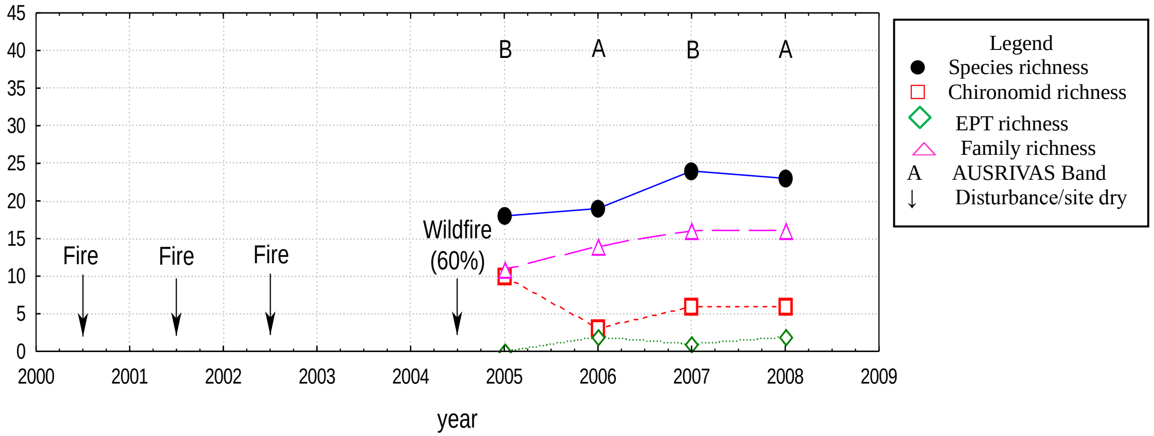


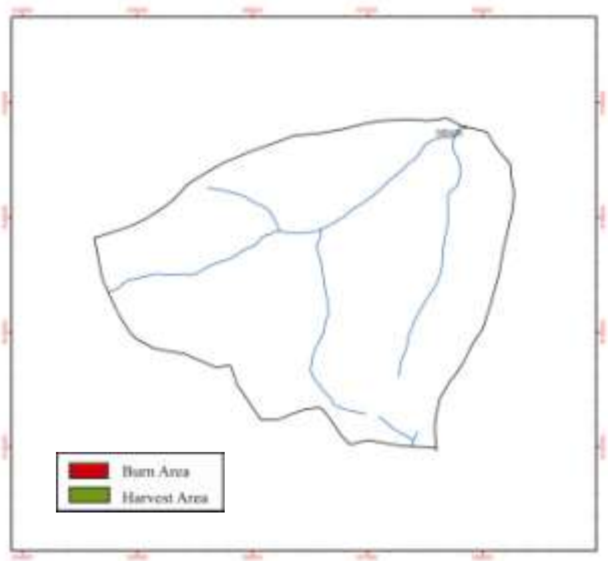
Disturbance areas for the previous 5 years

Disturbance areas for the previous 10 years.

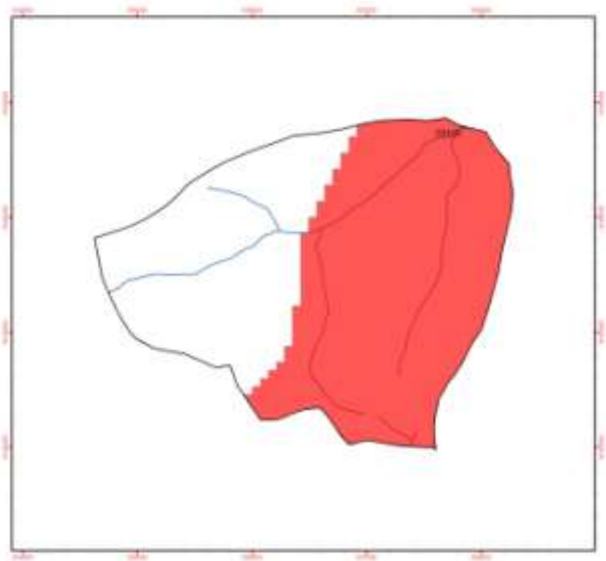
DEN26 QUICKUP FIRE

Latitude:	-34.8384
Longitude:	117.414
Area of catchment (ha):	717
Average Annual Rainfall (mm):	850
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2005
Year of Last Harvest:	1970's
Dieback Present (% catchment)	0

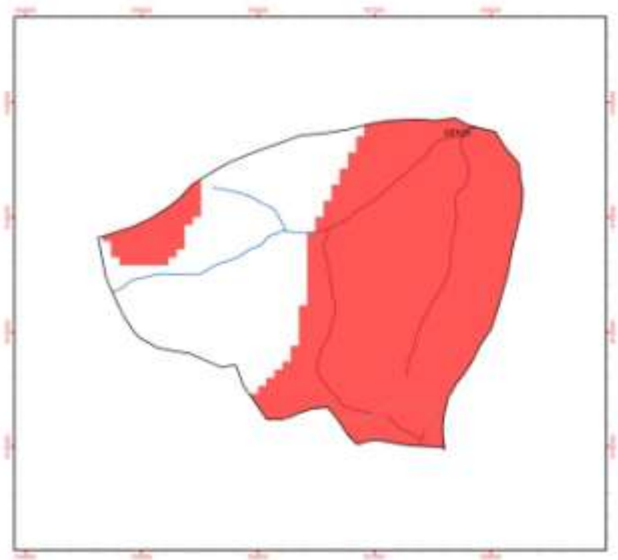




Disturbance areas for the previous 1 year.



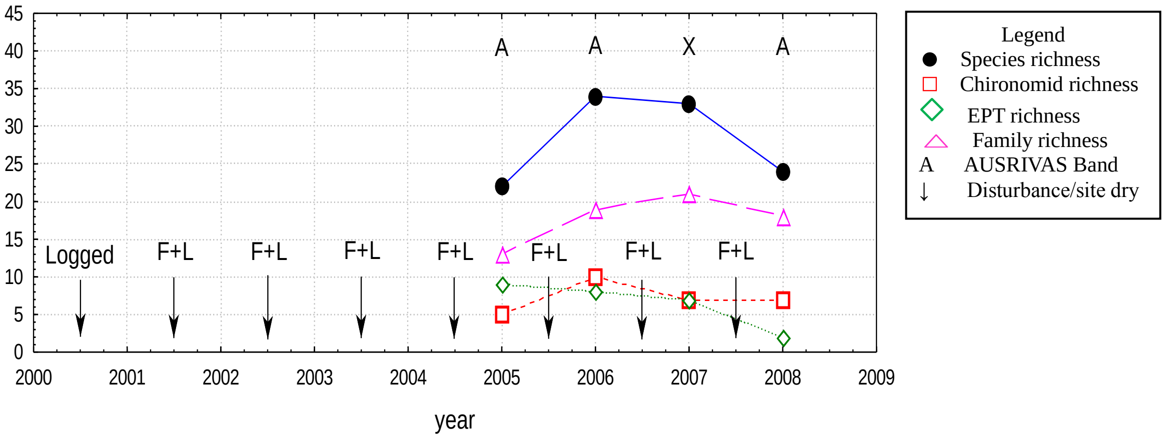
Disturbance areas for the previous 5 years



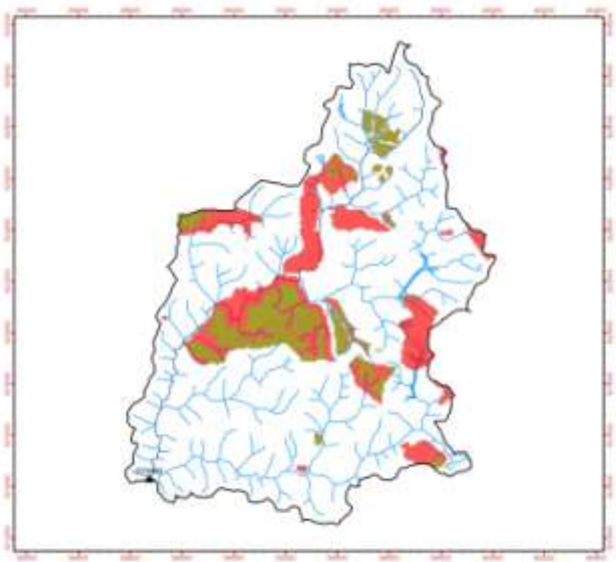
Disturbance areas for the previous 10 years.

DON03 BARLEE BROOK DICKSON RD

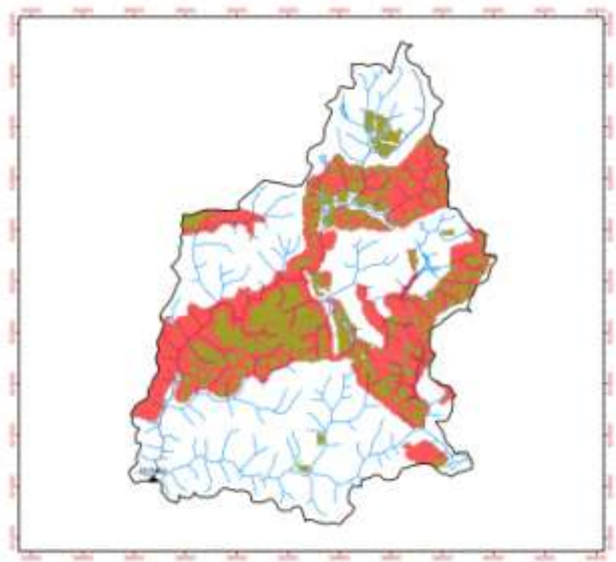
Latitude:	-34.2060
Longitude:	115.7706
Area of catchment (ha):	15,680
Average Annual Rainfall (mm):	1150
Discharge category:	4
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2008
Year of Last Harvest:	2007
Dieback Present (% catchment)	26



Disturbance areas for the previous 1 year.



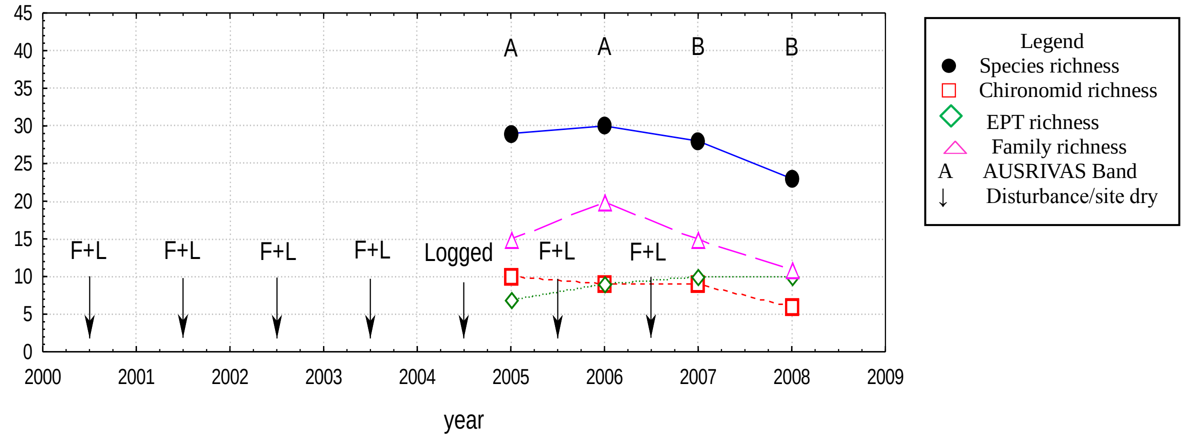
Disturbance areas for the previous 5 years

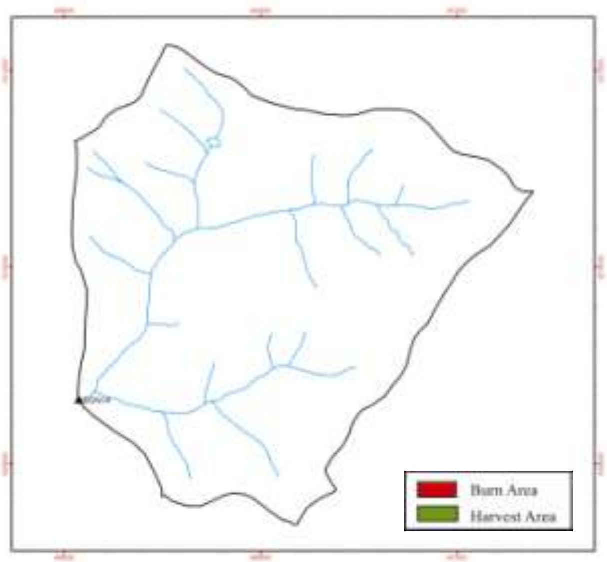


Disturbance areas for the previous 10 years.

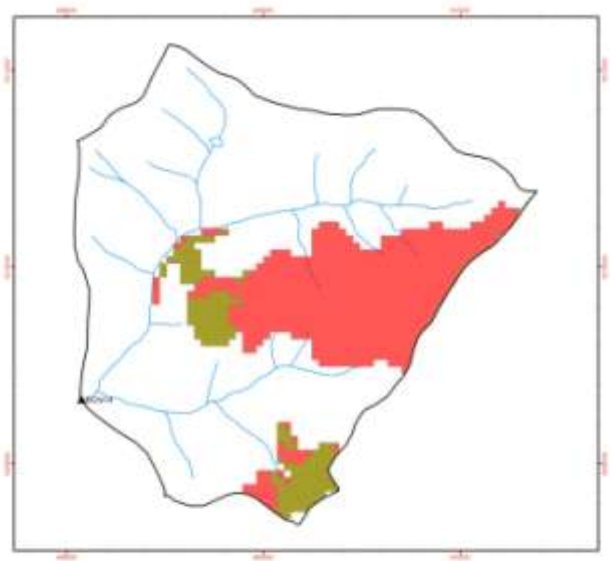
DON14 RECORD BROOK

Latitude:	-34.2590
Longitude:	115.9808
Area of catchment (ha):	1,400
Average Annual Rainfall (mm):	1225
Discharge category:	3
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2007
Year of Last Harvest:	2006
Dieback Present (% catchment)	17

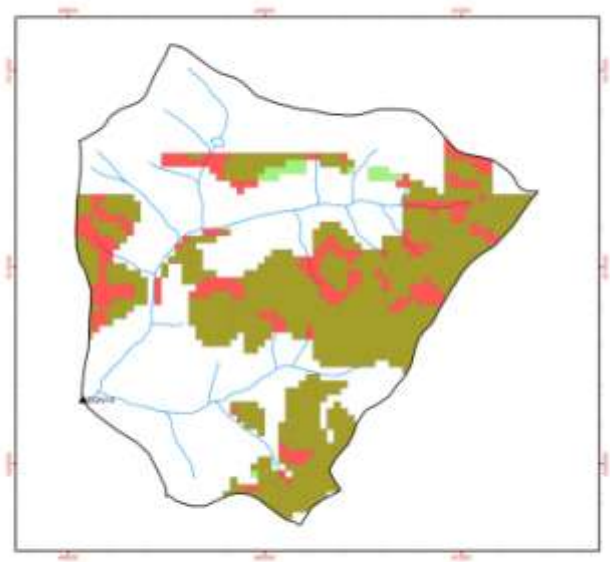




Disturbance areas for the previous 1 year.



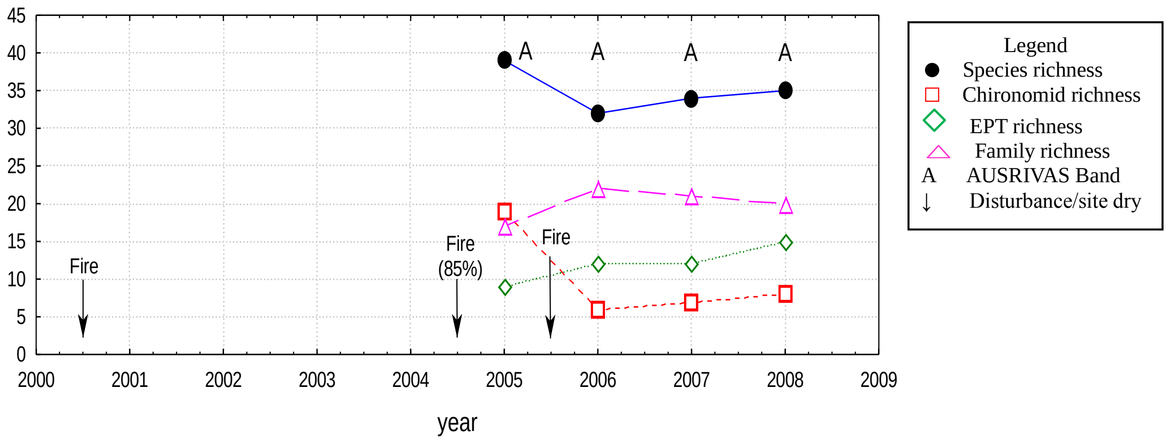
Disturbance areas for the previous 5 years

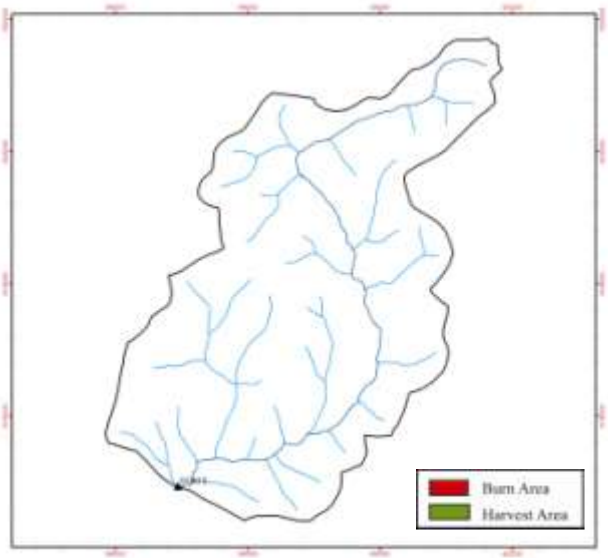


Disturbance areas for the previous 10 years.

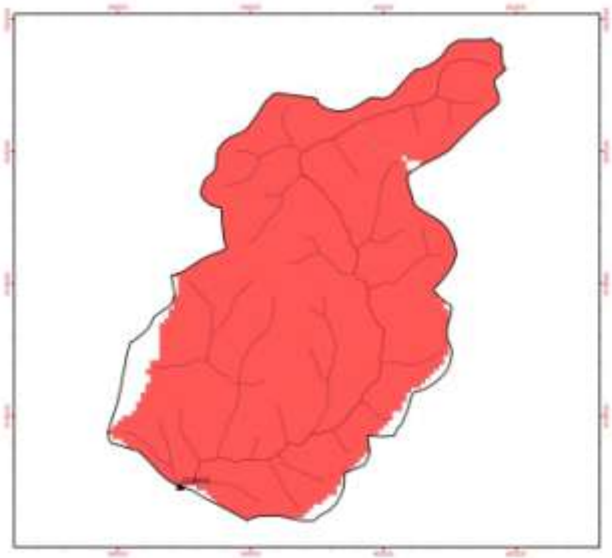
DON15 STIRLING TRACK

Latitude:	-34.3821
Longitude:	115.879
Area of catchment (ha):	2,420
Average Annual Rainfall (mm):	1400
Discharge category:	3
Forest type	Karri
Tenure at sampling point	National park
Year of Last Burn:	2006
Year of Last Harvest:	1999
Dieback Present (% catchment)	2

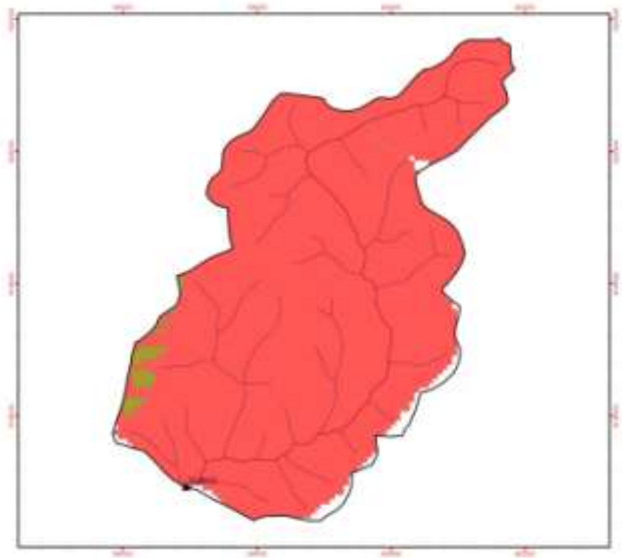




Disturbance areas for the previous 1 year.



