FOREST MANAGEMENT IN RELATION TO THE SILICON PROJECT

Department of Conservation and Land Management,
Western Australia

May 1987

SUMMARY

The Department of Conservation and Land Management has reviewed all aspects of the Silicon Project in so far as they relate to the provision of jarrah timber for the production of charcoal.

The resource available to the proponent has been checked and the Department is satisfied there is no difficulty with the level of resource required, nor will the Project have any adverse implications for the sustained yield of the forest.

This review outlines the Department's plans for providing the firewood resource from logging which is largely integrated with the current logging programme for the sawmill industry. CALM has adequate field control procedures to ensure compliance with all environmental protection requirements.

The environmental impacts of the provision of the firewood resource have been evaluated and no serious adverse impacts have been identified.

The Project has the potential to bring important benefits for management of the northern jarrah forest, improving the efficiency of timber utilisation and thus extending the old growth resource, improving the efficiency of forest regeneration and improving forest productivity.

INTRODUCTION

This review has been produced in response to points of concern raised by the EPA about aspects of forest management as they relate to the Silicon Project.

The proponent has estimated the timber resources available for the project and has made an assessment of the environmental impacts of supplying the timber. This assessment was necessarily incomplete, since the administration of the procurement of the firewood resource and of the forest from which it comes, are the responsibility of the Department of Conservation and Land Management (CALM). The comments made in this review are intended to elaborate on certain aspects of the Project to assist the Environmental Protection Authority in making its recommendations to Government.

OVERALL FOREST MANAGEMENT CONSIDERATIONS

The CALM Act sets out the overall objectives of forest management in Western Australia and requires the production of land management plans for all categories of land under the control of the Department. These plans set out the issues in each area and describe how CALM proposes to address them, together with management guidelines and policies currently in use. Accountability for field performance is the responsibility of the Operations Directorate of the Department.

The area of forest from which timber supplies will be drawn for the proposed charcoal production facility for the Silicon Project is covered by two CALM regional management plans - for the Northern Forest Region (1) and the Central Forest Region (2) - and by an overall State timber supply strategy (3). Draft copies of these documents are now available for public comment.

A feature of the jarrah forest is the large resource of timber which is below sawlog specification (see (3) Table 7) and which presents serious problems in forest management. Availability of a market for this poor quality material would have the effect of greatly facilitating efficient regeneration of cutover forest, of increasing the efficiency of utilisation of timber harvested and of increasing the growth rate of the forest as a whole. These points are elaborated upon later in this review.

The CALM Act also sets out a clear objective for the forest as a whole to be managed on a sustained yield basis. This is reflected in the forest management guidelines (4, P. 44), which state that the aim of management is to:

> "adjust the cut from the native forest progressively to a level consistent with the growth of the forest ....".

The sustainability of the timber yield from the forest is further considered under Resources, below, but sustainability can also be considered from the viewpoint of the maintenance of the jarrah forest ecosystem itself. This has been approached in two ways; reservation from felling of about 34% of the jarrah forest in secure reserves (3), and intensive, long-term research on forest management techniques to ensure the maintenance of the productivity of the forest.

The reserve system is one of the best and most comprehensive to be found anywhere in the world. As such it provides a complete range of reference sites against which any suspected changes can be evaluated.

With regard to research backing for forest management, the CALM publication Timber Production in Western Australia (3) lists no less than 177 references in the literature on the jarrah forest, and this list is by no means exhaustive. This research background is combined with an ongoing commitment to research by CALM.

There are, of course, some changes to the jarrah forest ecosystem clearly in progress where dieback disease has had a severe effect on the forests, and the bauxite mining industry is the cause of the conversion of about 350 ha a year to other eucalypt species. Apart from these changes, there is no evidence to suggest any past management actions have had a long-term adverse effect on the ecosystem as a whole.

FIREWOOD RESOURCES

The ERMP for the Western Australian Silicon Project (5) sets out (Tables 2.1 and 2.2) the estimated level of resources available to the industry.

The data quoted in the ERMP were taken from CALM records using appropriate conversion factors from cubic metres to tonnes. CALM carries out periodic broadscale Resource Level Inventories (RLI) over the jarrah forest, recording the volume of sawlogs, firewood and regrowth material by species. Although the inventory is based on a small sample of the forest, about 0.6% by area, the sample is statistically valid over the forest as a whole.

