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REVIEW OF INSECT PROBLEMS IN THE JARRAH FOREST

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REVIEW OF PAST AND CURRENT RESEARCH INTO INSECT PROBLEMS IN THE JARRAH FOREST, WITH RECOMMENDATIONS ABOUT THE FUTURE DIRECTION OF RESEARCH

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EXECUTIVE SUMMARY

1. Pest populations of two species of insect (Jarrah Leafminer and Gumleaf Skeletonizer) currently infest 53% of jarrah forest, or 56% of high quality (codominant height > 27m) jarrah forest.

2. Chronic infestation (for at least 20 years) by leafminer in southern forests has resulted in considerable loss of wood production, estimated to be in excess of $1M per annum sawlog royalty alone.

3. In areas of chronic infestation, jarrah crowns have deteriorated. Mazanec's plot data show that few trees have died within the past 20 years. However, with continued infestation it is unlikely that affected trees will recover.

4. The number of unhealthy or dying jarrah has recently prompted Operations staff to consider a widespread salvage operation.

5. According to Mazanec about 25% of jarrah poles are resistant to leaf damage by Leafminer. However this percentage requires confirmation. Moreover, resistant trees do not appear to be uniformly distributed.

6. Crown dieback on such a scale would also jeopardize conservation values of the southern jarrah forest, particularly the conservation of birds and possibly the water quality of streams within affected catchments.

7. Leafminer outbreaks are slowly expanding northwards. The current northern limit is the northern boundary of Collie District. There is no obvious barrier to further spread northward. The quality of the water supply to metropolitan Perth and the irrigation areas may therefore eventually be at risk.

8. Outbreaks by Gumleaf Skeletonizer began in 1982-3 and have persisted but are still confined to the lower southern jarrah forest. By analogy with leafminer, these infestations should also result in reduced wood production in affected stands. No jarrah resistant to Skeletonizer is known to exist. Forest infested by both Leafminer and Skeletonizer must be under greater stress than forest infested by one species alone.

9. Current research has revealed that outbreaks are neither highly correlated with nor overcome by silvicultural techniques such as logging or burning. Several options therefore remain : no action; monitoring; salvage logging; increasing the proportion of resistant trees in logging and regeneration; new research into possible biological control of both insect species. However such research will be expensive and necessitate provision of specialist staff and redeployment of others.

10. The attached report makes 18 recommendations, of which the most important is the formation of a task force to ensure that CALM's response to this grave problem is efficiently co-ordinated.

11. It is suggested that this report be discussed by the Policy Directorate and that infested areas in Collie and Manjimup Districts be inspected later this year. Subsequently the Minister for CALM should be briefed to present a case to Cabinet for special consideration.

RECOMMENDATIONS

1. Research Division should consider providing a 3 year grant for employing a taxonomist to clarify the taxonomy and life cycles of the chrysomelid defoliating beetles present in the forests of Western Australia.

2. Research Division should continue to quantify damage to jarrah leaves in the Southern jarrah forest each year, but once only (in November). The sites established in the NJF should also continue to be studied; at present biennial assessment (in November) seems sufficient. Because of the recent incursion of jarrah leafminer (JLM) into forest north of Collie, some sites need to be selected there to permit estimation of damage to jarrah leaves. These three sets of data provide the essential baseline to which future damage to jarrah leaves can be compared.

3. Forest Resources Division (Inventory Section) should obtain details of plot locations, tree measurements etc from CSIRO and maintain and incorporate these benchmark plots into the CALM system and then remeasure them from time to time.

4. Forest Resources Division (Inventory Section) should take over and expand the current inventory plot study on medium-term effects of JLM infestation on wood growth. Research Division should initiate a study of long-term effects of JLM on wood growth by counting and measuring growth rings in paired samples of adjacent resistant and susceptible jarrah.

5. Forest Resources Division (Inventory Section) should begin systematic searches for jarrah resistant to Gumleaf Skeletonizer (GLS). These searches would be best conducted in January within the GLS outbreak area, when plants with green crowns would be obvious.

6. Research Division should give major attention to the search for parasitoids and invertebrate predators of GLS by appointing a technical assistant to the entomologist shortly to be based at the Manjimup Research Centre and upgrading the insectary there. This type of research is best done close to the forest. The goals would be to identify parasitoids and predators, assess their abundance and distribution in the forest, select one or two of the more promising species for laboratory culturing, mass-rearing and subsequent release in the forest. It may also be necessary to investigate whether importation of parasitoids from South Australia (where GLS is not a pest) is practicable.