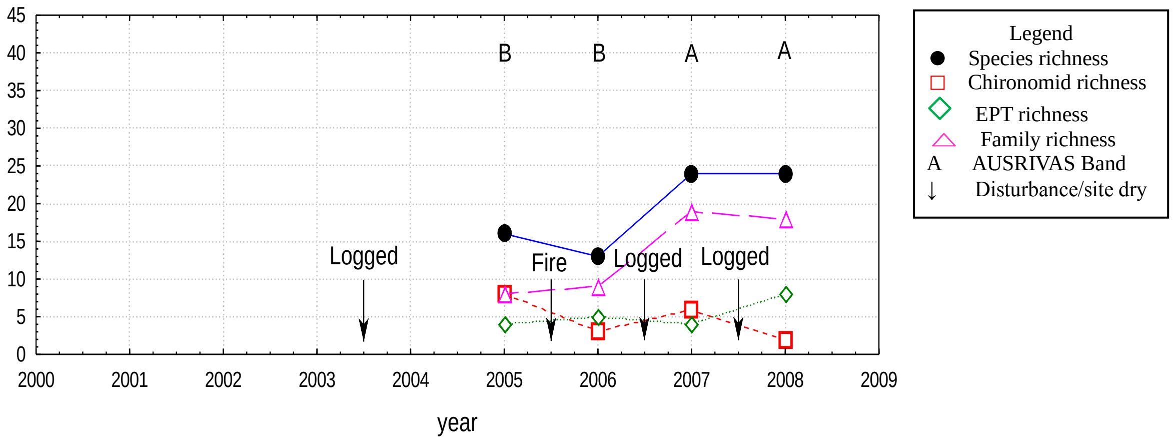
Disturbance areas for the previous 5 years

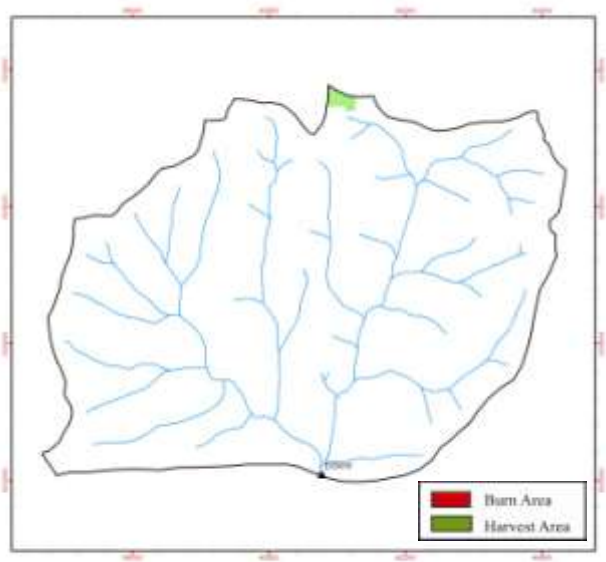


Disturbance areas for the previous 10 years.

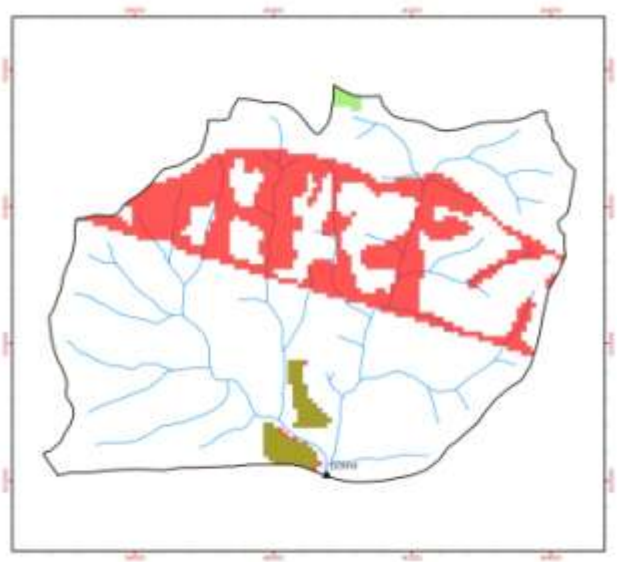
DON16 GOLD GULLY ROAD

Latitude:	-34.0471
Longitude:	115.925
Area of catchment (ha):	3,307
Average Annual Rainfall (mm):	1100
Discharge category:	3
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2006
Year of Last Harvest:	2007
Dieback Present (% catchment)	22

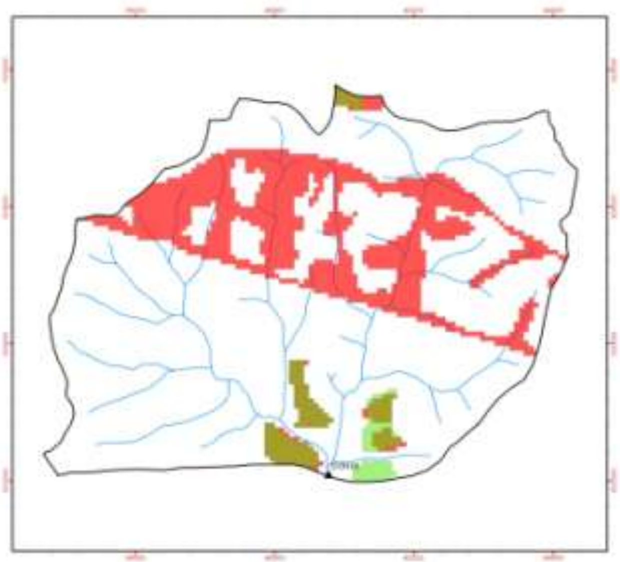




Disturbance areas for the previous 1 year.



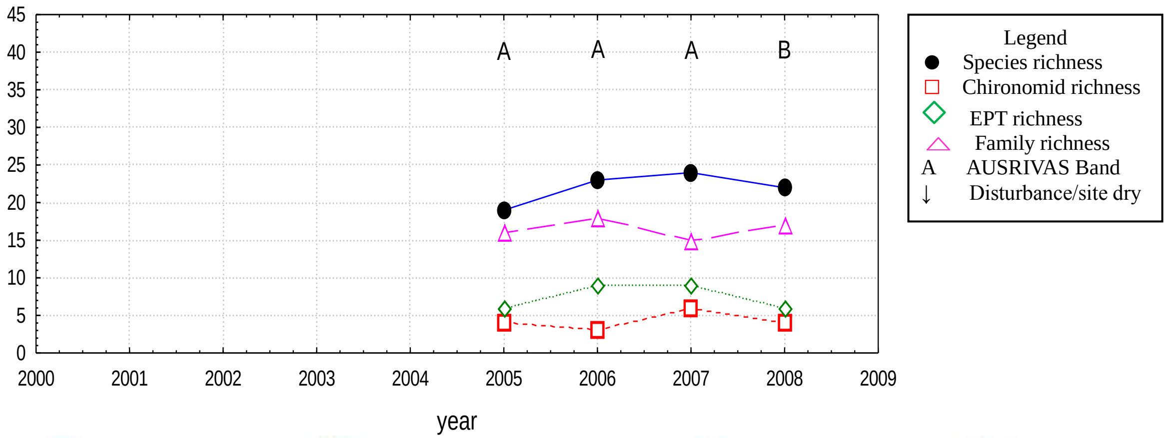
Disturbance areas for the previous 5 years

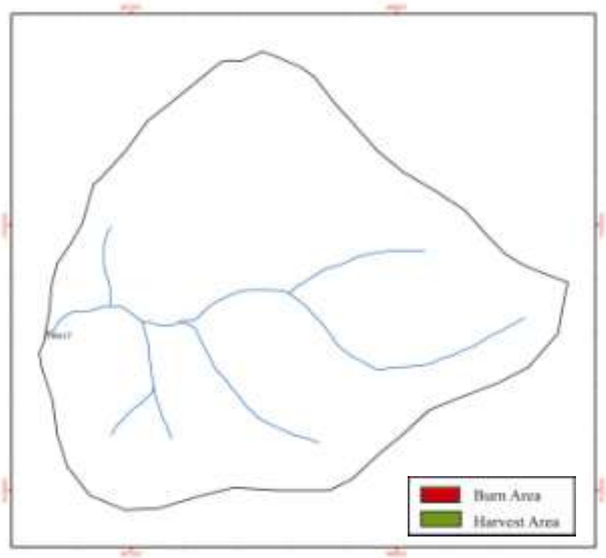


Disturbance areas for the previous 10 years.

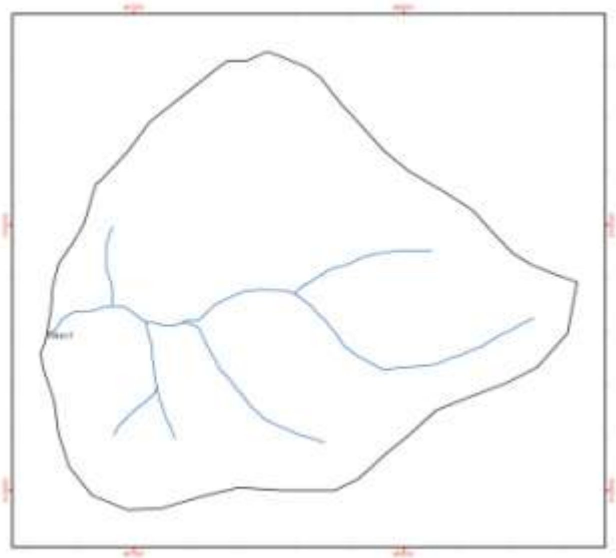
FRA17 BOXHALL CREEK

Latitude:	-34.975
Longitude:	116.854
Area of catchment (ha):	220
Average Annual Rainfall (mm):	1250
Discharge category:	2
Forest type	Karri
Tenure at sampling point	National park
Year of Last Burn:	2000
Year of Last Harvest:	NR
Dieback Present (% catchment)	0

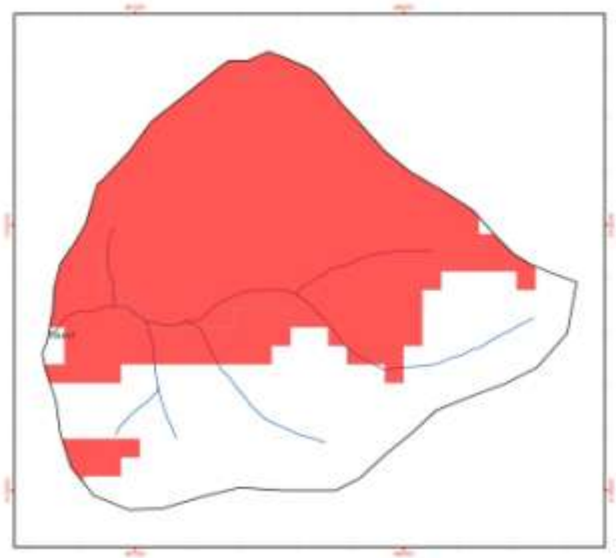




Disturbance areas for the previous 1 year.



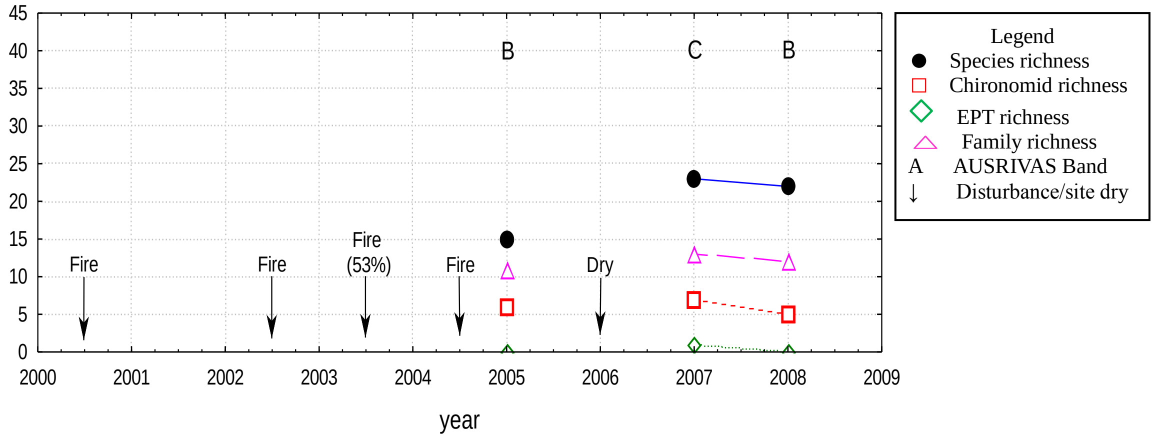
Disturbance areas for the previous 5 years

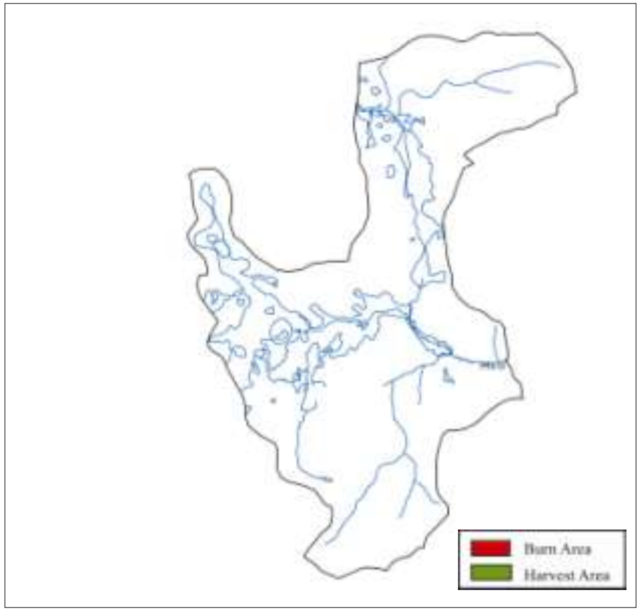


Disturbance areas for the previous 10 years.

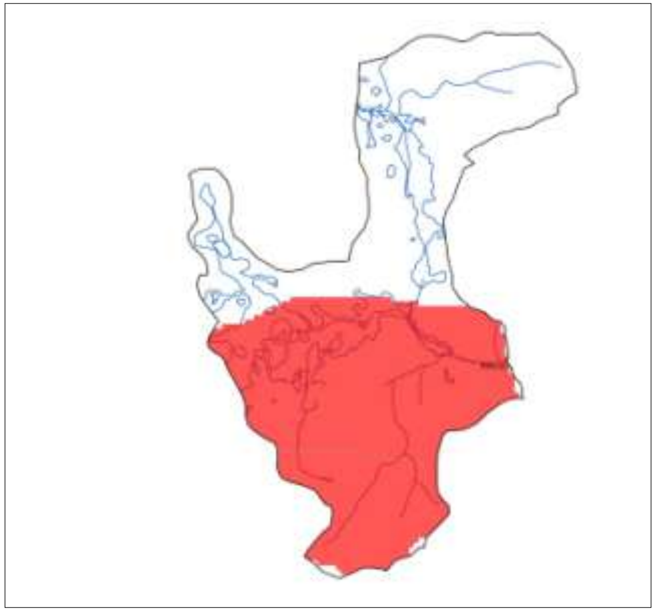
FRA18 CHITELUP RD NTH

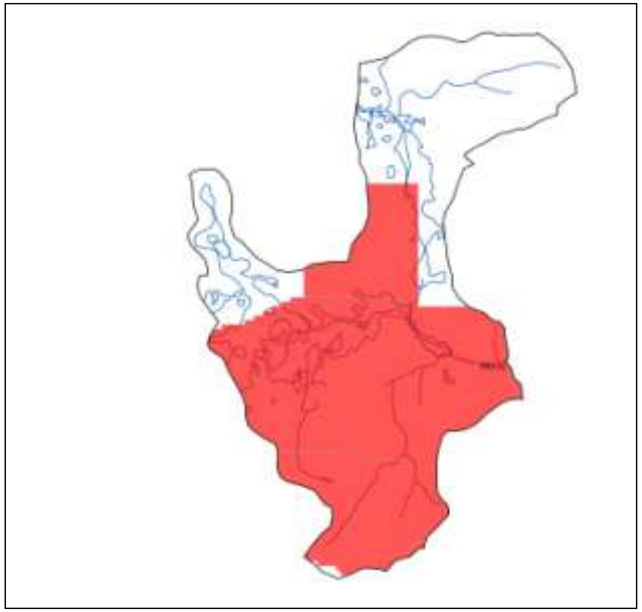
Latitude:	-34.5112
Longitude:	116.8400
Area of catchment (ha):	2347
Average Annual Rainfall (mm):	800
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2005
Year of Last Harvest:	1995
Dieback Present (% catchment)	0





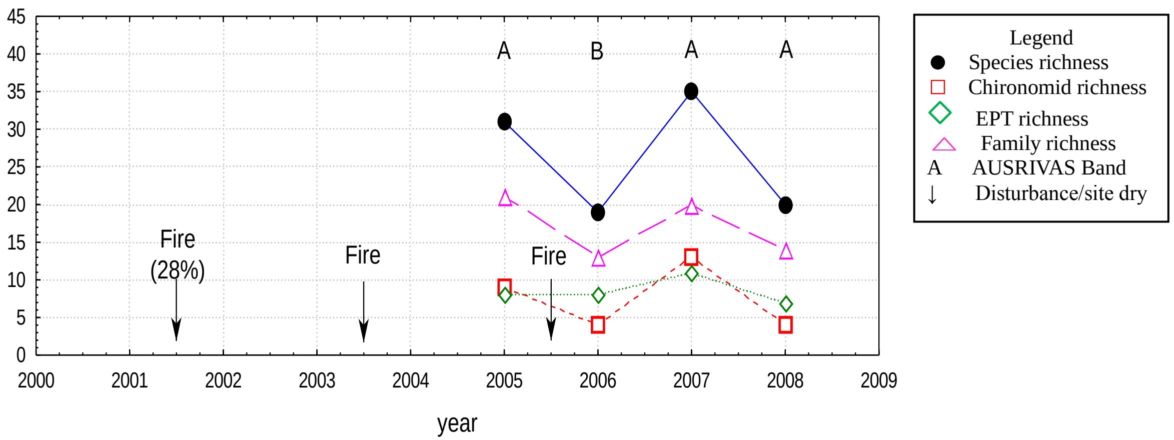
Disturbance areas for the previous 1 year.


Disturbance areas for the previous 5 years

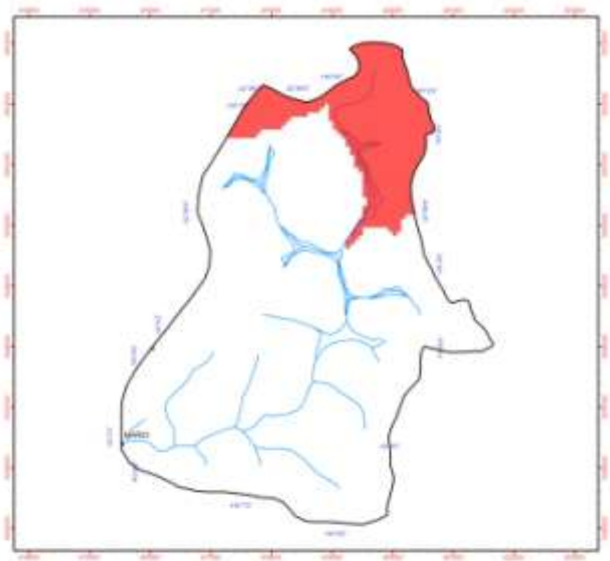

Disturbance areas for the previous 10 years.

HAR01   NEAR HOFFMAN'S MILL

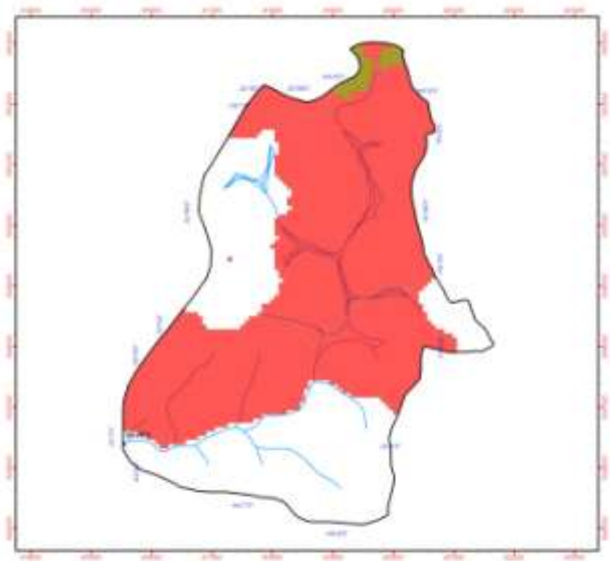
Latitude:	-33.0174
Longitude:	116.0956
Area of catchment (ha):	2,802
Average Annual Rainfall (mm):	1200
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2006
Year of Last Harvest:	1998
Dieback Present (% catchment)	45



Disturbance areas for the previous 1 year.



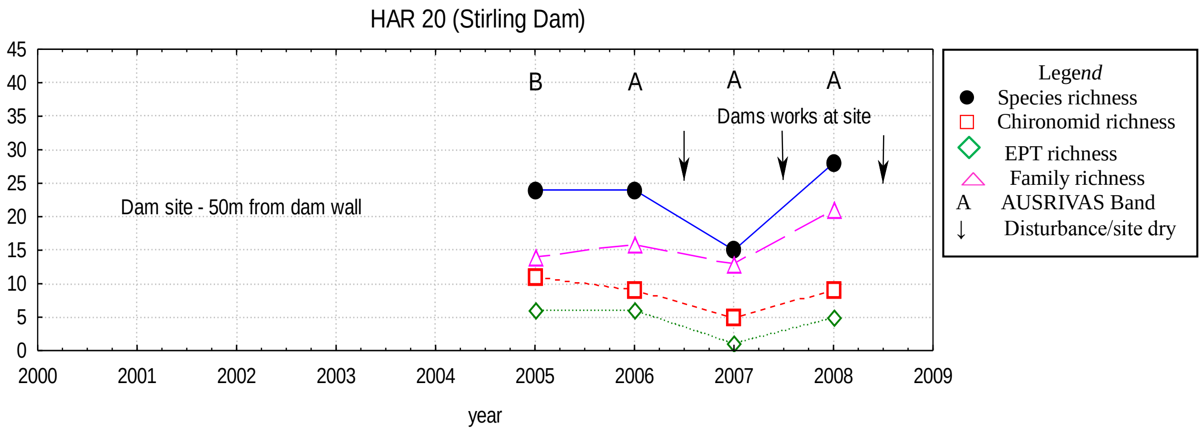
Disturbance areas for the previous 5 years



Disturbance areas for the previous 10 years.