In addition to the RLI, Management Level Inventory (MLI) is carried out on individual logging coupes to provide more precise data for the rolling five-year logging plans. These rolling plans are updated annually. Actual volumes harvested are checked against predicted MLI yield to monitor accuracy of predictions, to control the overall level of the cut and to provide continual adjustment to utilisation factors.

The firewood resource data in the ERMP combine both MLI and RLI data to develop the summary given in Table 2.1. It has been of some concern to CALM that the RLI data are over 10 years old and did not assess the firewood resource according to a precise specification which related to the requirements given for the Silicon Project.

The firewood specification given in the ERMP is completely unrealistic. It has been made quite clear to representatives of the proponent that CALM will only sell for firewood that quality of material which cannot be used for a higher value end use. Under no circumstances could material which could be used for sawlogs be used for firewood. The pressure on the sawlog resource is so great none could be wasted in this way, nor can the Government forego the extra financial return from sawlogs.

On this basis the resource data given in the ERMP have been re-evaluated in the light of recent discussions and field inspections with the proponent. The results of this re-evaluation are presented in the attached Table 1, which shows that, even on the worst case scenario, there is adequate resource of firewood available for the life of the project in the Dwellingup and Harvey districts.

Table 1 Silicon Project Resource Statement

Total firewood resource estimated by proponent using CALM base data (a)	5,777,000 t
Less 10% likely to be usable as second grade sawlog (b)	577,700 t
Less 20% likely to be unusable by charcoal plant (c)	1,155,400 t
Net Available Firewood Resource	4,044,000 t
Total firewood requirement for life of project (ERMP, Page 24)	2,480,000 t

Notes:

(a) This is the quantity assessed as being below the current sawlog marketability standard in areas available for timber production in the Dwellingup and Harvey forest districts only. This amount does not include "trade waste", which is material in the crowns of felled trees normally not used, but which can be used for firewood.

Additional resources are - trade waste 827,000 t
- ex bauxite mining 375,000 t

(Source: ERMP P. 24 and P. 27)

(b) This estimate is based on experience with the woodchip industry in the karri forest. About 10% of the trees classed as not marketable for sawlogs, when felled and inspected, can be used for second grade sawlogs.

(c) This is a "guesstimate" based on inspections of trial lots of firewood logs by staff of the proponent. In a worst case scenario, if 40% of the total resource estimated by CALM were not acceptable to the charcoal plant, the resource would be reduced to 2,889,000 t.

CALM concern about the precision of the overall estimate of firewood resources has been allayed by current field checks which are showing (eg in Scott, Cameron and Kennedy blocks) that the original RLI figures are within 1 to 3% of the current MLI figures. The critical factor, as shown in Table 1, is what will be the lower limit of acceptability as a charcoal quality log.

In terms of the effect of the Silicon Project on sustained yield of the jarrah forest in the Dwellingup and Harvey districts, the situation is as follows:

Area available for timber production in the Dwellingup and Harvey forest districts (from (5), Table 2.1, plus forest in the 25 year mining envelope and all forest cut over 1970-86, which is excluded from that total)	232,000 ha (approx)
Estimated current annual increment (from estimates in Table 7 in (3))	255,000 m^3
Total allowable cut of sawlogs, poles etc	103,000 m^3/yr

Of the 100,000 t of firewood to be provided from these two districts (see harvesting plans below) about half will be from live (green) trees and half from dead trees (from (5), Table 2.1). On this basis, about 50,000 t or about 50,000 m^3 will come from green trees. In practice, the figure will be less than this due to the use of timber being cleared from bauxite mine pits and no more than 40,000 m^3 of additional green timber will be harvested for the project.

On these data, overall increment in the forest greatly exceeds the level of harvest, even with this project included. Further, most green trees to be harvested for the project will be old, overmature trees which are contributing very little indeed to the forest increment. Their removal is essential if the increment of the forest is to increase to the potential outlined in Table 7 of the Timber Production Strategy. Even a temporary localised overcut would be justified to achieve the increase in increment which is possible.

It is the presence of these unmarketable trees which has prevented efficient regeneration and achievement of maximum potential increment in all selection cut jarrah forest. Their removal would be a major advance in silviculture of the jarrah forest (8). For the first time in this area complete, rather than partial, regeneration of cutover forest will be possible.