7. Research Division should determine which bird species in the jarrah forest eat GLS caterpillars.

8. Research Division should routinely continue sampling of GLS caterpillars, GLS parasitoids and invertebrate predators at least once each year.

9. Research Division should investigate whether there is a climatic basis to the JLM outbreak by obtaining appropriate information held in computer by the Bureau of Meteorology and WAWA. Annual expansion of the outbreak area should also be related to the logging and fire records held by CALM.

10. Research Division should undertake computer modelling studies linking the expansion (and contraction) of the outbreak area of GLS with SDI, WAWA and Bureau of Metereology data and logging and fire maps held by CALM.

11. Forest Resources Division (Inventory Section) should take over the annual mapping of brown canopies caused by JLM and GLS. They should also investigate if LANDSAT and other modern techniques allow an unequivocal basis for mapping forests damaged by defoliating insects.

12. Forest Resources Division (Inventory Section) should examine the degree of association between site-vegetation types and outbreak areas of JLM and GLS.

13. Research Division should appoint a physiologist to study the effects of various degrees of defoliation by JLM and GLS on the physiological condition of jarrah and how jarrah responds nutritionally to such leaf damage.

14. Research Division should liaise with WAWA and conduct joint historical research into the impact of past insect infestation on water quality in various subcatchments.

15. Research Division should conduct a series of censuses of bird populations within outbreak and non-outbreak forest stands in the SJF. This study should establish if birds are less abundant and less widespread within stands experiencing outbreaks of defoliating insects.

16. Research Division should appoint a microbiologist or insect pathologist with expertise in bacteriology, mycology and virology to undertake a study of the natural importance of bacteria, fungi and viruses in killing pest insects, and to evaluate if other bacteria, fungi or viruses should be introduced to control pest insect populations (Note :This scientist possibly could contribute to research on controlling foxes and feral cats).

17. Forest Resources Division and Research Division should survey and determine the adequacy of resistant jarrah regeneration and evaluate the feasibility of encouraging the development of resistant individuals and increasing their abundance by selective breeding and propagation. JLM

18. Policy Directorate should consider appointing a task force to investigate the insect problem in the jarrah forest. Forest Resources, Operations, Research and Services Divisions within CALM and a CSIRO entomologist and WAWA scientist should be represented on this task force. The duties of the task force would be to co-ordinate, supervise and implement the 17 recommendations made in this report. The Policy Directorate should ensure that sufficient resources are made available. In view of the gravity of the situation, it is also suggested that the Minister for CALM be briefed to present a case to Cabinet for special consideration.

CONTENTS

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*Abbreviations used in this report: SJF, southern jarrah forest (Collie southwards); NJF, northern jarrah forest (Collie northwards); JLM Jarrah leafminer; GLS, Gumleaf skeletonizer.

1. INTRODUCTION

No serious insect problem was reported in the jarrah forest until the early 1960's. CSIRO became involved in 1962 when M. Wallace surveyed much of the southwest for the presence/absence of JLM. He then researched the basic life history of the insect and investigated insecticidal control (Wallace 1966, 1970). Some of this work was continued by Z. Mazanec (1968 -) who made more detailed studies of larval development, selection of oviposition sites, ecology of parasitoids, predation of mines by birds and the consequence of JLM infestation on wood growth of jarrah (Mazanec 1974, 1978, 1980, 1981, 1983, 1984 ab, 1985, Mazanec and Justin 1986). He initiated (1968) mapping of the zone of moderate-severe infestation of JLM. His research terminates at the end of this year amd it is unlikely that he will be replaced by another forest entomologist (Ridsdill Smith, pers. comm.).

The Forests Department appointed S. Curry as forest entomologist in 1964, and for various reasons he was based in the Entomology Branch of the Department of Agriculture. His research on JLM sought to refine insecticidal treatments but was never written up. Most of the raw data was salvaged when Curry retired in 1984, but no research working plans were located. I found it impossible to understand exactly what was done. A trial aerial spraying of JLM - infested jarrah forest revealed little benefit in relation to cost (Van Didden 1967). The only other contribution from Forests Department personnel involved mapping the 'line of attack' of the JLM outbreak as it moved westwards toward Manjimup in 1964, 66 and 67 (A. Mather, see Appendix (a)).