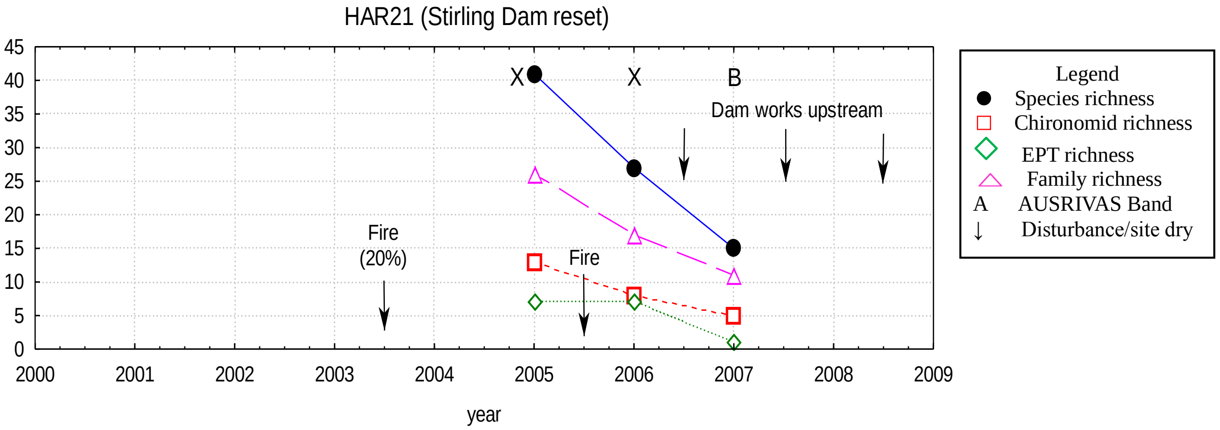
HAR20 STIRLING DAM 1

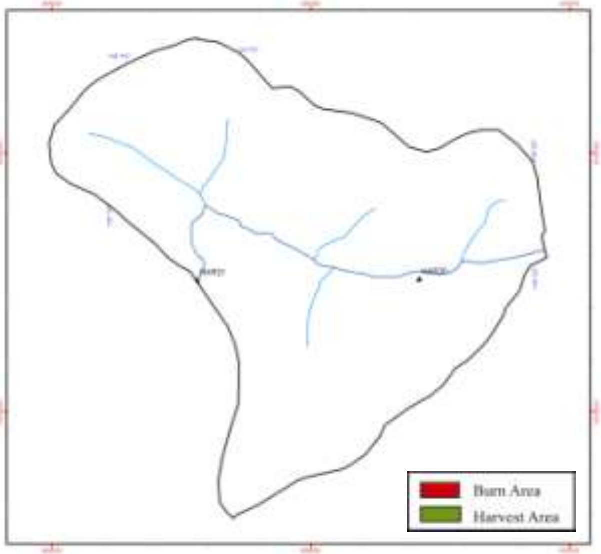
Latitude:	-33.1242
Longitude:	116.0290
Area of catchment (ha):	Dam
Average Annual Rainfall (mm):	1200
Discharge category:	4
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	
Year of Last Harvest:	
Dieback Present (% catchment)	0



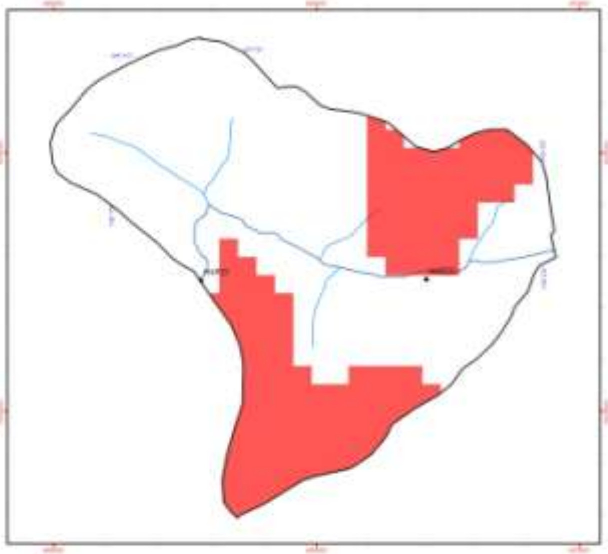
HAR21 STIRLING DAM 2

Latitude:	-33.1242
Longitude:	116.0198
Area of catchment (ha):	185
Average Annual Rainfall (mm):	1200
Discharge category:	4
Forest type	Jarrah
Tenure at sampling point	Other land (adj Crown reserve; 450m from State forest)
Year of Last Burn:	2007
Year of Last Harvest:	1960's
Dieback Present (% catchment)	0

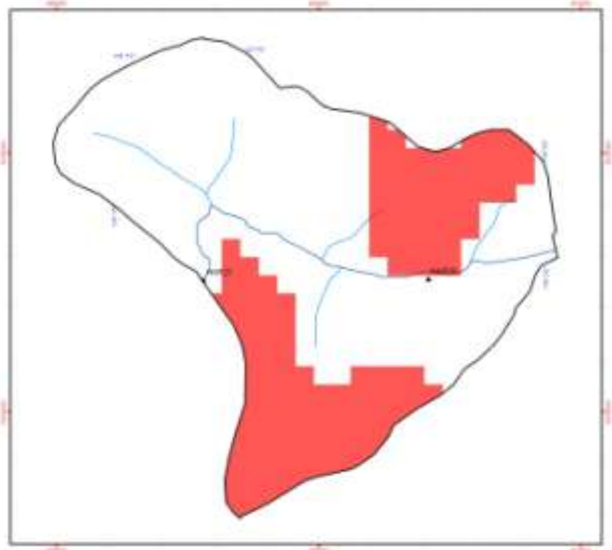




Disturbance areas for the previous 1 year.



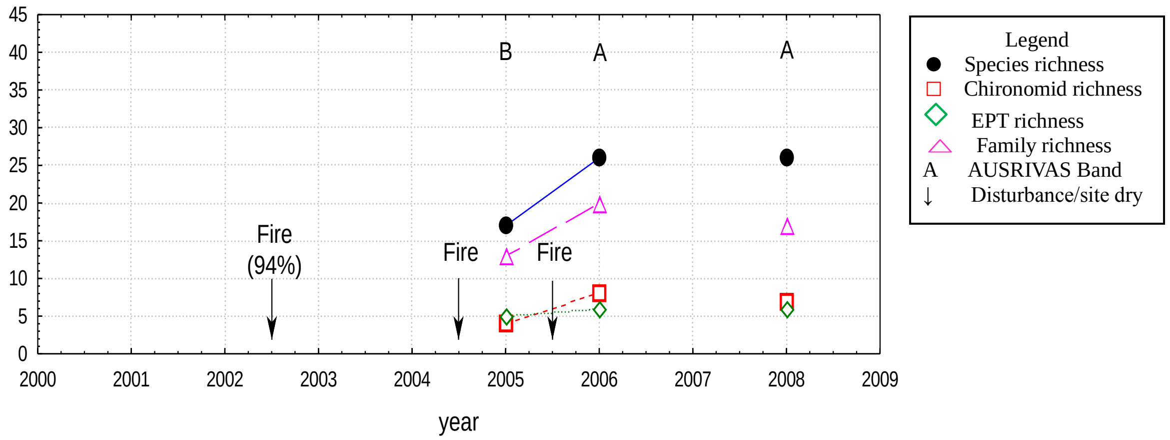
Disturbance areas for the previous 5 years



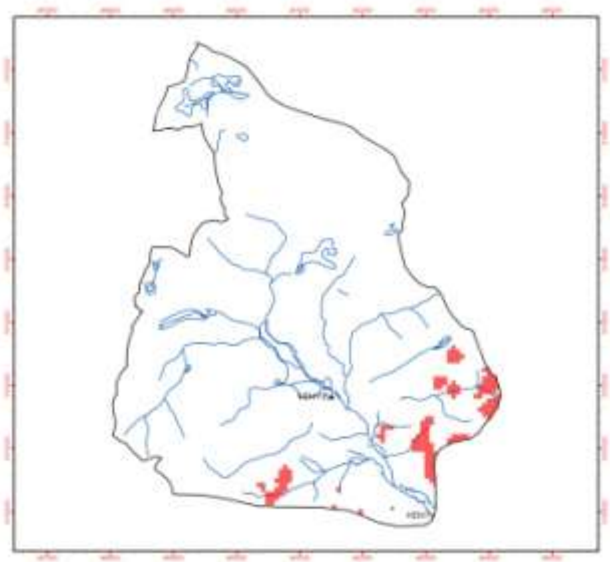
Disturbance areas for the previous 10 years.

KEN11 NILE CREEK

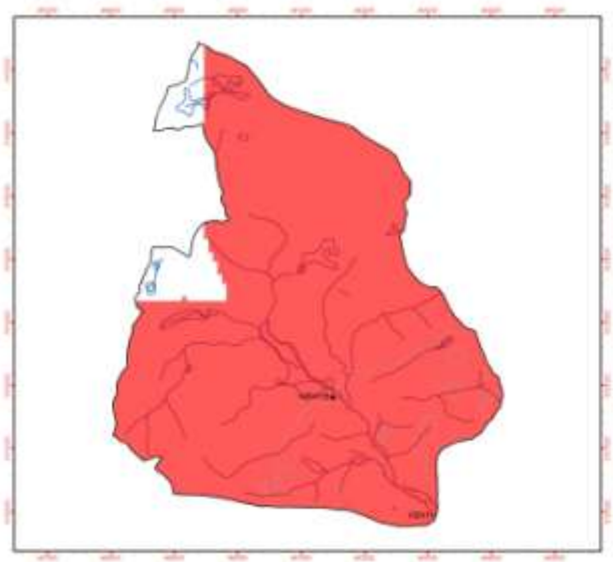
Latitude:	-34.7751
Longitude:	116.9077
Area of catchment (ha):	2,867
Average Annual Rainfall (mm):	1125
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2006
Year of Last Harvest:	1970's
Dieback Present (% catchment)	5



Disturbance areas for the previous 1 year.



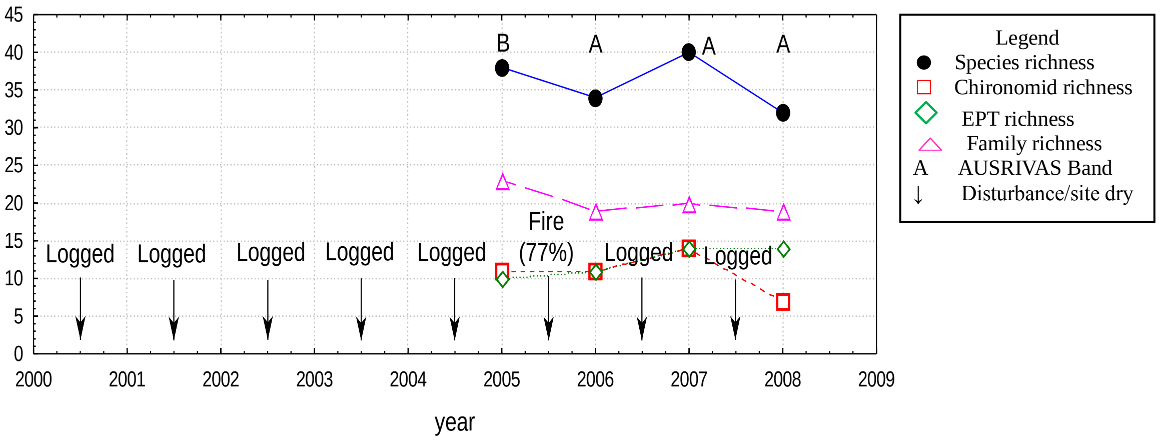
Disturbance areas for the previous 5 years



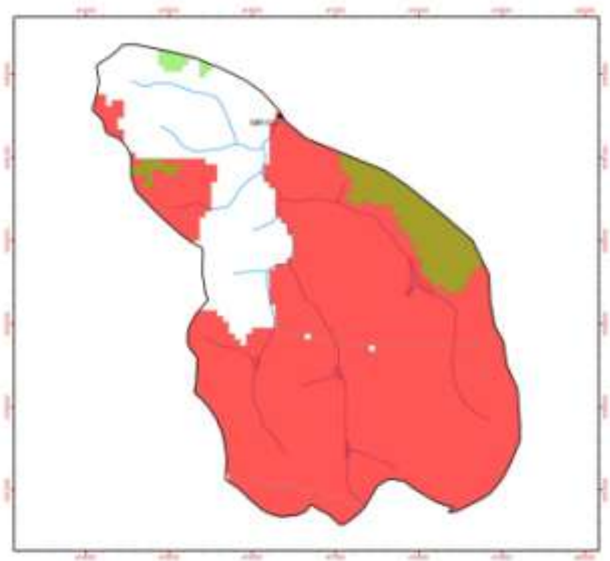
Disturbance areas for the previous 10 years.

MRY09 BIG BROOK

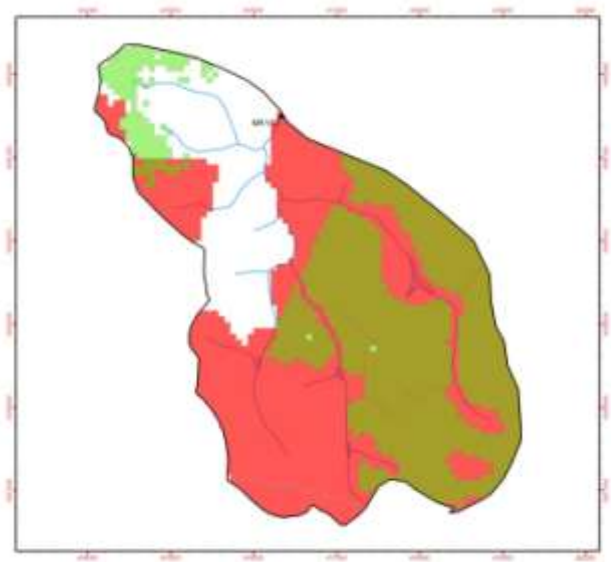
Latitude:	-32.88139
Longitude:	116.1056
Area of catchment (ha):	1,697
Average Annual Rainfall (mm):	1200
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	Conservation park
Year of Last Burn:	2006
Year of Last Harvest:	2007
Dieback Present (% catchment)	55



Disturbance areas for the previous 1 year.



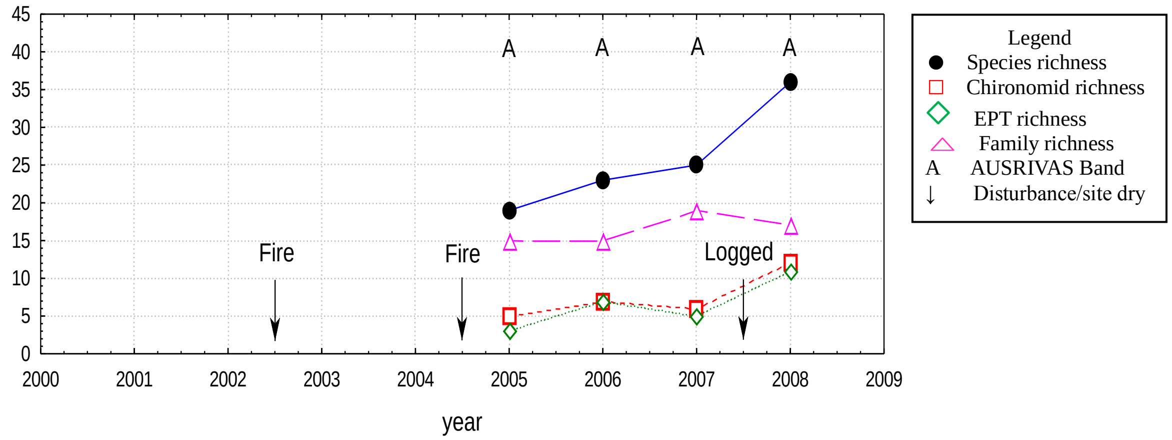
Disturbance areas for the previous 5 years

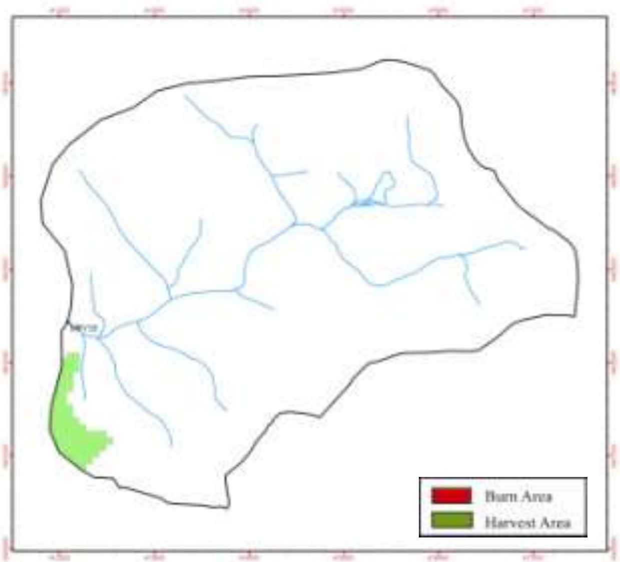


Disturbance areas for the previous 10 years.

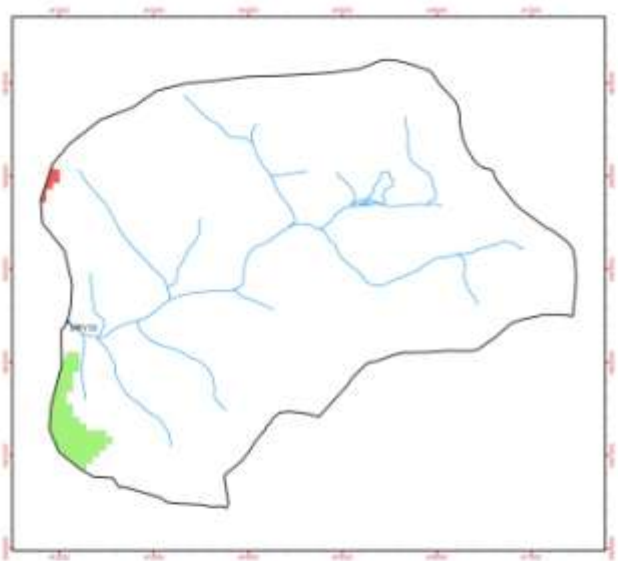
MRY33 FINLAY BROOK NORTH RD

Latitude:	-32.5118
Longitude:	116.0639
Area of catchment (ha):	1,756
Average Annual Rainfall (mm):	1300
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2006
Year of Last Harvest:	2007
Dieback Present (% catchment)	76

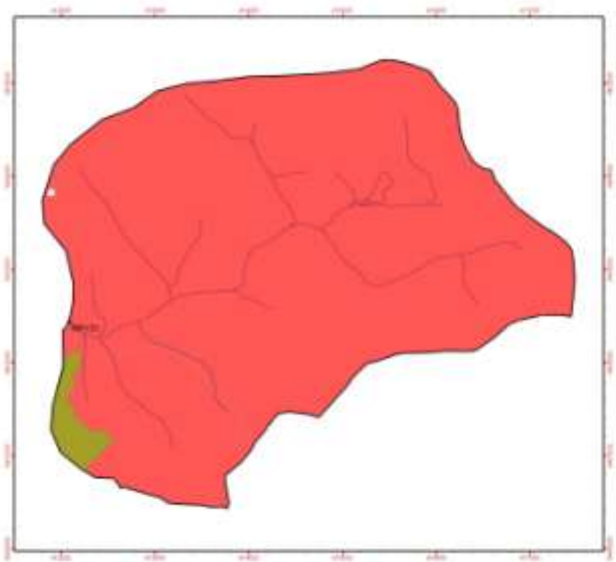




Disturbance areas for the previous 1 year.



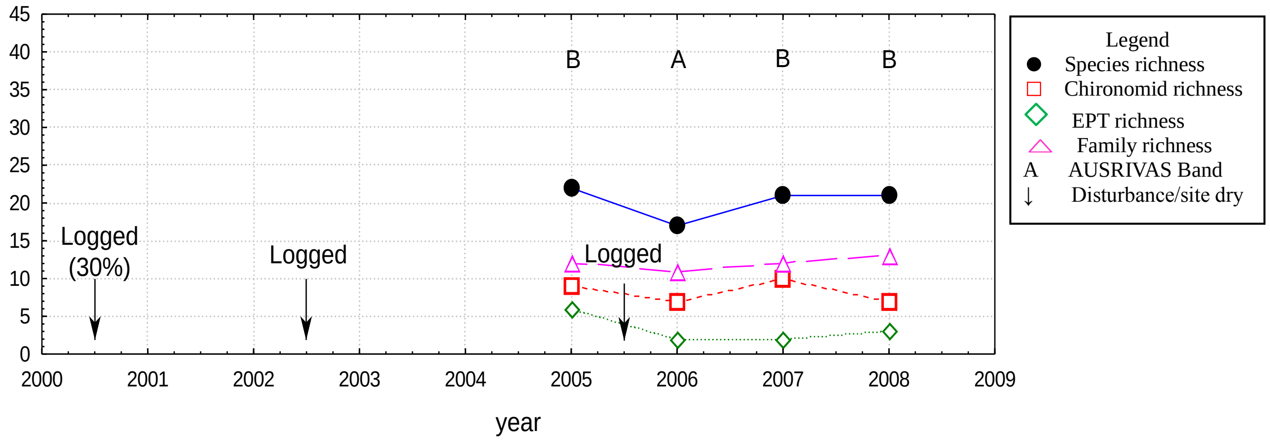
Disturbance areas for the previous 5 years



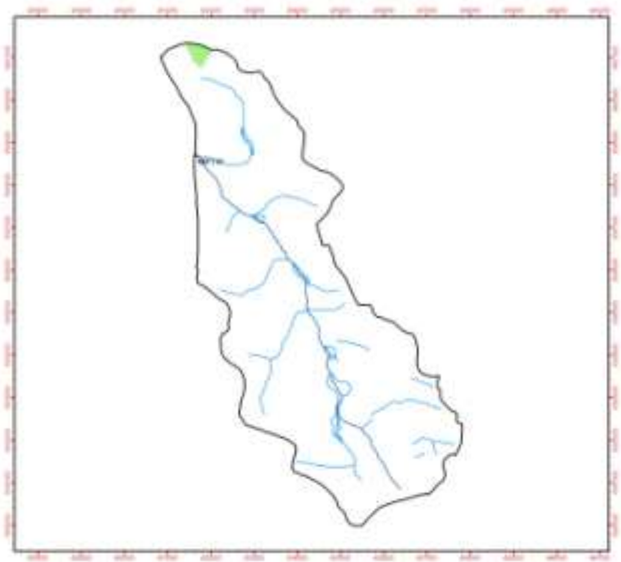
Disturbance areas for the previous 10 years.