These older, previously unmarketable, trees are the inevitable result of a selection cutting system where there was a market for only one main product - sawlogs. It is CALM's experience that the availability of a residue market enables a logging contractor to fell and evaluate virtually all trees nominated for removal. A percentage (averaging about 10%) of those trees will prove to be acceptable sawlogs, so, in this way, the Silicon Project would have a beneficial effect on the utilisation of the forest resource. It would actually increase the resource available to the sawmills operating in these two districts. This does not mean an increased rate of cutting, merely a larger resource.

It is important to note that the availability of a firewood market does not imply that all dead or defective trees will be felled. A significant proportion of dead trees and trees with hollow butts cannot be felled for safety reasons. There is also a continuing loss of trees in the jarrah forest due to dieback disease and to "natural causes".

In the Dwellingup and Harvey forest districts there are about 38,000 ha of high quality regrowth forest arising from intensive logging operations in the early part of this century. At present these forests are achieving little more than 1.1 m^3/ha/year increment due to severe overstocking. A programme of thinning these forests in the last three years has been constrained by the costs of the operation, which produces very small quantities of small sawlogs, posts and rails. Eventually, the charcoal plant will be partly supplied from this regrowth. The operation will then be self-financing and there will be a major expansion of the thinning programme. As a result of this thinning the annual increment will rise from 1.1 m^3/ha to 1.7 m^3/ha in these stands.

The potential to thin high quality regrowth forest would be major benefit to the forest from the Silicon Project, but this potential will not be realised for several years, due to the requirement to maximise the proportion of dry timber input for the first 6 years.

Page 28 of the ERMP states that there is a requirement for dry wood only to be supplied for the first 5 years, green firewood being supplied from year 6 onward. This is operationally quite impossible to achieve. CALM's proposals to meet the requirements of the charcoal production facility and of the silicon furnace at Wundowie are outlined below.

It has always been CALM's intention that supply of timber for the charcoal production facility would be integrated with other logging operations in order to achieve operational efficiency and economy, as well as maximum silvicultural benefit.

In practice, this means that existing logging operations in these districts, instead of supplying only sawlogs, poles and piles with some minor products, will now harvest dead trees and live, previously non-marketable, trees from the same logging coupes. Normally, the one contractor will be commissioned by CALM to remove all harvestable produce from a particular coupe. Allocation of logs to particular categories will be done according to specifications enforced by CALM field staff supervising the operation (see (6), Section 6). This document would, of course, be amended to include a firewood log specification if this Project proceeds.

As the resource obtainable from this operation will be only about 50% dry wood, the Project will require supplementation by a separate harvesting operation confined to areas of forest severely affected by dieback disease, where the majority of the yield would be dead trees.

The other requirement for 24,000 t per year of green firewood (ERMP, Page 28) for direct feed to the silicon furnaces at Wundowie could be obtained most economically from the thinning of high quality regrowth jarrah forest in the Mundaring area.

There would be thus four logging operations supplying timber to the proponent in the first instance, viz:

1. an integrated operation with logging for Yarloop mill,

2. an integrated operation with logging for Dwellingup mill,

3. a "pure" firewood operation in disease-affected forest (however this operation would throw up a few second grade sawlogs),

4. a regrowth thinning operation near Mundaring.

As soon as practicable, a regrowth thinning operation would be mounted in the Dwellingup or Harvey area.

IMPACT OF THE SILICON PROJECT ON THE FOREST

The proposed Silicon Project has a number of potential impacts on the forest in such areas as spread of dieback disease, export of nutrient capital, salinity of streams, increased soil erosion and adverse effects on flora, fauna and the ecology of the forest in general. These will be considered in turn.

(a) Dieback Disease

The planning and performance of all forest operations in the northern jarrah forest are dominated by the requirements for the prevention of further infections of the dieback disease due to the soil fungus Phytophthora cinnamomi. The requirements for protection of forest from the disease and for handling areas already infected are

spelt out in great detail in field operational manuals (6 and 7). All CALM staff involved in control of hardwood logging are required to have a sound knowledge of the biology and management of the disease, and there is also training of industry personnel as required. The latter is increasing in importance as staff constraints within CALM mean that responsibility for certain aspects of forest operations is being devolved onto industry.

The specifications for logging hygiene include strict requirements for mapping disease occurrence, evaluation of potential disease impact before logging and (in areas subject to the disease risk regulations) the use of a decision model to guide how or if an operation may take place.