The outbreak of GLS, first noticed by foresters in January 1983, was studied by S. Curry and G. Strelein until about mid 1984. I was appointed forest entomologist in November 1983. My first task involved a critical review of previous research; this was completed in February 1984 but not published until December 1985. Much of 1984 was spent writing up results of my previous research on jarrah silviculture. My entomological research begun in November 1984. I was then assisted by one technician, and a second from February 1986. Throughout much of 1985 and then subsequently Manjimup Research Centre contributed about 20 technician-days per annum.

The ultimate aims of jarrah forest entomological research currently conducted by CALM are

* to formulate a plan for controlling JLM, by combining the results of the 20 year study by CSIRO (report due 1988) with those from research conducted by CALM. The most urgent need is to reduce the rate of spread of the outbreak north of Collie.

* to formulate a plan for controlling GLS, after experimental evaluation of the efficacy of fire, thinning, birds, spiders, parasitoids, bacteria, fungi and viruses in suppressing the insect.

* to devise a stand hazard-rating system for JLM and GLS, suitable for use by Inventory and Operations.

* To maintain surveillance of other leaf feeding insect species, assemble basic life history data for each, and obtain baseline estimates of their population size while these insects are still not in outbreak.

The purpose of this paper is to review our knowledge of insect problems in the jarrah forest, and consider if a task force should be formed to co-ordinate a multi-Divisional study. The need for such a review is almost self-evident. Firstly, there has been a loss of staff. Two positions (one professional, one technical) have been transferred from WADA to CALM, but the technical one cannot be filled until another position within Research Division is lost. K. Low, formerly of Environmental Protection Section, was responsible for monitoring insect outbreaks but was not replaced when he transferred to Operations Division. Second, forestry staff in the Southern Region have noted the expansion of GLS each summer since 1982/3 and are concerned about the future condition of the SJF.

It is my perception that both the popular conservation movement and the senior management of CALM do not appreciate the magnitude of current insect problems. This report is intended to inform the latter group about these problems so that they are not overlooked in future when Departmental policies and priorities are formulated.

2. LEAF DAMAGE BY INSECTS

(a) Development of methods for sampling leaves

This is basic to any measurement of the loss of leaf area attributable to insects. Popular methods of sampling leaves involve picking leaves or shooting at foliage in the canopy, but neither is unbiassed because leaves already abscissed following extensive damage are unavailable for sampling.

The method consistently adopted was to tag new leaves as soon as the petiole is long enough to hold the tag (generally November).

(b) **Identification of types of damage**

This has been achieved by compiling a herbarium of damaged foliage, by collecting the commonly seen insects and returning them to the Como shadehouse where they were allowed to feed on undamaged leaves of potted jarrah plants held in cages. More than 20 insect species have been found damaging jarrah leaves within a 50 km radius of Manjimup. Twelve of these could be described as the principal folivores with only two of these (JLM, GLS) of present concern.

Leaves damaged by fungi were sent to the Plant Pathology Branch of the Department of Agriculture and to Dr H. Swart, Botany Department, University of Melbourne. All samples proved to be of an undescribed species in the genus Mycosphaerella.

There is urgent need for fundamental taxonomic research on forest insect species, especially chrysomelid beetles which are already important pests of eucalypt forests elsewhere in Australia. The two insect taxonomists on the staff of the WA Museum do not have research interests in taxonomy of forest insects, and a similar state of affairs exists in most states. However, Mr C.A.M. Reid is completing a PhD degree on taxonomy of part of the Chrysomelidae at the Australia National University and is the only scientist in Australia with the necessary expertise. It is worth noting that this Family is also likely to have a very high proportion of endemic species in SW Australia, indicating that their conservation value will be high.

RECOMMENDATION 1 : **Research Divison should consider providing a 3 year grant for employing a taxonomist to clarify the taxonomy and life cycles of the chysomelid defoliating beetles present in the forests of Western Australia.**

(c) **Quantification of actual damage**

In November 1984, 600 new leaves of jarrah ground coppice (i.e. 30 leaves x 20 sites) were tagged, and in January 1985 360 new leaves in jarrah pole crowns (30 leaves x a subset of 12 of the above 20 sites) were tagged from a cherrypicker, 14 m above ground level. Transparent plastic sheets were used to trace the outline of each leaf and of each kind of damage on it. These traces were then converted to areas using the digitizer in Mapping Branch, Como. The actual method was devised and implemented by technical assistant P. Van Heurck. The data in the digitizer can then be analysed by computer and arithmetic means of % leaf area damaged by each agent printed out.