MRY41 O'NEILL BROOK

Latitude:	-32.5467
Longitude:	116.2718
Area of catchment (ha):	3,510
Average Annual Rainfall (mm):	975
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2000
Year of Last Harvest:	2005
Dieback Present (% catchment)	13



Disturbance areas for the previous 1 year.

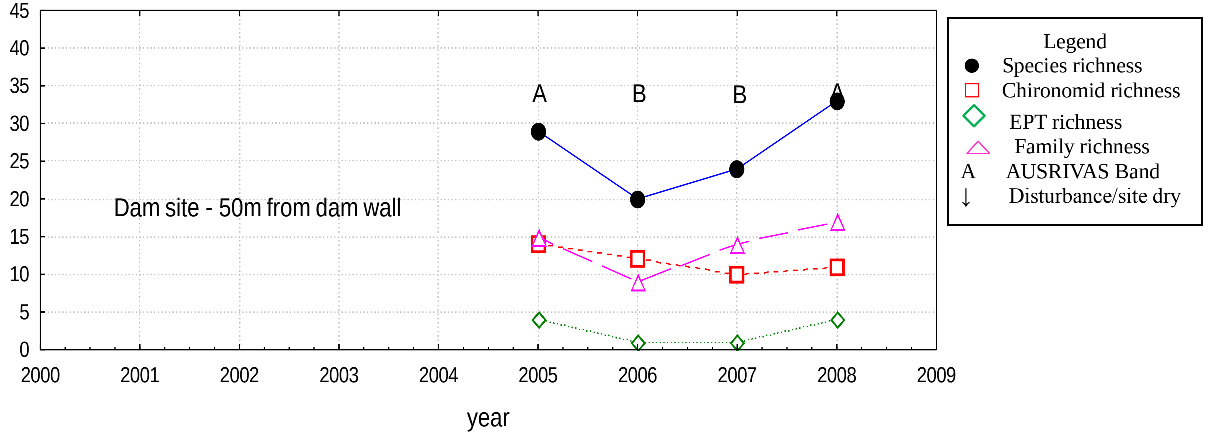


Disturbance areas for the previous 5 years

Disturbance areas for the previous 10 years.

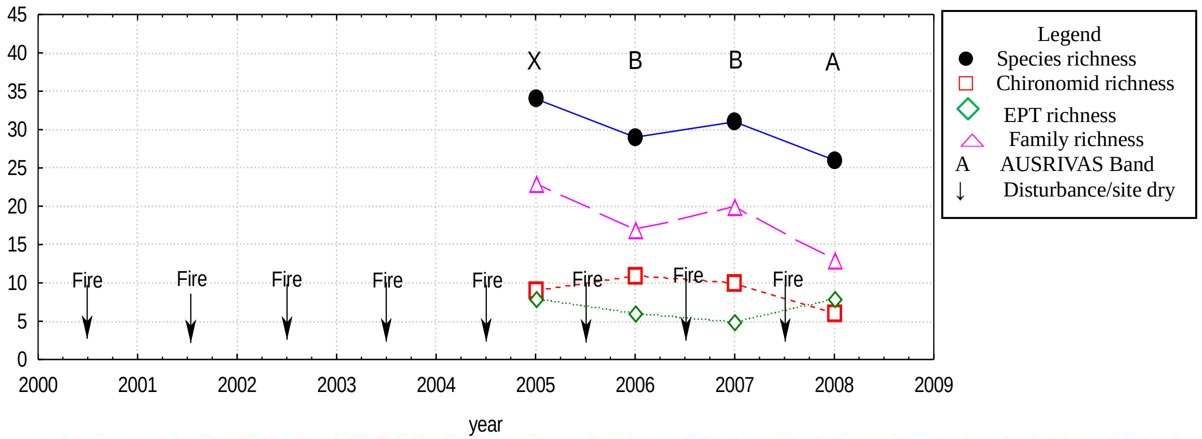
MRY42 SERPENTINE DAM 1

Latitude:	-32.3744
Longitude:	116.0570
Area of catchment (ha):	Dam
Average Annual Rainfall (mm):	1250
Discharge category:	5
Forest type	Jarrah
Tenure at sampling point	Other crown reserves/freehold
Year of Last Burn:	0
Year of Last Harvest:	
Dieback Present (% catchment)	0

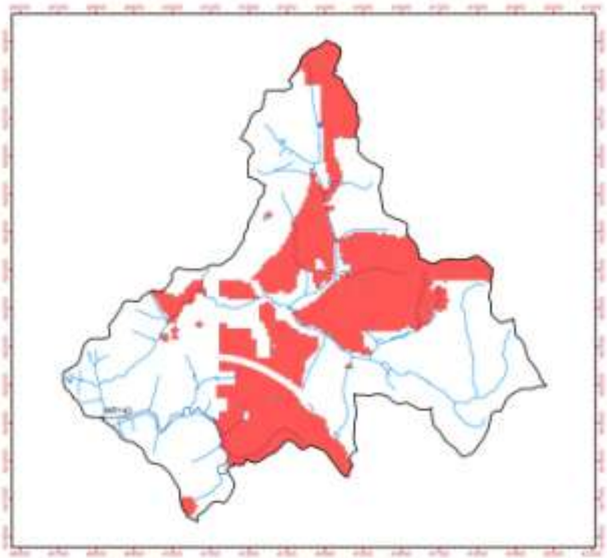


MRY43 SERPENTINE DAM 2

Latitude:	-32.3611
Longitude:	116.0237
Area of catchment (ha):	6,784
Average Annual Rainfall (mm):	1100
Discharge category:	4
Forest type	Jarrah
Tenure at sampling point	Other crown reserves
Year of Last Burn:	2008
Year of Last Harvest:	1990's
Dieback Present (% catchment)	40



Disturbance areas for the previous 1 year.

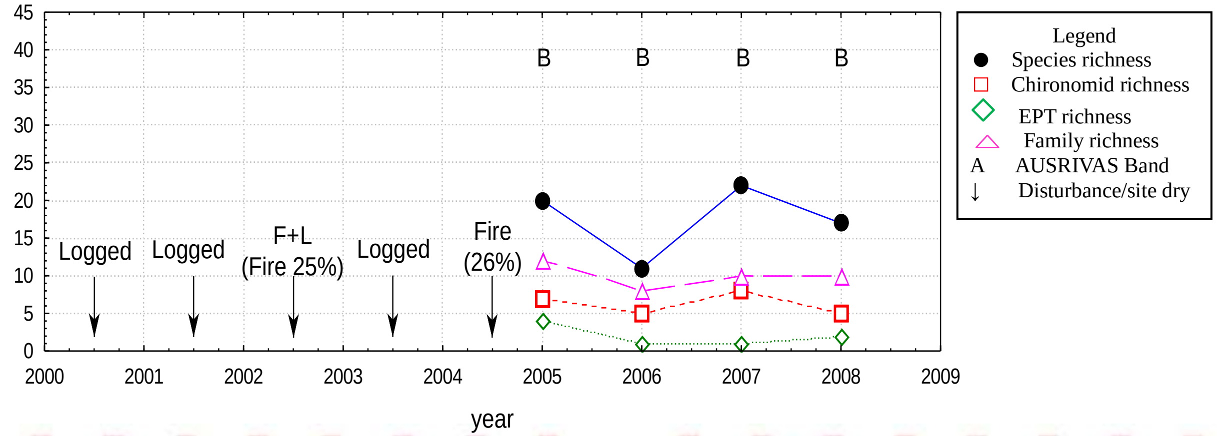


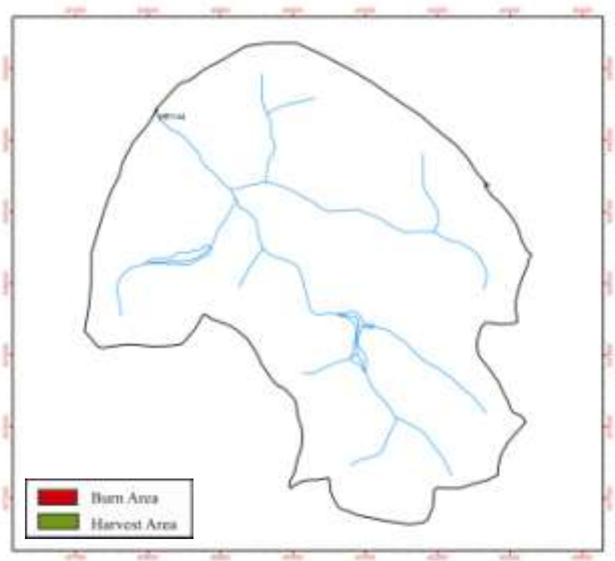
Disturbance areas for the previous 5 years

Disturbance areas for the previous 10 years.

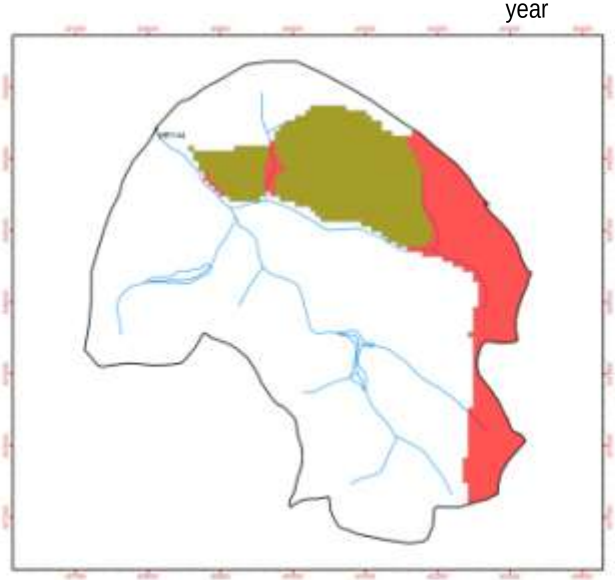
MRY44 SCENIC RD

Latitude:	-32.6935
Longitude:	116.233
Area of catchment (ha):	2,574
Average Annual Rainfall (mm):	1000
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2005
Year of Last Harvest:	2003
Dieback Present (% catchment)	4

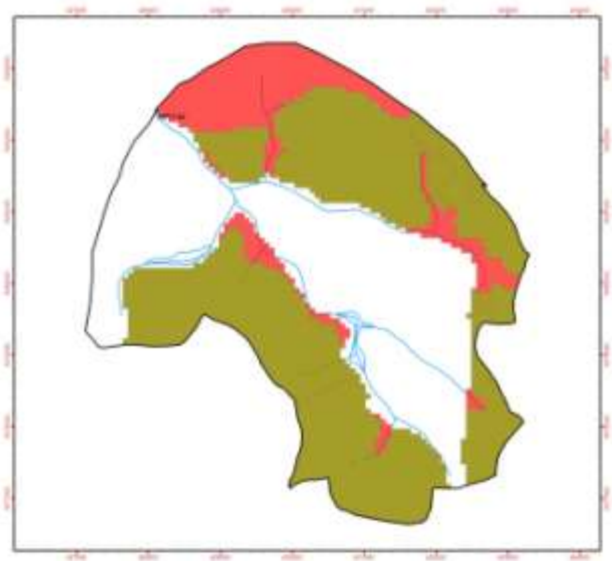




Disturbance areas for the previous 1 year.



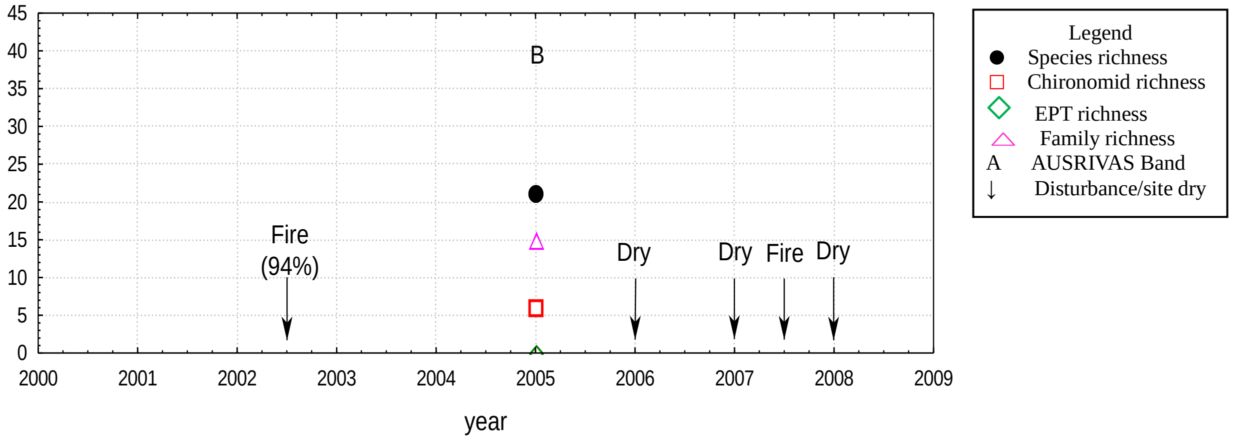
Disturbance areas for the previous 5 years

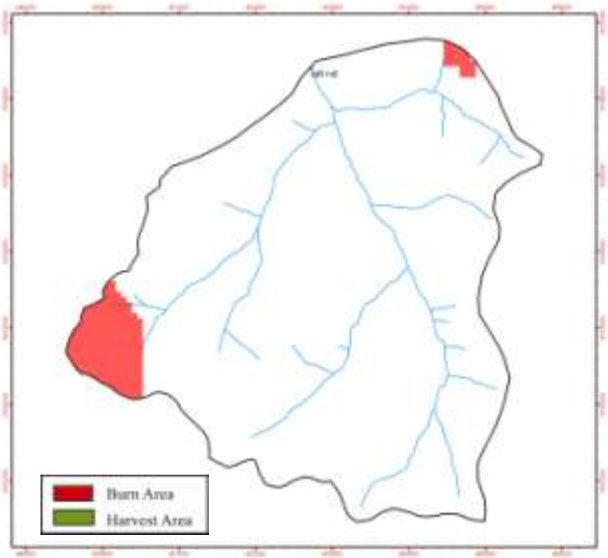


Disturbance areas for the previous 10 years.

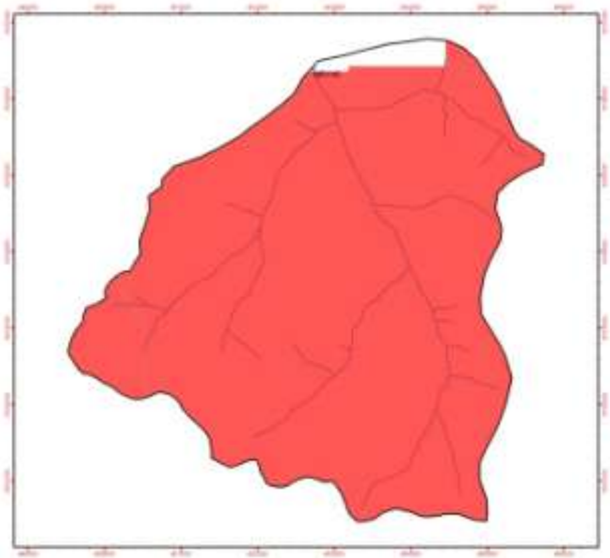
MRY45 OLD STOCKYARD BK

Latitude:	-33.1099
Longitude:	116.4929
Area of catchment (ha):	2,465
Average Annual Rainfall (mm):	700
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	National park
Year of Last Burn:	2008
Year of Last Harvest:	1990's
Dieback Present (% catchment)	0

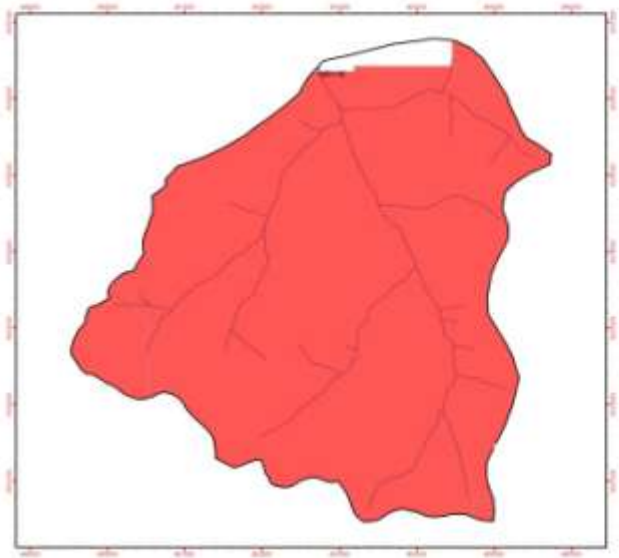




Disturbance areas for the previous 1 year.



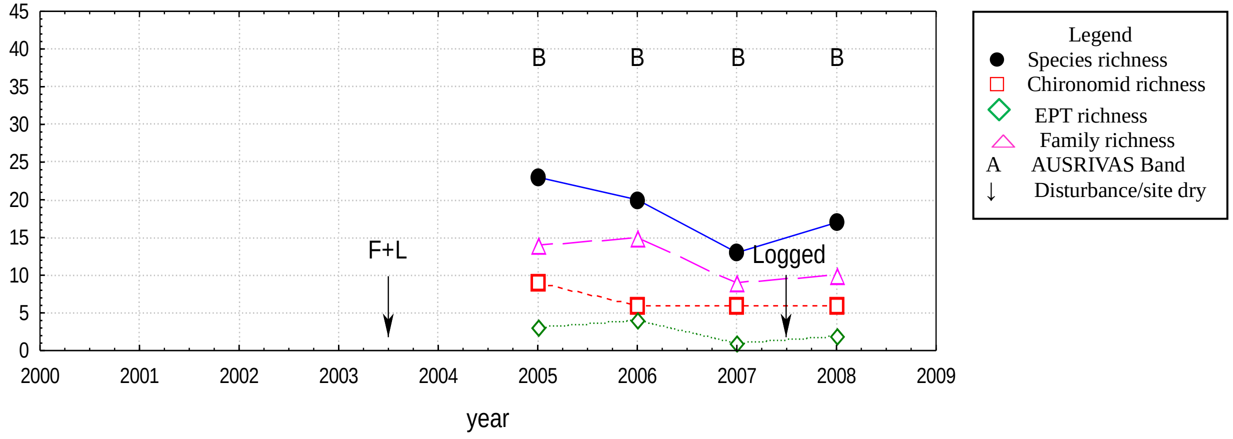
Disturbance areas for the previous 5 years

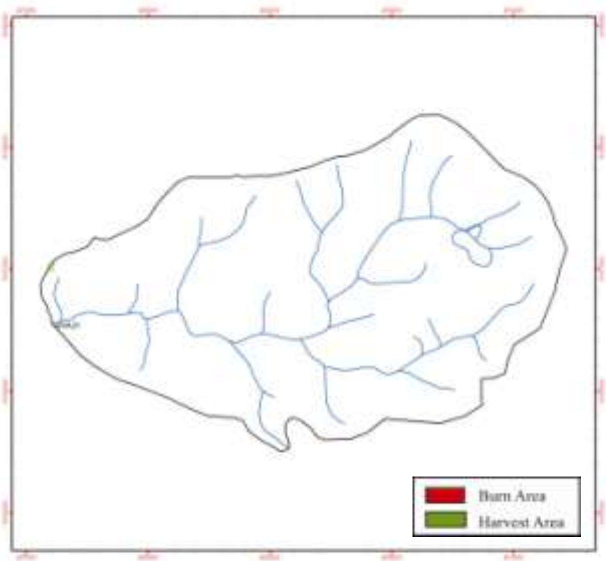


Disturbance areas for the previous 10 years.