In areas free of dieback disease logging is effectively excluded for the wet period of the year (4-6 months depending on seasonal conditions), so that all logging activity is concentrated in the summer months and stock-piles are accumulated to operate sawmills through the winter. However, in areas already affected by the disease, all year round logging is possible, provided strict rules for hygiene are adhered to, in order to prevent transport of infected soil out of the infected area.

The harvesting of firewood for the Silicon Project would be subject to the same stringent controls as are applied to all other timber harvesting activities. It has been made quite clear to the proponent in discussions with CALM staff, that the proposed industry will receive no concessions at all in this respect. On this basis the Project will not result in an increased potential for spread of the disease.

CALM also has a strong commitment to ongoing research on dieback disease. Most of the resources of the Dwellingup Research Station have been devoted to this problem for many years. The close ties between research and operational staff within CALM ensure that any significant new research results are promptly incorporated into field practice.

Current research covers biology of the fungus, evaluation of severity of disease expression on the wide range of sites encountered in the forest, means of mapping those sites, and monitoring of experimental logging trials. The results of the latter, reported in (9) provide a convincing vindication of the effectiveness of the procedures presently used.

(b) Export of Nutrients from the Forest

A possible long-term loss in forest productivity due to the export from the forest of the nutrients contained in the wood is often raised as an argument against intensive forest management. The argument has stimulated a great deal of research in Australia in the last 10 to 15 years, some of it in the jarrah forest.

Research published by Hingston et al from CSIRO (10) gives estimates of the available nutrient pool on typical jarrah forest sites and confirms what was already well known, that jarrah grows on extremely infertile sites. It is able to do this because it has low requirements for the essential nutrient elements and because it efficiently recycles what is available. These facts are confirmed by the low nutrient element content of the timber and is the very reason why jarrah charcoal is attractive for the production of high grade silicon metal - it contains very low levels of chemical "impurities". The proposed Silicon Project will therefore not have a significant effect on the nutrient capital of the forests.

The data obtained by Hingston et al are consistent with similar research by the same group in the karri forest and other workers studying nutrient recycling in Eastern States eucalypt forests. As a generalisation it can be said that there is a risk of progressive site depauperation with continual cropping on a short rotation of, say, 50 years. With a rotation of 100 years there is generally believed to be little risk of a significant reduction in soil fertility. In jarrah forest the physical rotation is 200 years or more, so there is adequate margin for error in this regard.

In any case, the question is a hypothetical one. Should at any time a decline in productivity due to nutrient removal be detected, it would be readily and economically corrected by the administration of the required nutrients in fertiliser.

(c) Stream Salinity

The environment of the northern jarrah forest, as a whole, is an area of widespread concern with respect to stream salinity. The area contains all the surface catchment areas feeding dams supplying the Metropolitan Area and is well known to be underlain, in part, by subsoil strata containing a large store of salt (11, 12). Concern over the possible adverse effects of bauxite mining in this area led to the initiation in the mid 1970's of a large amount of research on land use and stream salinity in this area (13, 14, 15).

There is now a very complete body of knowledge on regional trends in soil and stream salinity and a great deal is known about hydrological processes in the region (16). Using this knowledge we are now able to predict with reasonable precision the consequences of any significant change in land use.

The removal of dead standing trees or logs on the forest floor can have no possible influence on stream salinity. The removal of live trees could have an adverse effect only if all trees were removed, without regeneration, over large areas of the forest in the eastern zone (less than 1100 mm rainfall). This could not happen, since the prime silvicultural objective of the potential new market for residue logs is to improve the quality of the regeneration of the forest and to improve forest health and vigour. There are also forest management guidelines for the eastern zone of the forest, agreed upon with the Western Australian Water Authority, which ensure that the amount of forest left after a logging operation does not fall to a level which would disturb the hydrological balance.

A further safeguard is provided by the fact that the over-riding priority for forest management for all jarrah forest north of Collie is protection of catchment values. No operation can be permitted if it would compromise that objective. CALM maintains close consultation with the Western Australian Water Authority in catchment management matters and field operational prescriptions are under continual review.

Logging coupes are also widely dispersed over the forest. Normally only a small proportion of any catchment area is affected each year.