Damage to leaves of jarrah ground coppice by the fungus Mycosphaerella was as important as damage by insects (Table 1). Insect damage to leaves was about 50% higher on average in crowns than in ground coppice but the total damaged area was similar in crowns and ground coppice (Table 1). It is important to note that JLM infestation within the sampling area (50km radius around Manjimup) was in remission in 1985 and 1986.

(d) Quantification of when damage occurs

The November 1984 cohort of leaves tagged on ground coppice was examined each quarter. Nearly all fungal damage takes place when the leaf is 0-3 months old. Most rasping occurs at ages 6-12 months, and leaf biting at 0-3 months and again at 9-15 months. JLM damage takes place at age 6-12 months, with a slight (1.8%) increase at 18-24 months. Total damage (insect and fungus combined) averaged 24.9% at 12 months and 30.0% at 24 months.

(e) Correlation of insect damage to leaves with environmental and stand characteristics.

Data on 12 variables describing each of 20 entomological sites in the SJF were assembled. They were altitude, stand basal area, distance from private property, number of years since last fire, number of years since last logging, annual rainfall zone, % forest cover; % jarrah cover and % gravel, % coarse sand, % fine sand and % silt and clay in topsoil. The 20 sites were selected to give good coverage of all variables : included were some virgin (unlogged) stands; one stand unburnt for 20 years; stands near the karri belt; others near wandoo; one stand had been clear felled 4 years earlier; some sites were sandy and others were gravelly. The four textural properties were considered potentially important because the JLM larva oversummers in the topsoil (see Sect. 5a).

The 12 variables were used in a multiple linear regression analysis to predict leaf damage caused by JLM, Mycosphaerella fungus, leaf rasping insects, leaf biting insects, and damage caused by all organisms combined. The only statistically significant regressions found were between:

% leaf area damaged by JLM and average annual rainfall (-ve, r^2 = 33%).

% leaf area damaged by JLM and time since last fire (-ve, r^2 = 17%)

and % leaf area damaged by fungus and % forest cover (+ve, r^2 = 48%).

Thus JLM damage is greatest in stands experiencing low average annual rainfall and a recent fire, and fungal damage is greatest in stands with the densest canopy cover. These correlations suggest how jarrah stands differ in their vulnerability to damage by JLM and Mycosphaerella fungus. However, more importantly, these correlations require experimental validation.

It is particularly noteworthy that stand basal area, time since logging and soil texture did not help in predicting leaf damage caused by JLM.

(f) Comparison of damage to leaves with the other seven eucalypt species present in the SJF.

The seven species involved are Karri, Marri, Wandoo, Bullich, Yarri, *Eucalyptus decipiens* and *E. rudis*. The purpose was to discover if leaves of Jarrah are especially badly damaged by insects and fungi in comparison to the other species. This study was done over one year, with the tagged November 1985 cohort of leaves (on ground coppice or saplings) being traced in November 1986.

Flooded Gum experienced most damage (Table 2) followed by Yarri and Jarrah. Jarrah sustained the second highest level of insect damage (after Yarri) and the second highest level of fungal damage (after Flooded Gum).

(g) Comparison of leaf damage in pole crowns and ground coppice of jarrah.

JLM caused similar levels of damage to leaves in pole crowns and ground coppice (Table 1), whereas leaf biting insects caused nearly twice as much damage in the crown. Most of this damage is attributable to GLS. Wind also contributes to loss of leaves from crowns. This study showed that GLS is mainly a defoliator of crowns, necessitating use of a cherrypicker.

(h) Comparison of leaf damage in jarrah ground coppice in the SJF and NJF.

In November 1985, 20 sites covering a wide range of average annual rainfall zones, logging and fire histories etc were selected in the NJF (between Brookton Highway and North East Road). Leaves were tagged then and traced one year later. These traces were compared to those from the November 1985 cohort of leaves tagged on the 20 plots in the SJF (see Sect. 2c).