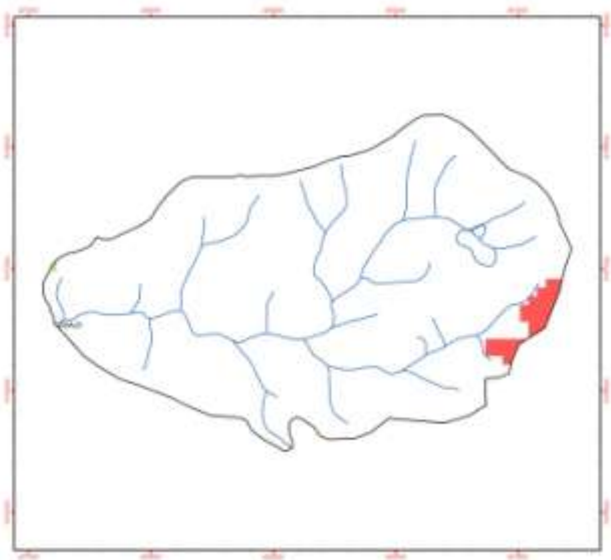
SHA21 UNA BROOK

Latitude:	-34.7306
Longitude:	116.2050
Area of catchment (ha):	768
Average Annual Rainfall (mm):	1400
Discharge category:	3
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2004
Year of Last Harvest:	2007 (<1%)
Dieback Present (% catchment)	0

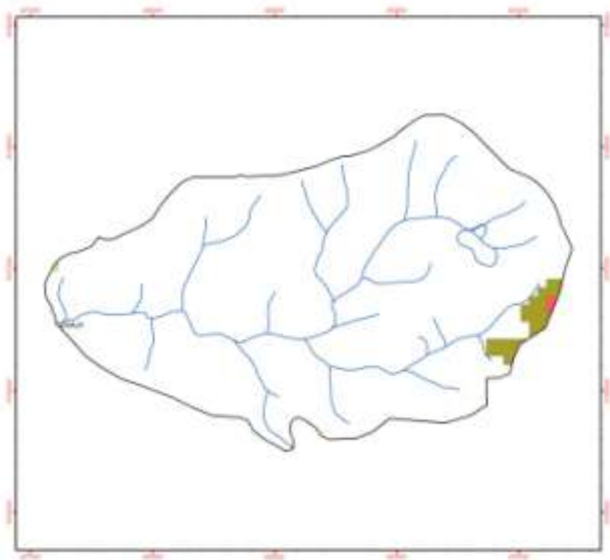




Disturbance areas for the previous 1 year.



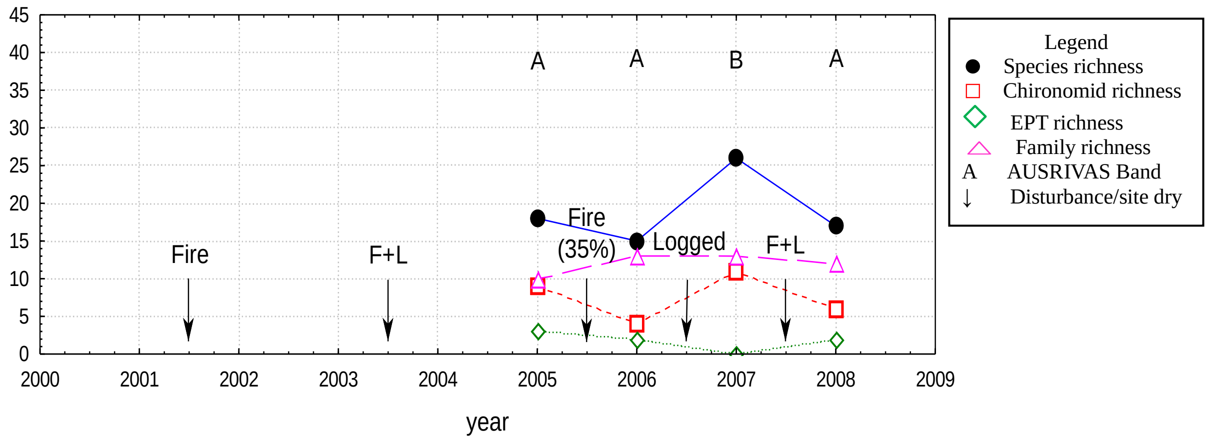
Disturbance areas for the previous 5 years

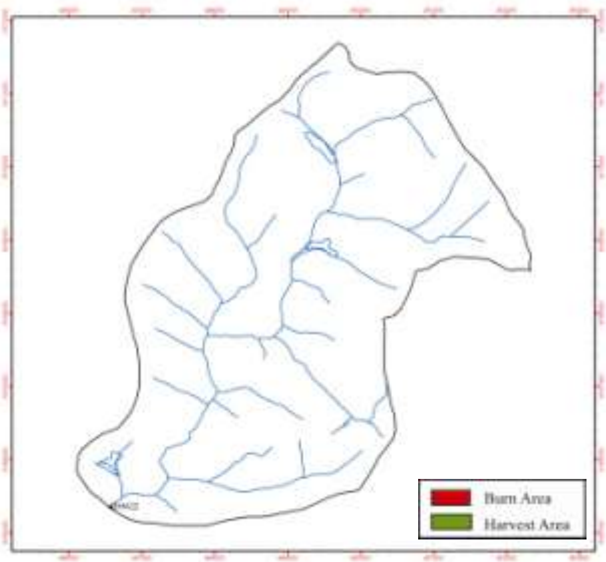


Disturbance areas for the previous 10 years.

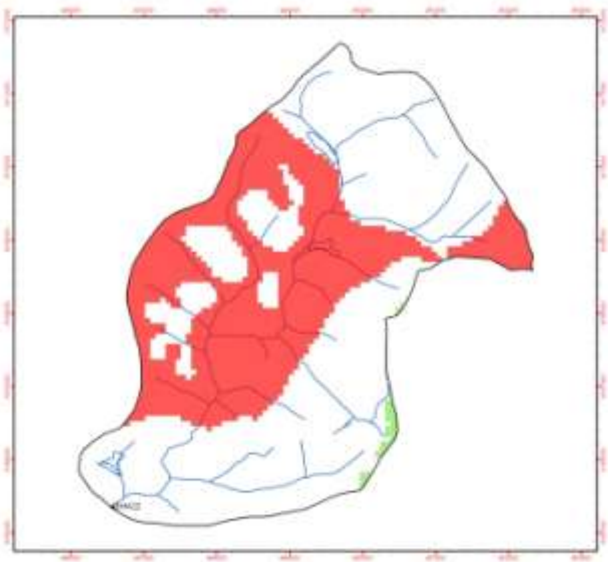
SHA22 FISH CREEK

Latitude:	-34.6522
Longitude:	116.4170
Area of catchment (ha):	2,242
Average Annual Rainfall (mm):	1275
Discharge category:	3
Forest type	Karri
Tenure at sampling point	National park
Year of Last Burn:	2008
Year of Last Harvest:	2007
Dieback Present (% catchment)	11

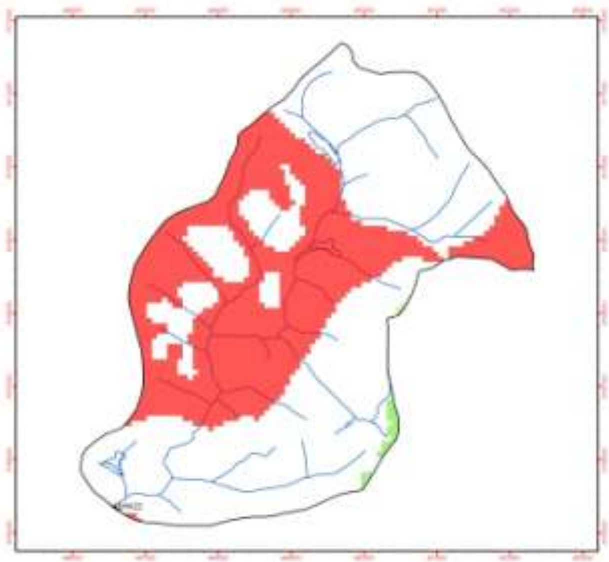




Disturbance areas for the previous 1 year.



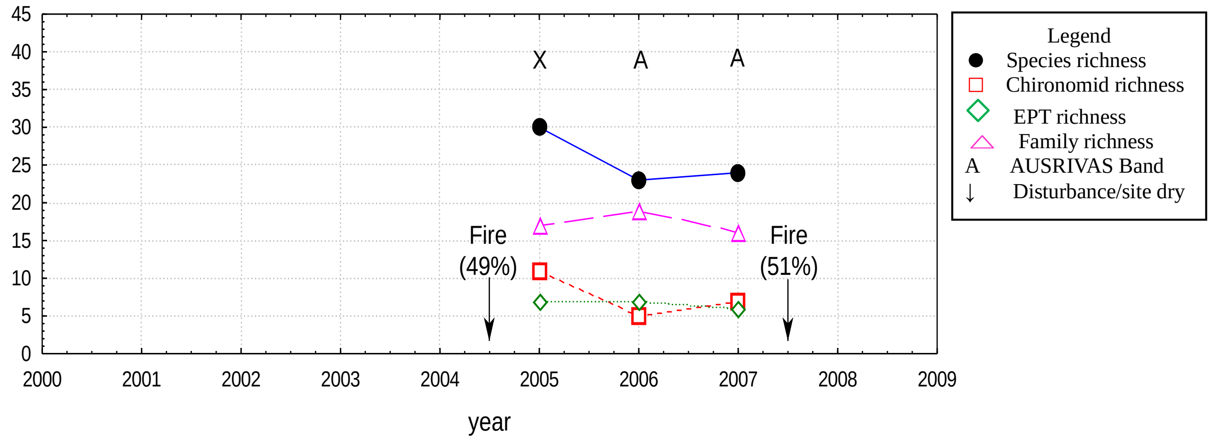
Disturbance areas for the previous 5 years

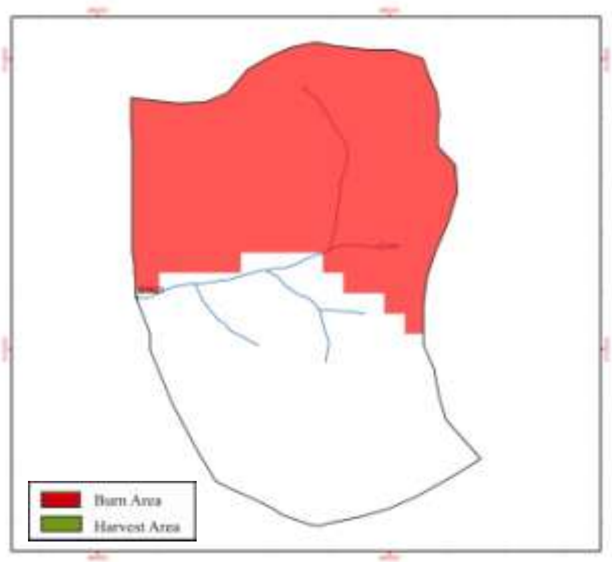


Disturbance areas for the previous 10 years.

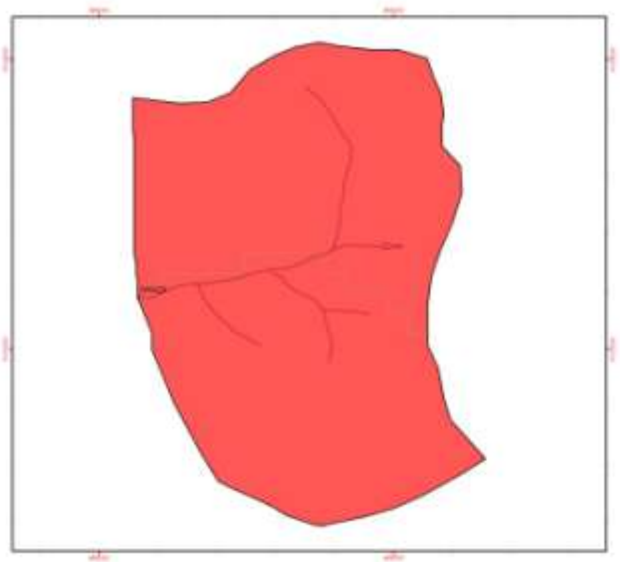
SHA23 COMPASS ROAD

Latitude:	-34.9433
Longitude:	116.651
Area of catchment (ha):	150
Average Annual Rainfall (mm):	1400
Discharge category:	2
Forest type	Karri
Tenure at sampling point	National park
Year of Last Burn:	2008
Year of Last Harvest:	1970's
Dieback Present (% catchment)	31

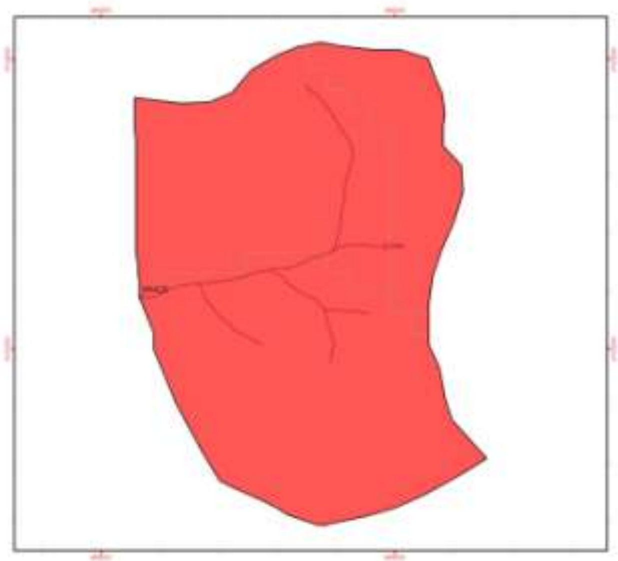




Disturbance areas for the previous 1 year.



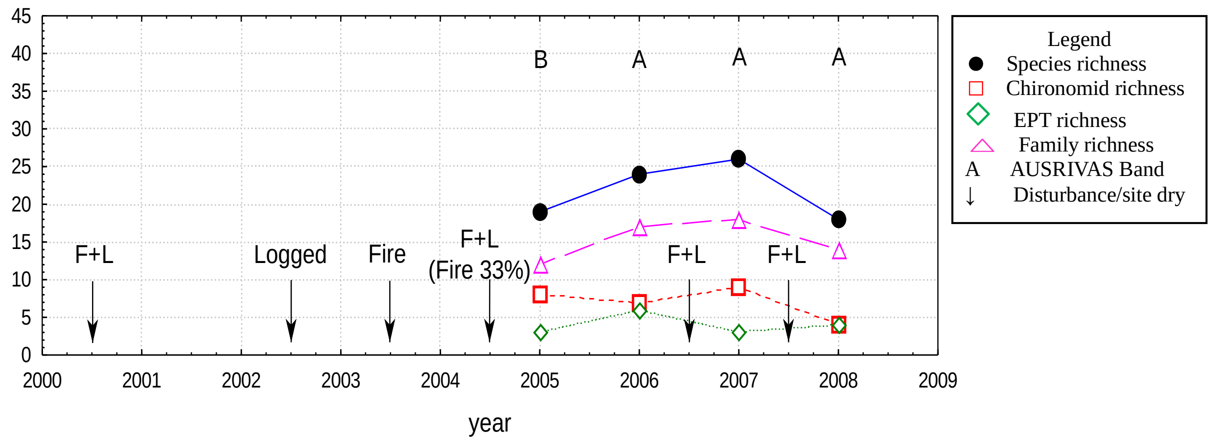
Disturbance areas for the previous 5 years

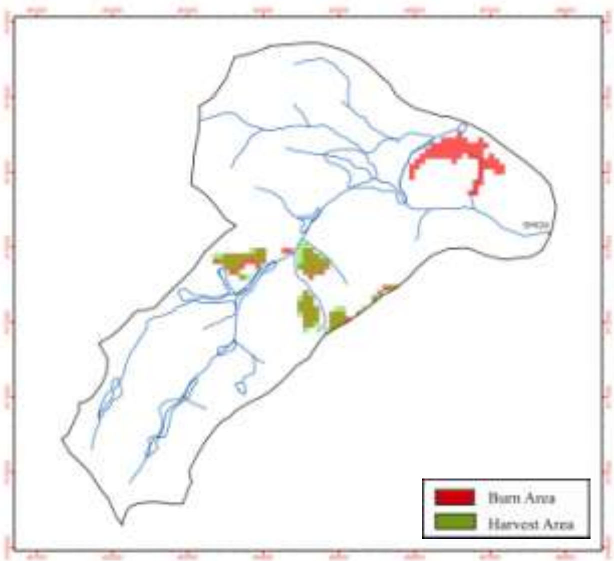


Disturbance areas for the previous 10 years.

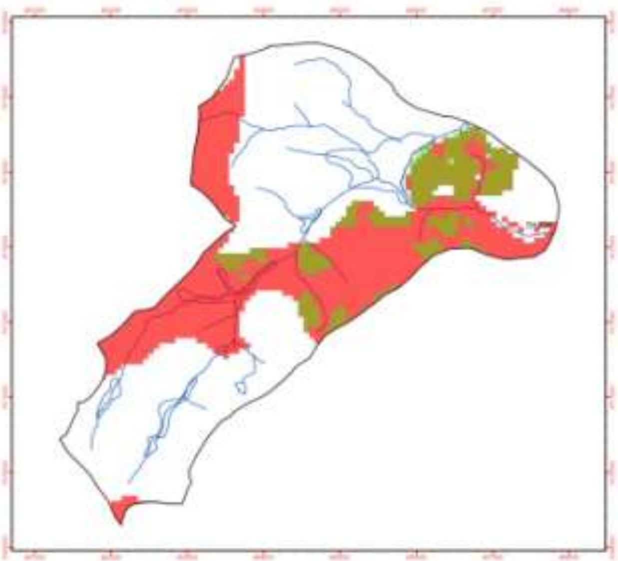
SHA24 ARTHUR RD

Latitude:	-34.5822
Longitude:	116.5400
Area of catchment (ha):	1,768
Average Annual Rainfall (mm):	1000
Discharge category:	3
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2007
Year of Last Harvest:	2007
Dieback Present (% catchment)	56

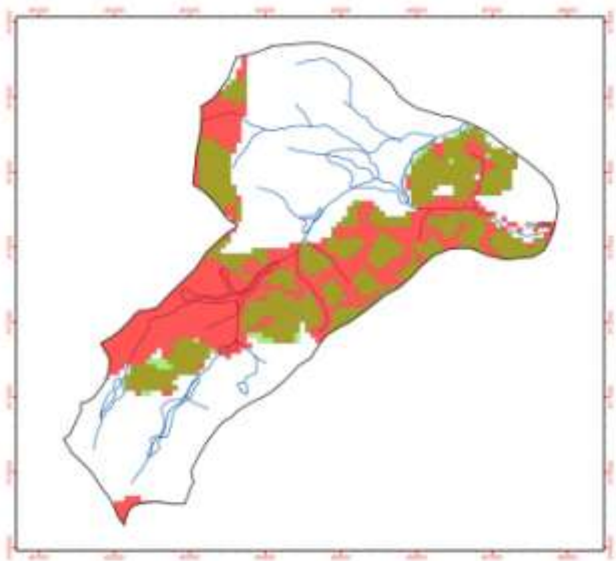




Disturbance areas for the previous 1 year.



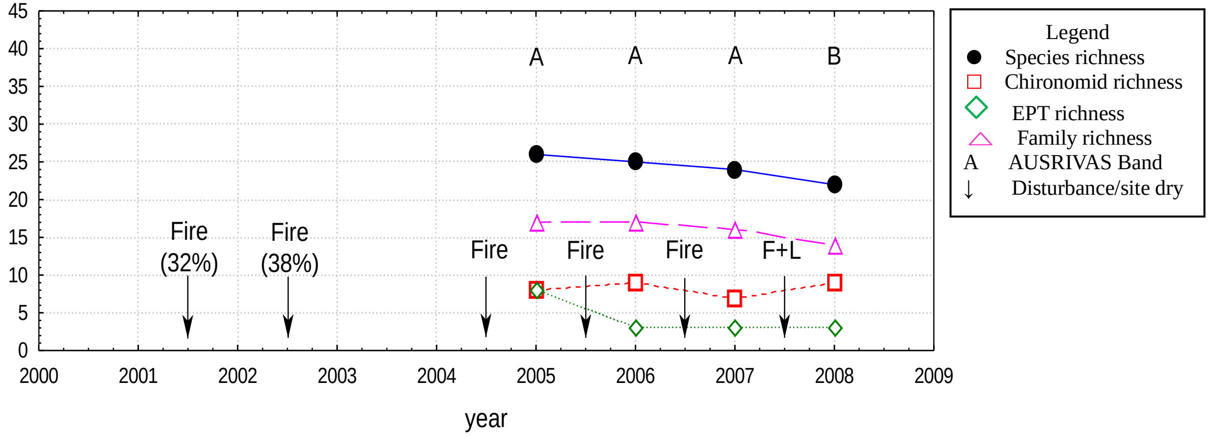
Disturbance areas for the previous 5 years

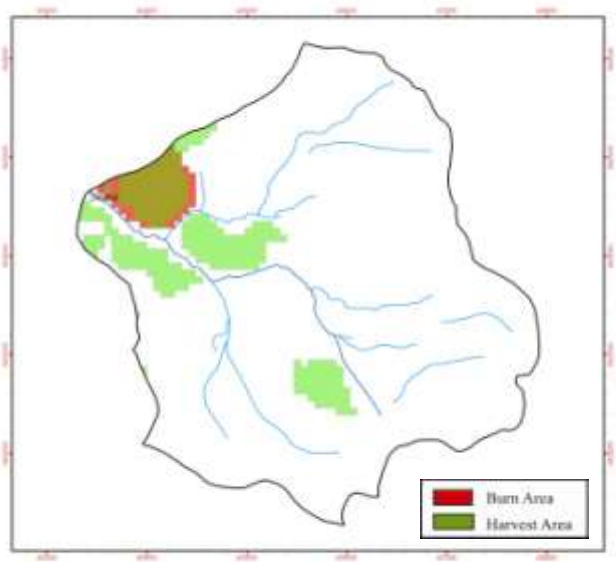


Disturbance areas for the previous 10 years.