(d) Soil Erosion

Soil erosion control is covered in forest harvesting operations by prescriptions in operational manuals (6), where the logging contractor is obliged to install appropriate structures to contain erosion. Of more concern to CALM are the possibilities of soil damage through continuation of logging operations in excessively wet conditions. This is approached in two ways: ceasing harvesting operations, particularly log skidding into the bush landings, when soil damage exceeds certain levels (see (6) Section 5), and by requiring the contractor to carry out rehabilitation on soil damaged by logging and on log landings. The manuals also specify procedures to prevent entry of sediment into streams.

The proposed Silicon Project will be required to conform to all these specifications, consequently no additional erosion nor stream sedimentation will result.

(e) Impact on Flora and Fauna

The proposed increase in the harvest from the forest for the Silicon Project is unlikely to have any observable effect on the flora of the region. The increased intensity of logging due to a higher level of cut per hectare to remove trees previously left behind does offer the potential for more soil compaction, which could possibly adversely effect some species of flora. However, the gravelly and generally coarse-textured soils which predominate in the jarrah forest are less susceptible to compaction than most soil types.

The removal of more jarrah trees is also not expected to have a serious adverse effect on the quantity of jarrah nectar produced and hence an effect on the beekeeping industry. The trees to be removed will be dead, in poor health due to over maturity or come from dense regrowth stands. In the latter two cases the trees to be removed will be making little contribution to nectar production due to poor health or competition respectively. The more vigorous forest which will result from improved silvicultural treatment made possible by residue removal is likely to produce more nectar.

The effect of the proposed Project on fauna is more complex. As the provision of firewood for the charcoal production facility will largely utilise dead or defective standing trees and logs already on the ground, there will undoubtedly be a decline in the availability of nest sites for hole nesting fauna and of cover for fauna requiring logs on the ground. However, as noted previously, not all standing dead trees nor all trees with hollow butts can be felled. Further, a proportion of the logs on the ground, mainly the older ones, will be too rotten or too heavily attacked by termites to be worth using for firewood.

The jarrah forest - because of the incidence of wildfire and jarrah dieback - has large numbers of dead and defective trees. It also has a large quantity of material on the ground - logs, crowns and stumps remaining from past logging operations. This means that the number of nest holes and log habitats is greatly in excess of that which would have been present in the "natural forest". This together with the fact that not all nest hole and log habitats will be removed would ensure that the project would not have a significant impact on fauna.

The larger fauna will not be affected by the project as they have coped very well with a much larger timber industry in the past than exists today, although there are only observational data to support this contention.

More quantitative data are available from recent research on bird habits in the jarrah forest. Abbott and van Heurck (17) studied the bird population in jarrah and yarri (E. patens) forest in unlogged forest and in forest where half the trees had been removed. They found the number of bird species and total bird populations were similar in both areas, suggesting that most bird species will tolerate a high level of disturbance in the forest. Other work by the same authors (18) suggests that some foraging bird species may be disadvantaged by thinning in regrowth stands. However, this must be kept in perspective. Only a small proportion of the jarrah forest in the region will be affected by logging in any period of, say, 3 years. Further, by dispersing the logging coupes, in a manner similar to that used in the karri forest, any detrimental effect can be minimised.

It should also be remembered the silicon project will not utilise marri trees, which are a significant component of the northern jarrah forest. Old marri provide, in fact, better hole nest sites than jarrah. For example, they tend to be the preferred nest trees for possums.

The intention of the proponent to fund a research project to examine these aspects is welcome. If the project is undertaken within the CALM research organisation, any worthwhile results can be rapidly incorporated into field practice. No problems are foreseen if it becomes necessary to exclude from logging particular trees which have obvious high value as nest sites, so long as no more than two or three trees per hectare are involved.

MONITORING IMPACTS OF THE PROJECT

A high degree of monitoring of the impacts of the Project would take place as a matter of course during existing procedures. As mentioned above, the resource estimates for each logging coupe are checked against actual yield for each product and the progressive yield of each (first grade sawlog, second grade log, pole, pile etc) is checked against the buyer of the product to ensure accurate rendering of accounts for royalty payment and progressive monitoring of the yield against the allowable cut and supply contracts.

In the field, there is daily supervision of logging procedures by CALM field staff, who take prompt corrective action should any environmental problems arise - whether in respect of disease hygiene, soil erosion, soil damage, sediment discharge into streams etc. In this context it is very important that the logging contractor be employed by CALM and not by the proponent of this project. In this way the forest manager has complete control over all operations in the forest.