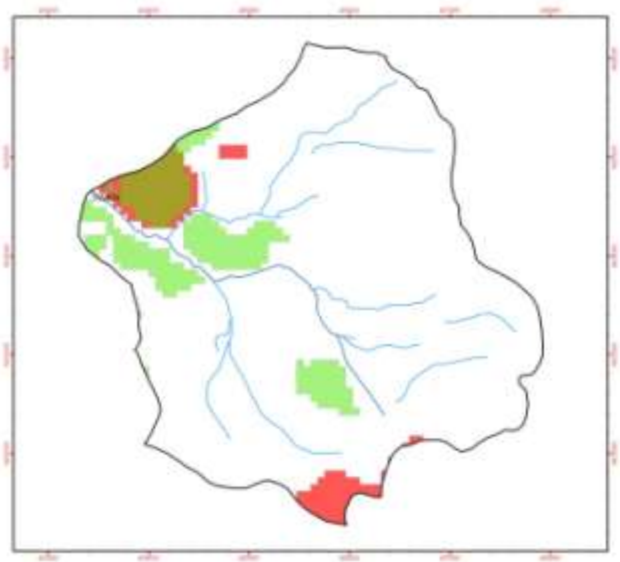
SWA04   WUNGONG BROOK

Latitude:	-32.3121
Longitude:	116.1864
Area of catchment (ha):	1,395
Average Annual Rainfall (mm):	1150
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	1007
Dieback Present (% catchment)	48

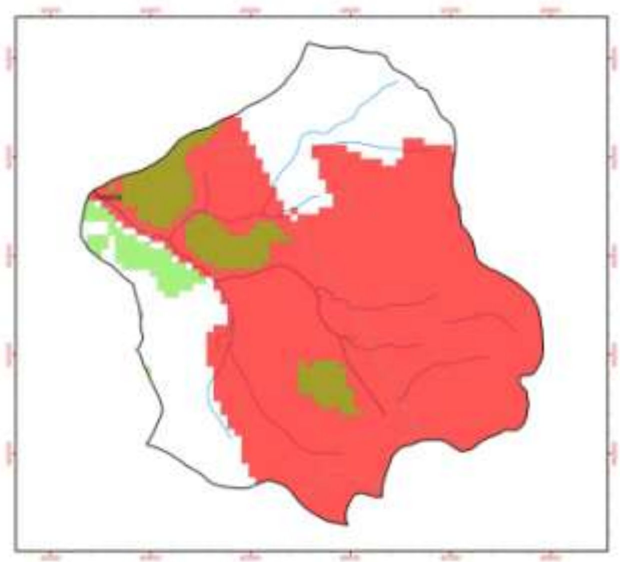




Disturbance areas for the previous 1 year.



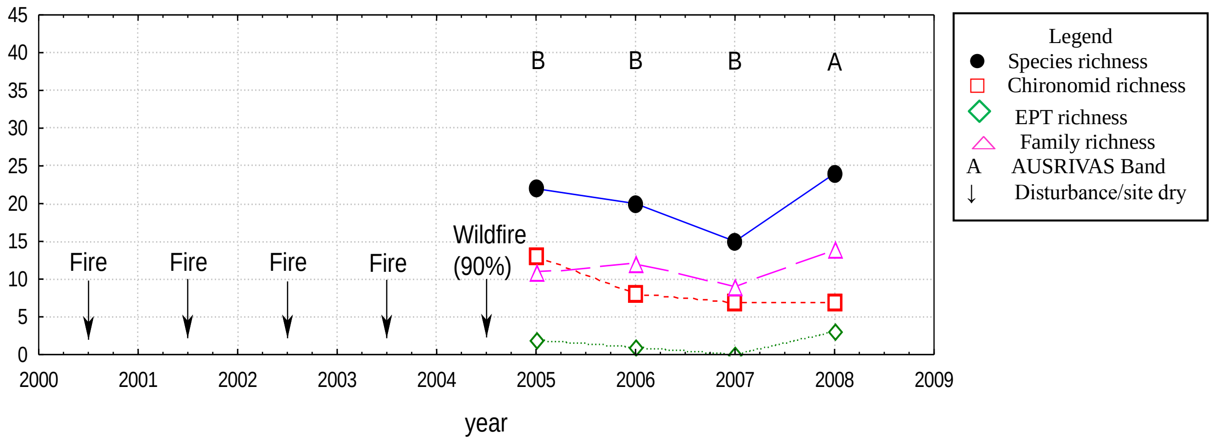
Disturbance areas for the previous 5 years



Disturbance areas for the previous 10 years.

SWA24 LITTLE DARKIN RIVER

Latitude:	-32.0465
Longitude:	116.2356
Area of catchment (ha):	2,984
Average Annual Rainfall (mm):	950
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2005
Year of Last Harvest:	1998
Dieback Present (% catchment)	3



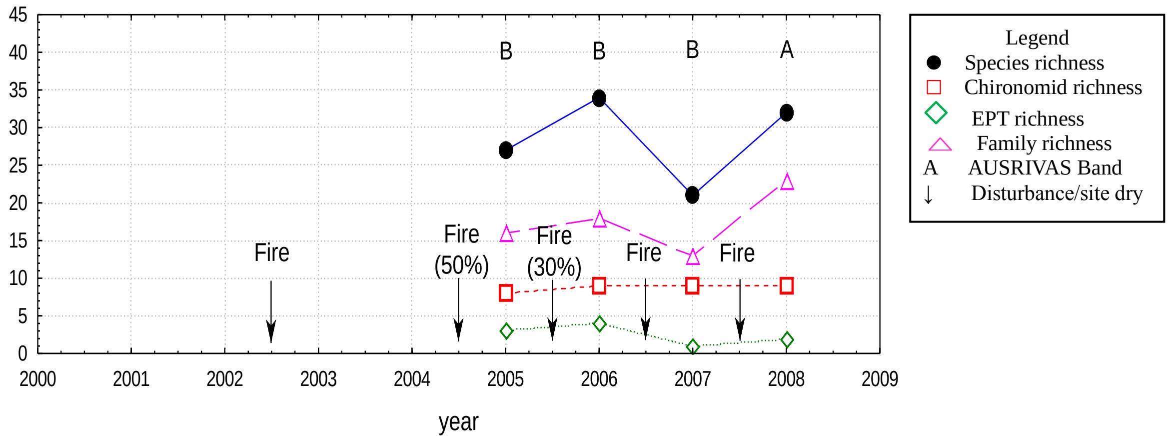
Disturbance areas for the previous 1 year.

Disturbance areas for the previous 5 years

Disturbance areas for the previous 10 years.

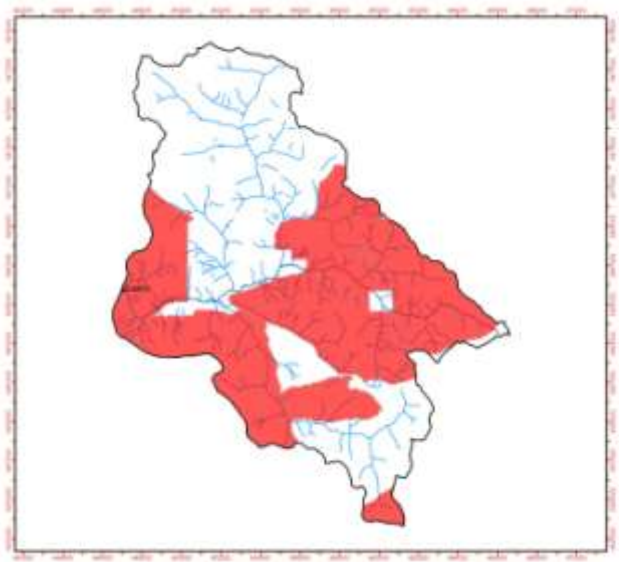
SWA31 HELENA RIVER

Latitude:	-31.9426
Longitude:	116.4391
Area of catchment (ha):	24,566
Average Annual Rainfall (mm):	675
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	1970's
Dieback Present (% catchment)	0



Disturbance areas for the previous 1 year.

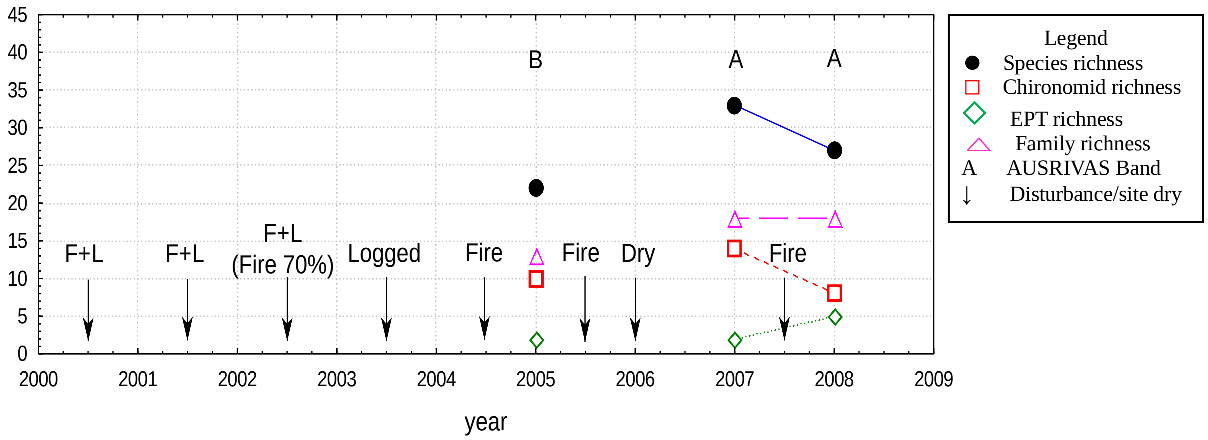
Disturbance areas for the previous 5 years



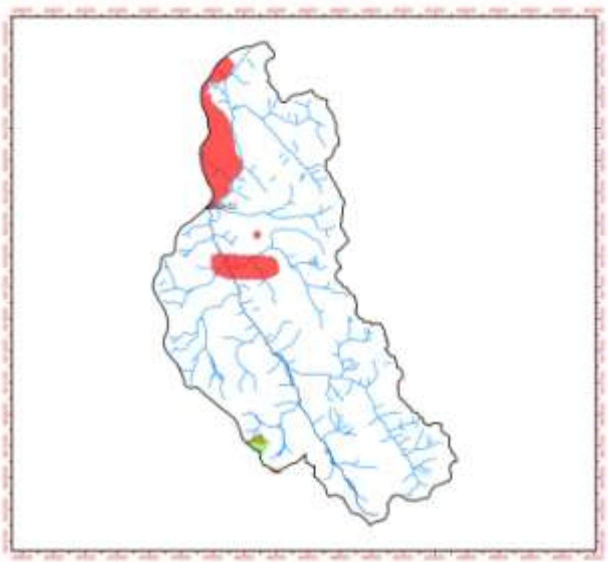
Disturbance areas for the previous 10 years.

SWA32 CANNING R, RANDALL RD

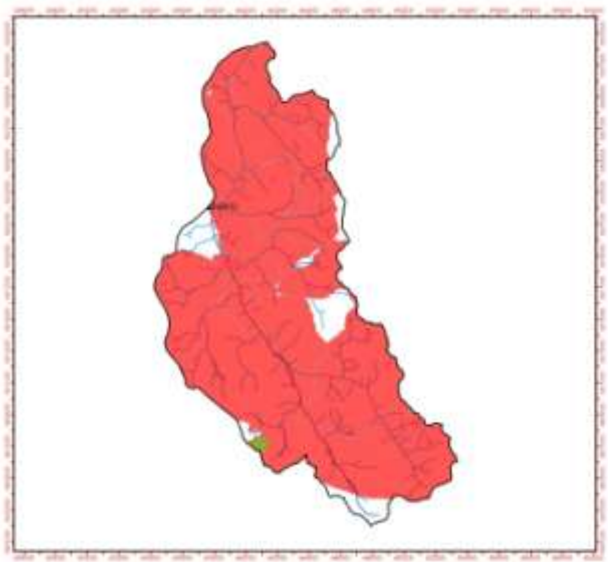
Latitude:	-32.3363
Longitude:	116.3374
Area of catchment (ha):	28,331
Average Annual Rainfall (mm):	875
Discharge category:	4
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	2003
Dieback Present (% catchment)	5



Disturbance areas for the previous 1 year.



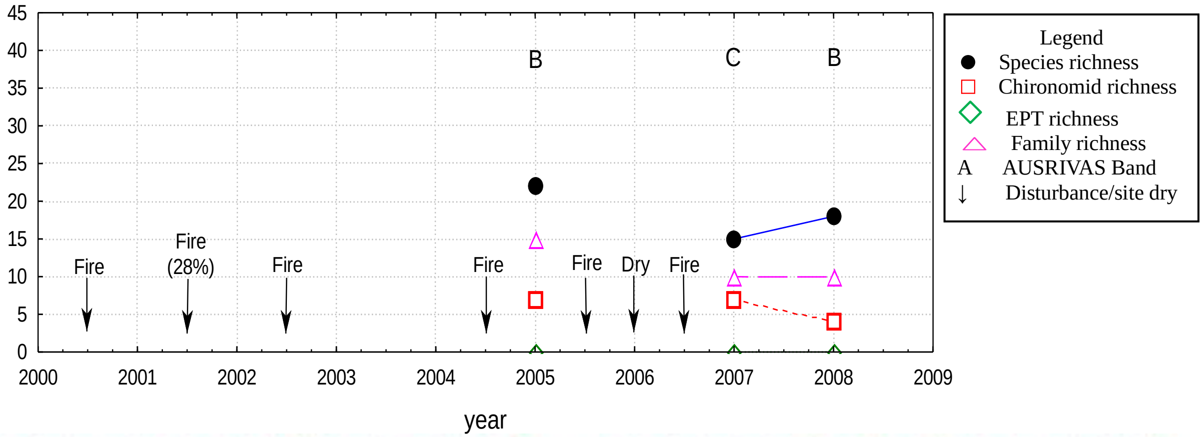
Disturbance areas for the previous 5 years

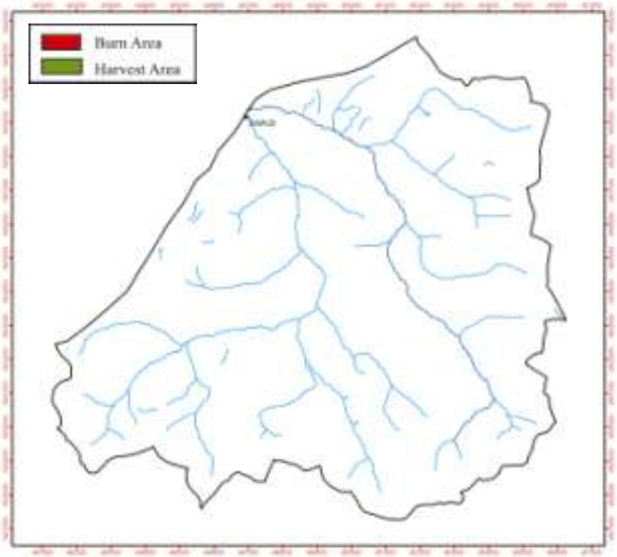


Disturbance areas for the previous 10 years.

SWA33 WILLIES RD

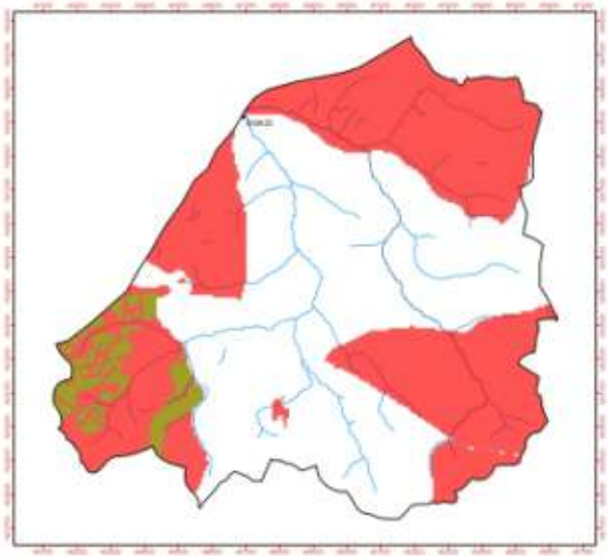
Latitude:	-32.1824
Longitude:	116.437
Area of catchment (ha):	14,110
Average Annual Rainfall (mm):	725
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	Conservation park
Year of Last Burn:	2007
Year of Last Harvest:	2000
Dieback Present (% catchment)	0





Disturbance areas for the previous 1 year.

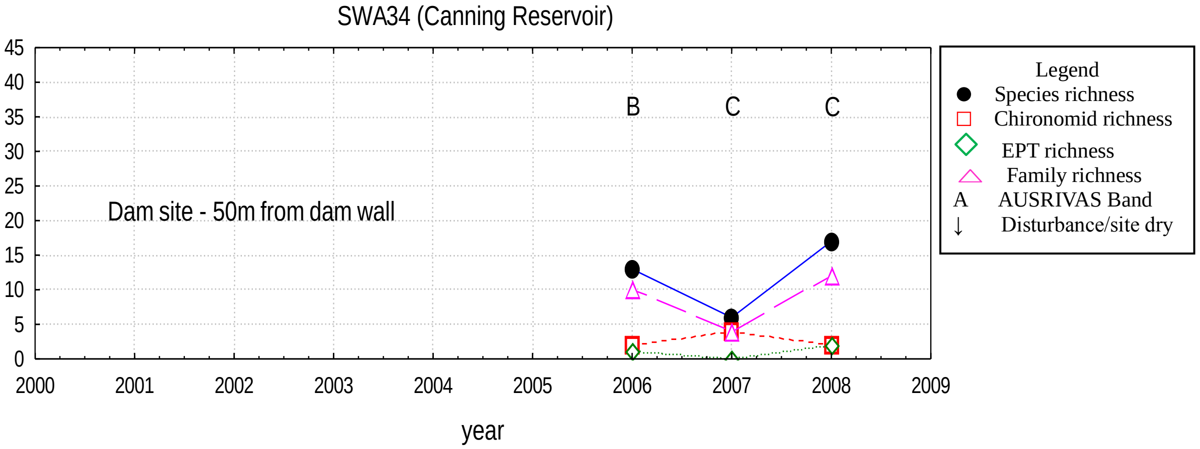
Disturbance areas for the previous 5 years



Disturbance areas for the previous 10 years.

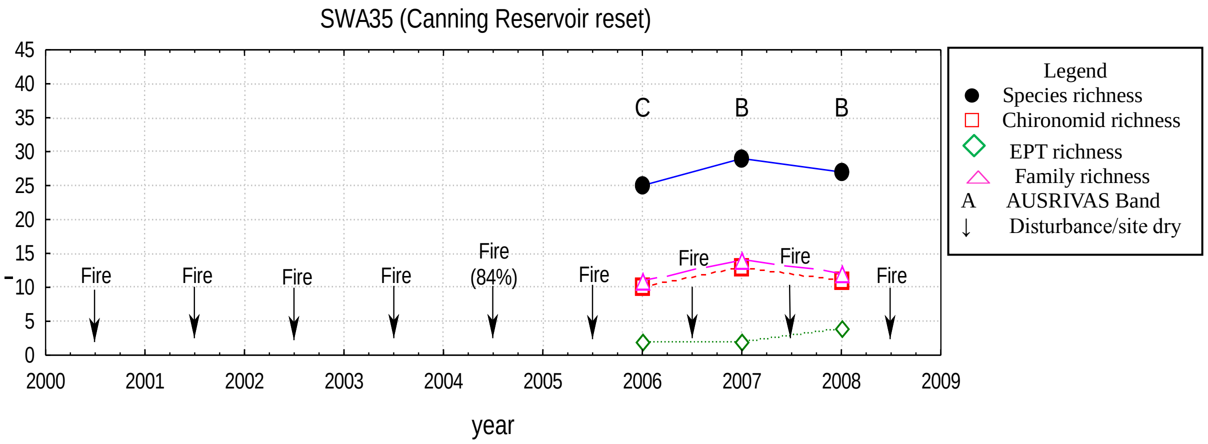
SWA34 CANNING RESERVOIR 1

Latitude:	-32.151
Longitude:	116.124
Area of catchment (ha):	Dam
Average Annual Rainfall (mm):	1250
Discharge category:	5
Forest type	Jarrah
Tenure at sampling point	Other land (300m from national park; 1km from State forest)
Year of Last Burn:	
Year of Last Harvest:	
Dieback Present (% catchment)	0

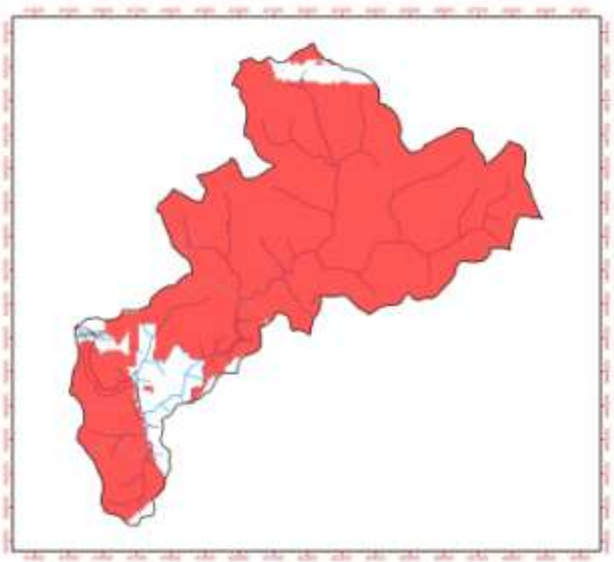


SWA35 CANNING RESERVOIR 2

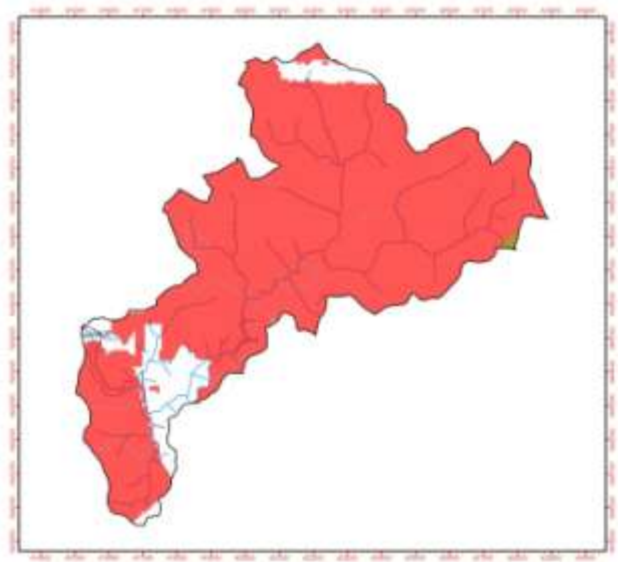
Latitude:	-32.1252
Longitude:	116.101
Area of catchment (ha):	7,555
Average Annual Rainfall (mm):	1275
Discharge category:	5
Forest type	Jarrah
Tenure at sampling point	5 (1) (g), (h) reserve - conservation
Year of Last Burn:	2008
Year of Last Harvest:	1998
Dieback Present (% catchment)	12



Disturbance areas for the previous 1 year.



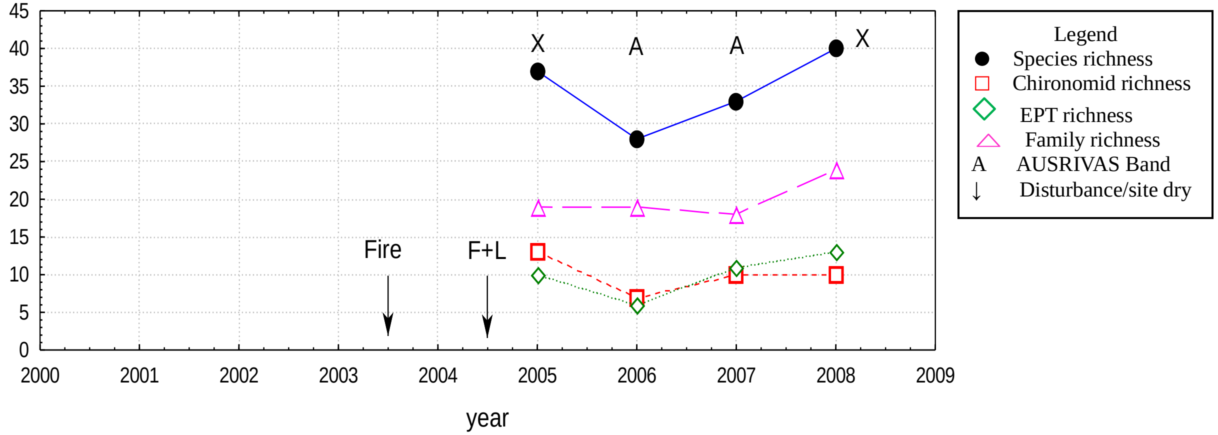
Disturbance areas for the previous 5 years

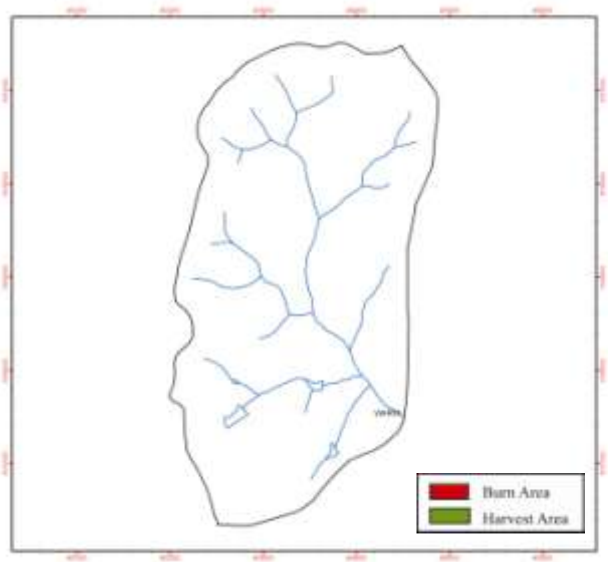


Disturbance areas for the previous 10 years.

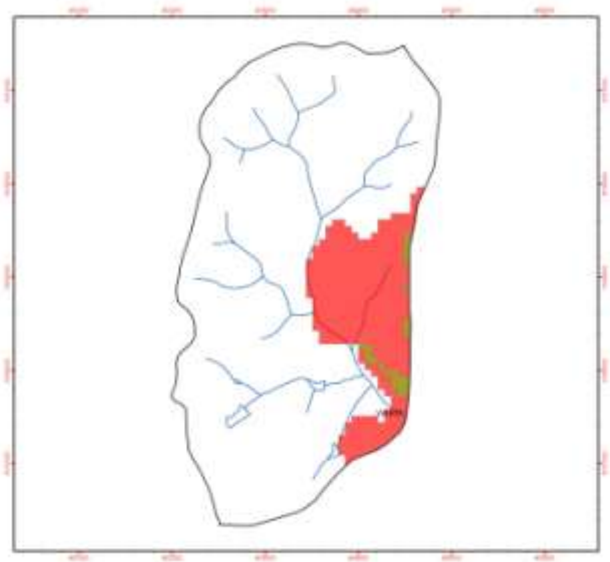
WAR01 TRACK OFF EAST BREAK RD

Latitude:	-34.4500
Longitude:	115.9606
Area of catchment (ha):	1,130
Average Annual Rainfall (mm):	1400
Discharge category:	3
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2005
Year of Last Harvest:	2004
Dieback Present (% catchment)	0

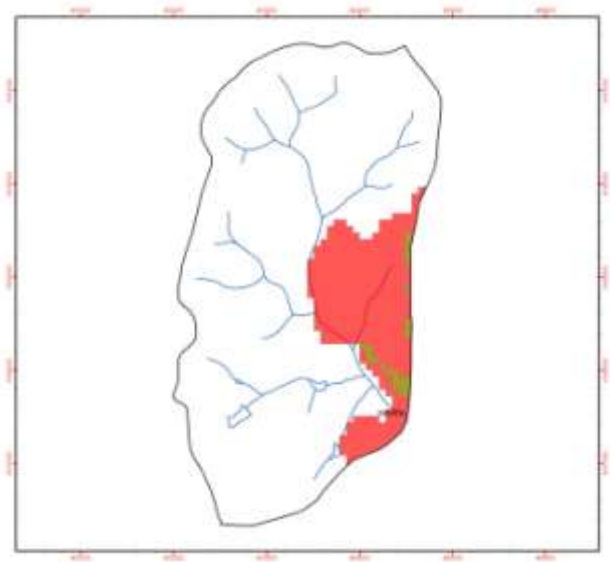




Disturbance areas for the previous 1 year.



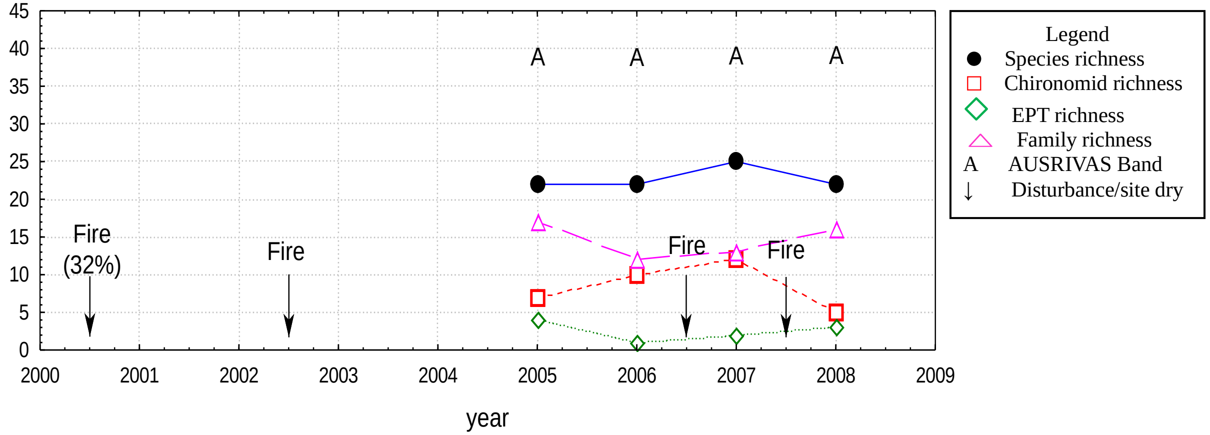
Disturbance areas for the previous 5 years

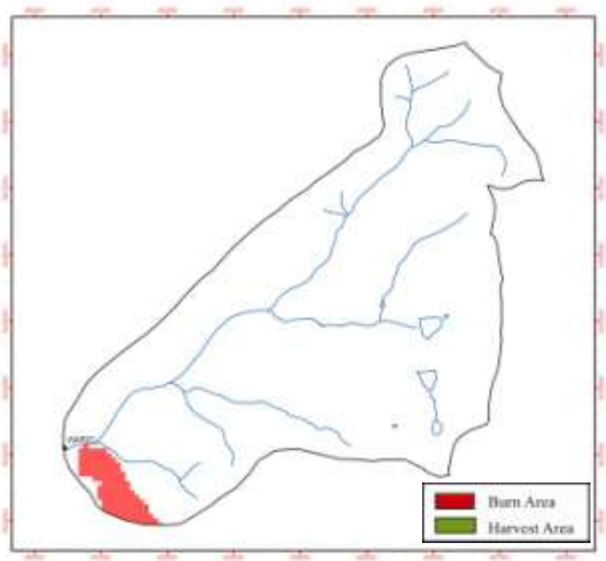


Disturbance areas for the previous 10 years.

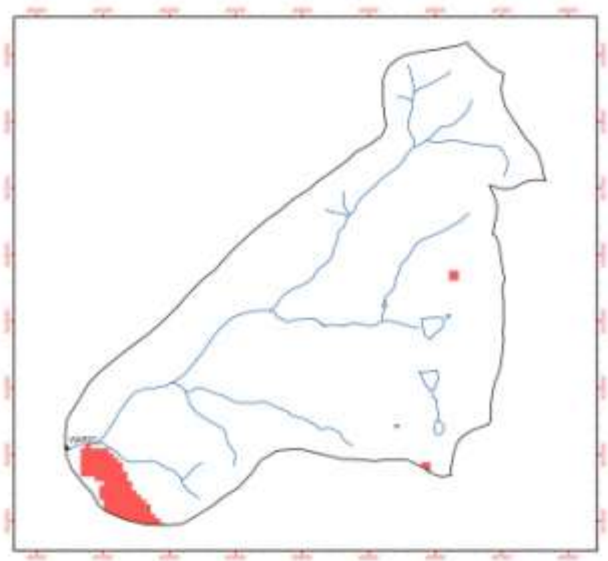
WAR02   WHIM LANDING RD

Latitude:	-34.1306
Longitude:	116.2458
Area of catchment (ha):	2,707
Average Annual Rainfall (mm):	900
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	1990's
Dieback Present (% catchment)	3

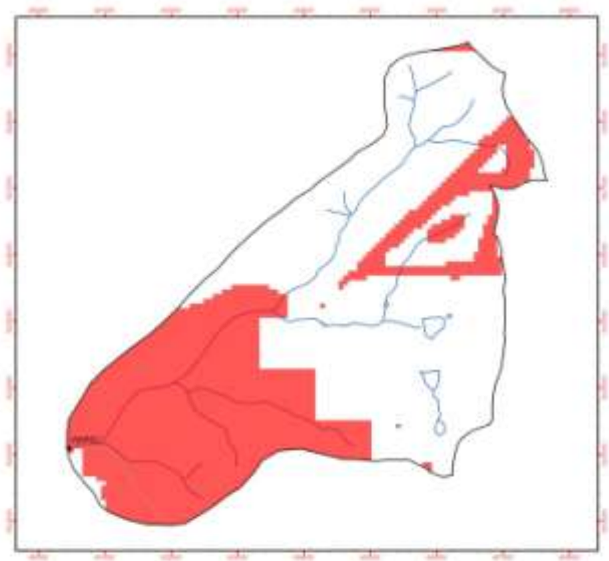




Disturbance areas for the previous 1 year.



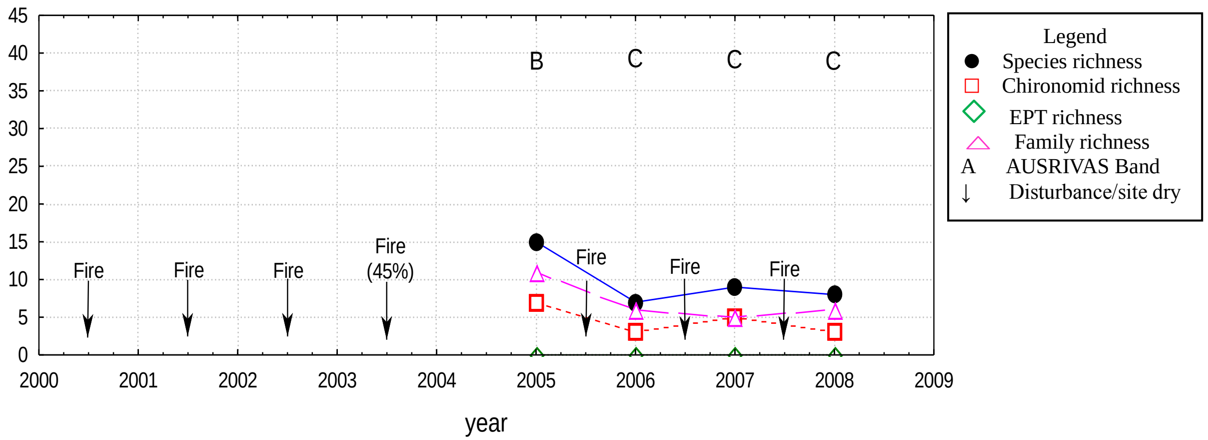
Disturbance areas for the previous 5 years

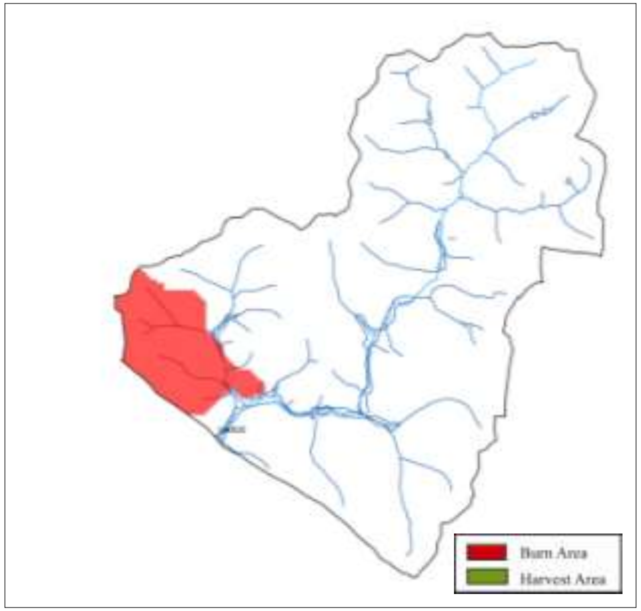


Disturbance areas for the previous 10 years.

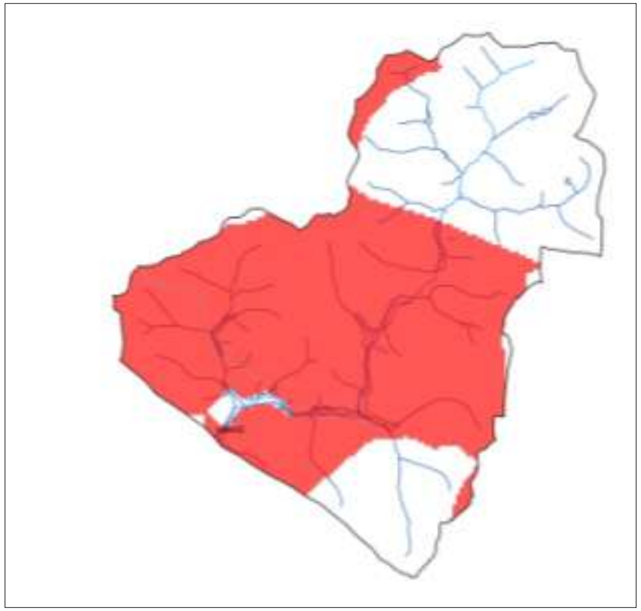
WAR05 EAST BOUNDARY BLOCK 1661

Latitude:	-34.1144
Longitude:	116.5789
Area of catchment (ha):	5,793
Average Annual Rainfall (mm):	725
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	Nature reserve
Year of Last Burn:	2008
Year of Last Harvest:	1970's
Dieback Present (% catchment)	0

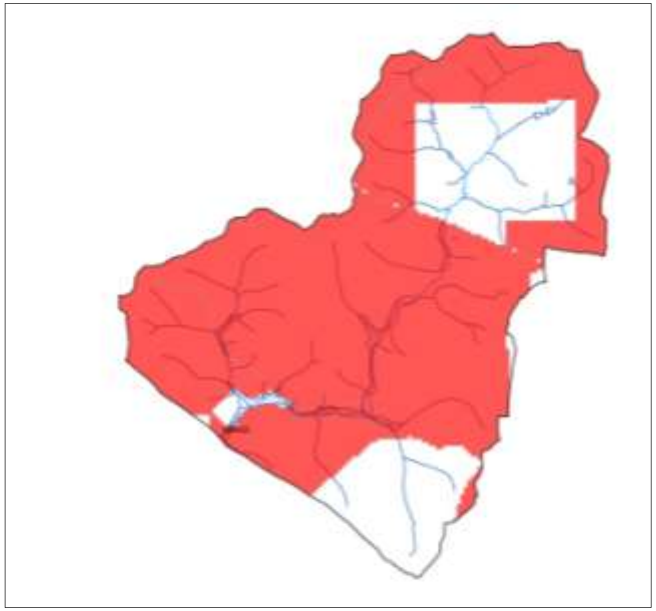




Disturbance areas for the previous 1 year.



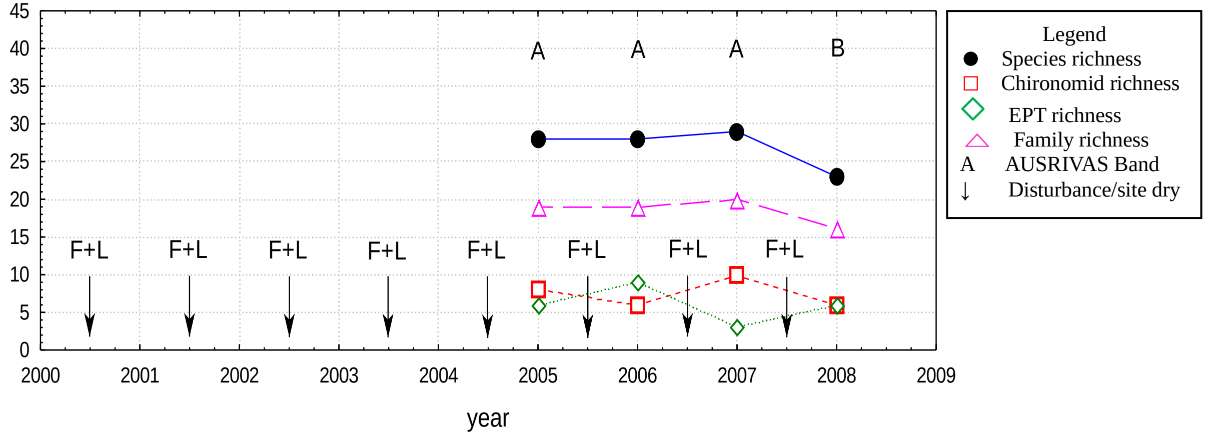
Disturbance areas for the previous 5 years



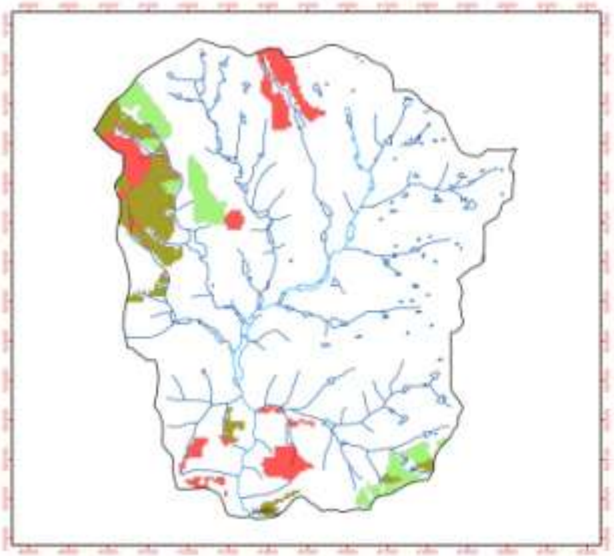
Disturbance areas for the previous 10 years.