No special monitoring of stream salinity is planned following logging which includes firewood procurement for the Silicon Project. Research trials which have been under way for several years using the same silvicultural regime which would be followed if the Project is approved, will provide an early warning of any problems in this regard. However, the accumulated weight of evidence from much recent research on the hydrology of the jarrah forest indicates any adverse effect on stream salinity is a remote possibility indeed. This is particularly so where it is considered in the light of the wide dispersion of logging coupes which is the normal practice.

Monitoring fauna impacts is more difficult. The postgraduate study to be funded by the proponent will be of assistance in this regard and any useful results will be immediately incorporated into field practice.

CONCLUSIONS

The Department of Conservation and Land Management has thoroughly reviewed all aspects of the proposal to harvest jarrah for the production of charcoal for the Silicon Project. It is satisfied that there will be no difficulty in availability of timber resource for the Project, although there are currently unresolved questions relating to the precise specification for timber to be supplied to the charcoal production facility and to the arrangements for logging contracts. However, these are in the process of being resolved.

No significant adverse environmental impacts of the Project are foreseen in respect of its impacts on the forest. CALM is also confident that its 10 years of experience with a residue-using industry in southern forests will enable it to control the new industry successfully.

The Project will also have important beneficial effects on forest management in the northern jarrah forest, improving the efficiency of timber utilisation, improving the efficiency of forest regeneration and improving forest productivity.

REFERENCES

1. Anon. 1987. Draft Management Plan, Northern Forest Region. Department of Conservation and Land Management, W.A.

2. Anon. 1987. Draft Management Plan, Central Forest Region. Department of Conservation and Land Management, W.A.

3. Anon. 1987. Timber Production in Western Australia (Draft). A Strategy to take W.A.'s Forests into the 21st Century. Department of Conservation and Land Management, W.A.

4. Anon. 1987. Draft Management Plans Supporting Papers. Department of Conservation and Land Management, W.A.

5. Anon. 1986. Environmental Review and Management Programme, Western Australian Silicon Project. Maunsell and Partners Pty Ltd.

6. Anon. 1986. Manual of Specifications for Control of Hardwood Logging Operations in the Northern Jarrah Forest. Department of Conservation and Land Management, W.A.

7. Anon. 1987. Code of Hardwood Logging Practice. Department of Conservation and Land Management, W.A.

8. Abbott, I. and O. Loneragan. 1986. Ecology of jarrah (Eucalyptus marginata) in the Northern Jarrah Forest of Western Australia. Bulletin No. 1, Department of Conservation and Land Management, W.A.

9. Low, K., Ridley, J., Jordan, B., and M. Giblett. 1985. Hygiene Logging Trials: Results of Monitoring. Department of Conservation and Land Management, W.A.

10. Hingston, F.J., Dimmock, G.M. and A.G. Turton. 1980. Nutrient distribution in a jarrah (Eucalyptus marginata Donn. ex Sm.) ecosystem in South-west Western Australia. Forest Ecology and Management 3: 183-207.

11. Dimmock, G.M., Bettenay, E. and M.J. Mulcahy. 1974. Salt content of lateritic profiles in the Darling Range, Western Australia. Australian Journal of Soil Research 12: 63-69.

12. Herbert, E.J., Shea, S.R. and A.B. Hatch, 1978. Salt content of lateritic profiles in the Yarragil catchment, Western Australia. Research Paper 32, Forests Department of W.A.

13. Ritson, P., Herbert, E.J. and S.R. Shea. 1981. Groundwater hydrology studies in the Yarragil catchment, Western Australia. Research Paper 66, Forests Department of W.A.

14. Shea, S.R. and A.B. Hatch. 1976. Stream and groundwater salinity in the South Dandalup catchment of Western Australia. Research Paper 22, Forests Department of W.A.

15. Anon. 1984. Bauxite Mining in the Jarrah Forest. Bulletin 169, Department of Conservation and Environment, W.A.

16. Shea, S.R., Hatch, A.B., Havel, J.J., and P. Ritson. 1975. The effect of changes in forest structure and composition on water quality and yield from the northern jarrah forest. Proceedings Ecological Society of Australia 9: 58-73.

17. Abbott, I. and P. van Heurck. 1985. Response of bird population in jarrah and yarri forest in Western Australia following removal of half the canopy of the jarrah forest. Australian Forestry 48: 227-234.

18. Abbott, I. and P. van Heurck. 1985. Tree species preferences of foraging birds in jarrah forest in Western Australia. Australian Wildlife Research 12: 461-466.