WAR15 CHANNYBEARUP RD

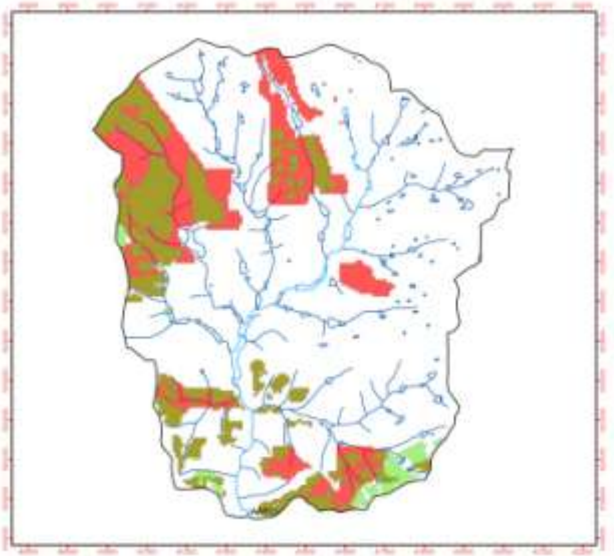
Latitude:	-34.342
Longitude:	116.06
Area of catchment (ha):	9,203
Average Annual Rainfall (mm):	1175
Discharge category:	4
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2008
Year of Last Harvest:	2007
Dieback Present (% catchment)	13



Disturbance areas for the previous 1 year.



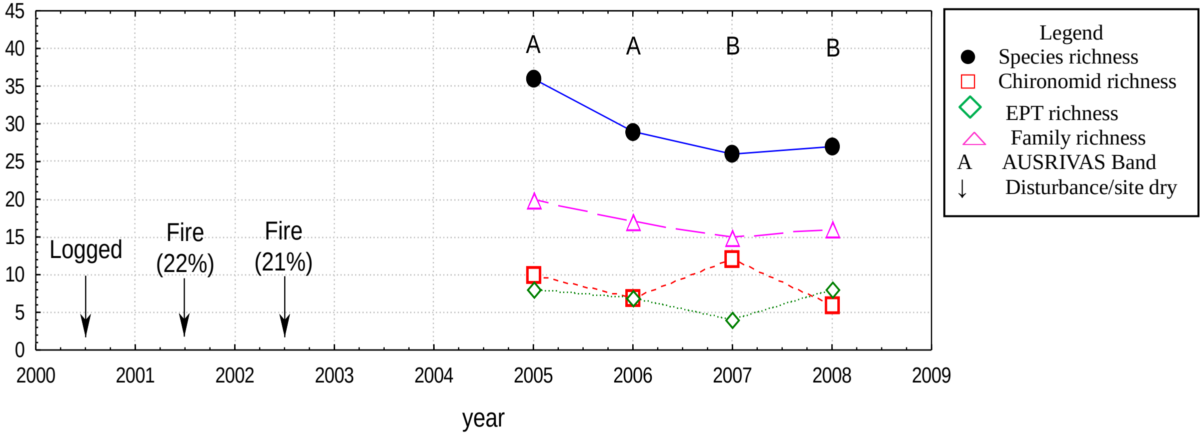
Disturbance areas for the previous 5 years

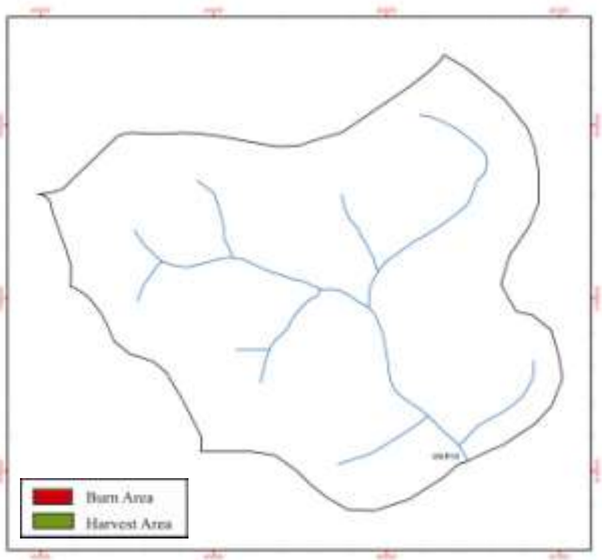


Disturbance areas for the previous 10 years.

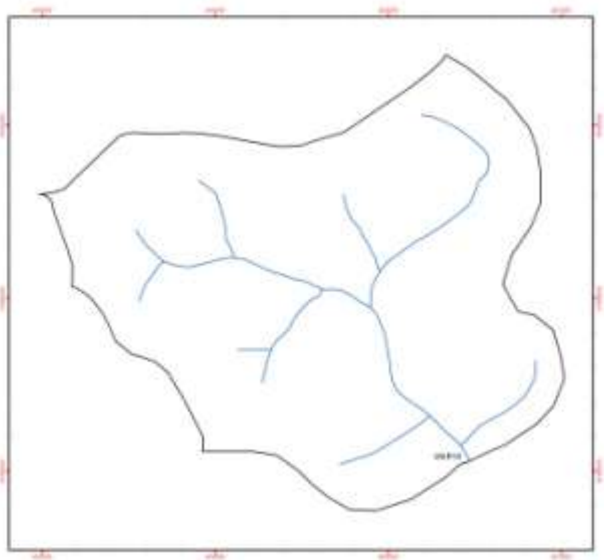
WAR16 BANNISTER RD

Latitude:	-34.4461
Longitude:	116.1339
Area of catchment (ha):	498
Average Annual Rainfall (mm):	1150
Discharge category:	2
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2003
Year of Last Harvest:	2000
Dieback Present (% catchment)	35

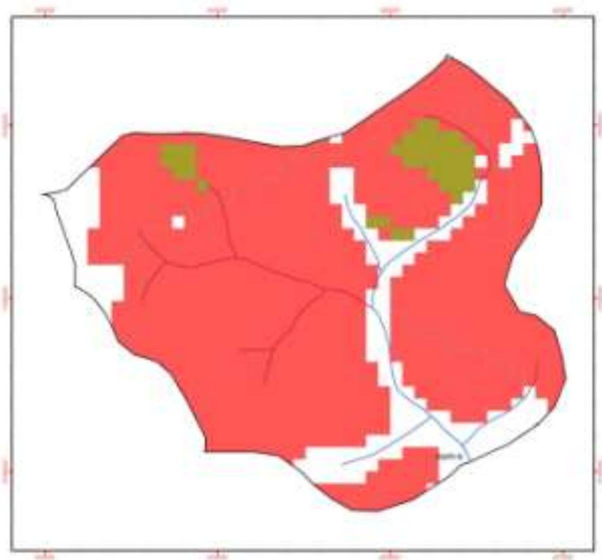




Disturbance areas for the previous 1 year.



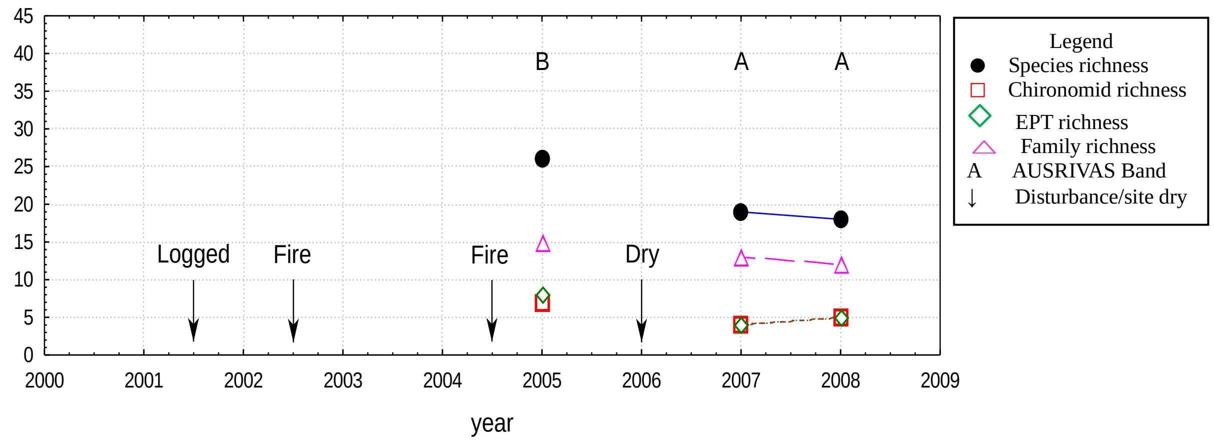
Disturbance areas for the previous 5 years

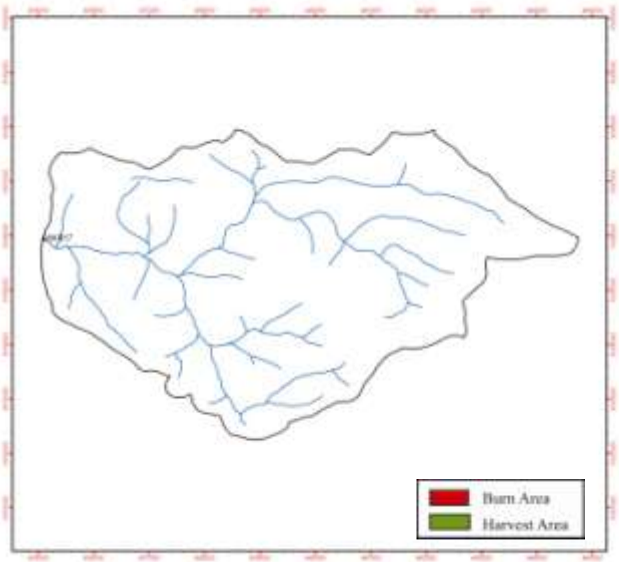


Disturbance areas for the previous 10 years.

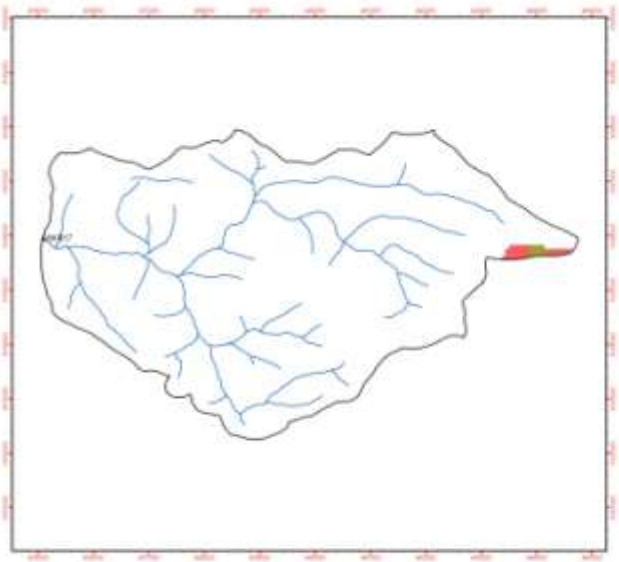
WAR17 SIX MILE BK

Latitude:	-34.4658
Longitude:	116.2930
Area of catchment (ha):	3,441
Average Annual Rainfall (mm):	1050
Discharge category:	3
Forest type	Karri
Tenure at sampling point	State forest
Year of Last Burn:	2007 (<0.1%)
Year of Last Harvest:	2001
Dieback Present (% catchment)	6

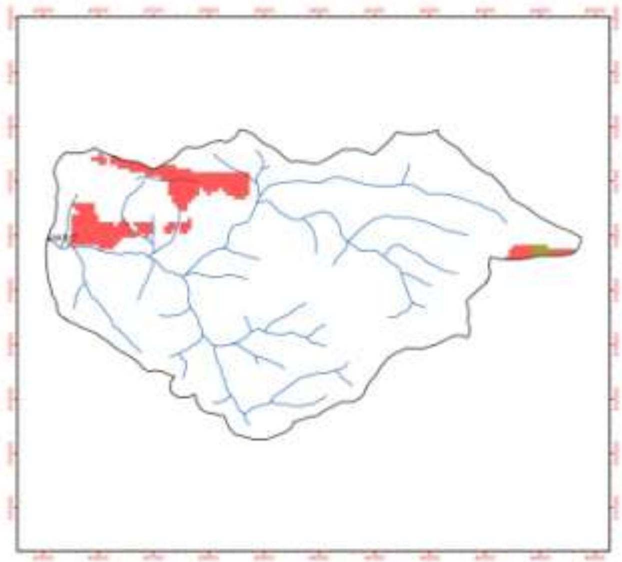




Disturbance areas for the previous 1 year.



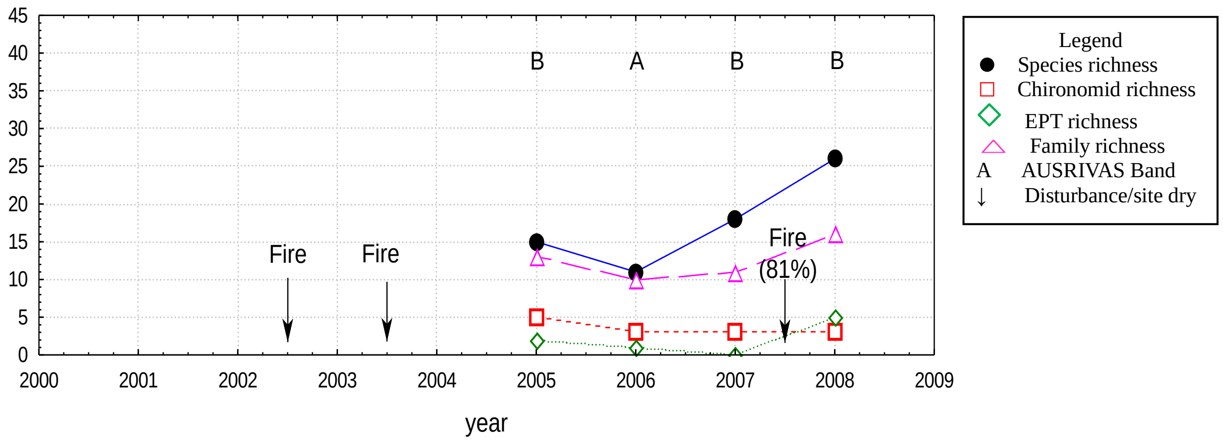
Disturbance areas for the previous 5 years

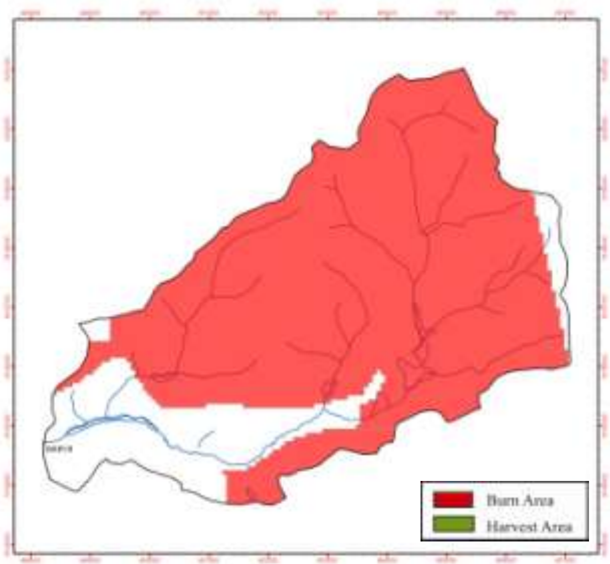


Disturbance areas for the previous 10 years.

WAR18 MUIRS HWY

Latitude:	-34.3875
Longitude:	116.4366
Area of catchment (ha):	3,681
Average Annual Rainfall (mm):	800
Discharge category:	3
Forest type	Jarrah
Tenure at sampling point	Other land ;adj. State forest
Year of Last Burn:	2008
Year of Last Harvest:	1990's
Dieback Present (% catchment)	3





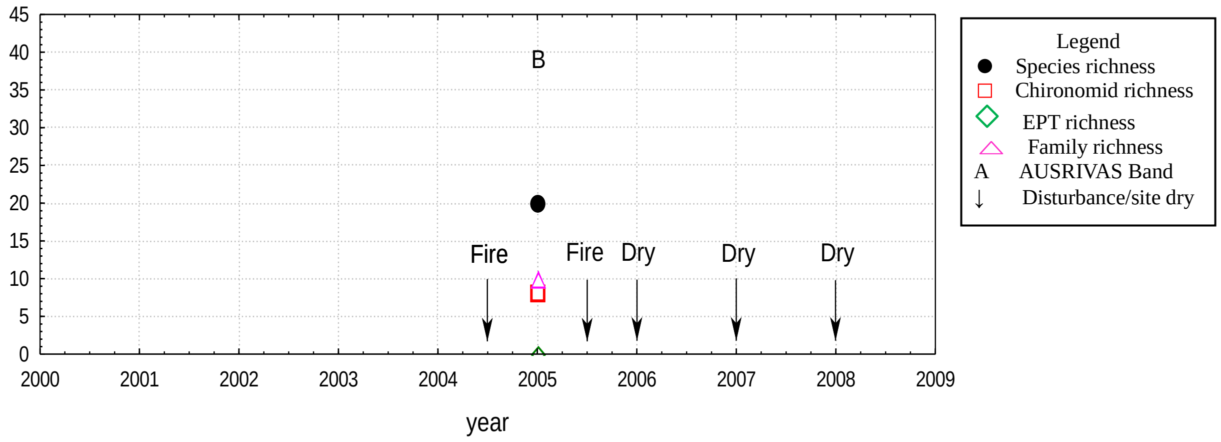
Disturbance areas for the previous 1 year.

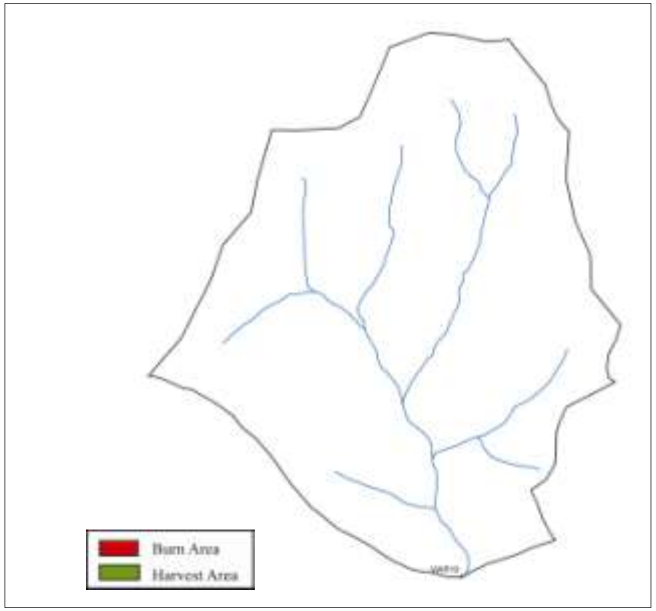
Disturbance areas for the previous 5 years

Disturbance areas for the previous 10 years.

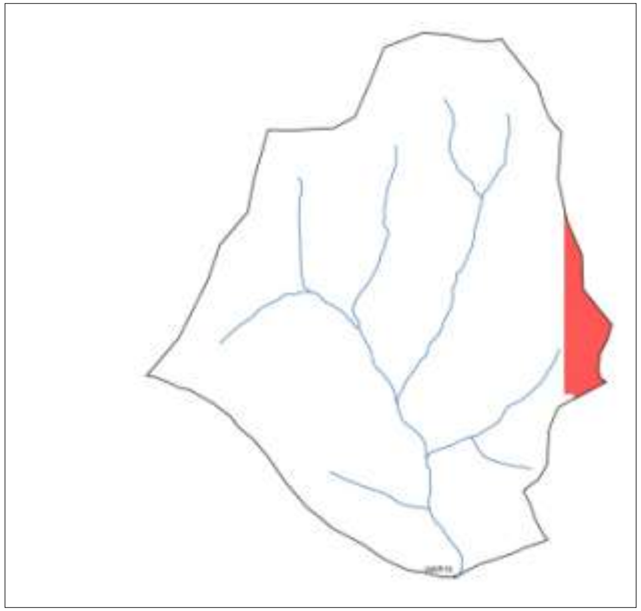
WAR19 DE LANDGRAFFT RD

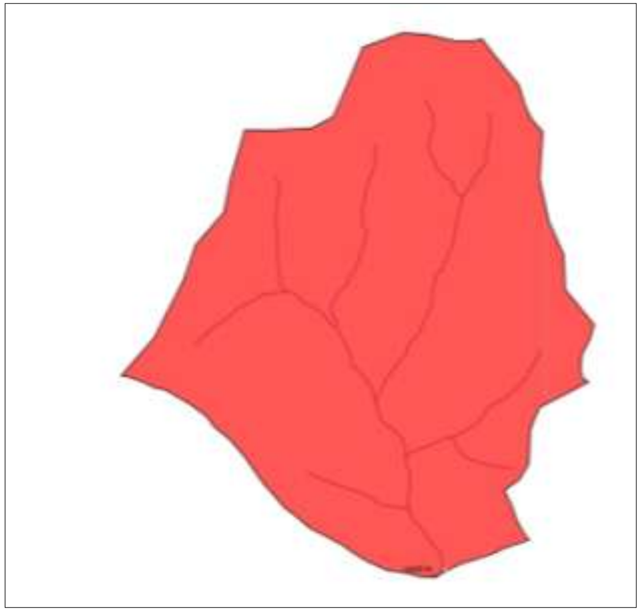
Latitude:	-34.2616
Longitude:	116.6372
Area of catchment (ha):	918
Average Annual Rainfall (mm):	675
Discharge category:	2
Forest type	Jarrah
Tenure at sampling point	Nature reserve
Year of Last Burn:	2006
Year of Last Harvest:	1970's
Dieback Present (% catchment)	0





Disturbance areas for the previous 1 year.


Disturbance areas for the previous 5 years


Disturbance areas for the previous 10 years.