The total damage caused by insects was similarly low in both regions (Table 3), probably because 1986 was a year when JLM infestation was in remission in the Manjimup region. There was less leaf biting by insects in the SJF and no damage by JLM in the NJF. Mycosphaerella fungus damage was much less in the NJF, so that the total % area of leaf damaged was higher in the SJF (26.0%) than in the NJF (18.4%).

RECOMMENDATION 2 : Research Division should continue to quantify damage to jarrah leaves in the SJF each year, but once only (in November). The sites established in the NJF should also continue to be studied; at present biennial assessment (in November) seems sufficient. Because of the recent incursion of JLM into forest north of Collie, some sites need to be selected there to permit estimation of damage to jarrah leaves. These three sets of data provide the essential baseline to which future damage to jarrah leaves can be compared.

3. JARRAH RESISTANT TO INFESTATION BY JLM

According to Mazanec (1974) and Abbott (unpubl. data), about one quarter of jarrah poles and ground coppice respectively are resistant to leaf damage by JLM. However, an annual survey of 15 Inventory plots NE of Manjimup by J. Hall since 1983 recorded that none of the 406 trees was strictly resistant to JLM. At this stage I do not know if a different definition of "resistance" was used but the plots will be checked next year in order to clarify the discrepancy. In addition, J. Bradshaw (pers. comm.) believes that resistant jarrah are not as abundant or as widely distributed as claimed by Mazanec (1974).

It would be valuable to determine whether susceptible jarrah produce as much seed as resistant jarrah; if not there could be strong natural selection for resistance operating. The heritability of resistance to JLM is not known. If it were high then breeding and planting of resistant jarrah could be practicable.

4. WOOD GROWTH

(a) Short-term effect of JLM on wood growth.

Mazanec (1974) assessed the short-term impact of JLM on diameter increment by measuring DOB of 58 resistant trees and an equal number of susceptible trees on four sites near Manjimup from 1967 to 1971.

One site, Diamond, had very low levels of leaf damage (not specified by Mazanec 1974, but certainly <<40%, Mazanec pers. comm.), and a comparison of the diameter increments of resistant and susceptible trees there showed no appreciable difference. However the other three sites experienced 'severe' leaf damage (i.e. >60% of the average leaf area of susceptible jarrah was damaged by JLM, Mazanec pers. comm.), so that the annual loss of diameter increment per susceptible tree at these sites ranged from 64-79% (mean 71%). The annual loss of diameter increment per tree (susceptible and resistant jarrah combined) varied from 49-61% (mean 54%). Thus, within severely infested forest, diameter increment of the jarrah component is about half of its value in non-outbreak forest.

Mazanec (1974) estimated that 400 000 ha (25%) of State Jarrah Forest was affected by moderate to heavy JLM infestation (i.e. an average of >40% of leaf area damaged). The loss in wood growth over such a large area cannot be regarded as trivial.

The four plots just mentioned were a subset of seven plots established by Mazanec in 1969 in which 20 trees were tagged. An additional four plots were established in 1980.

RECOMMENDATION 3 : **Forest Resources Division (Inventory Section) should obtain details of plot locations, tree measurements etc from CSIRO and incorporate these benchmark plots into the CALM system and then remeasure them from time to time.**

(b) Medium-and long-term effects of JLM on wood growth.

Medium-term effects have been assessed on a selection of Inventory jarrah plots in Manjimup, Pemberton and Nannup Districts. Most of these plots were first measured in 1961 or 1971. Colin Ward (Manjimup Research Centre) visited 15 plots, selected codominant and subdominant jarrah poles, noted whether they are resistant or susceptible to JLM, and remeasured DOB and bark thickness. These data allow calculation of growth losses over 15-25 year periods (Table 4).

The DUB loss in high quality stands is 52% for codominant poles and 21% for subdominant poles (or an average of 38%). In low quality stands the comparable figures are 75% and 57% (66%). Because future intensive silviculture will be carried out only in high quality stands, low quality forest can be ignored. To put these data on a stand basis, it is necessary to multiply by 0.75 (the proportion of susceptible trees). Assuming that average volume UB production is $1m^3$/ha/yr and given that 420 000 ha of high quality jarrah forest is or has been infested by JLM, then the annual loss in wood growth caused by JLM is about 0.38 x 0.75 x 420 000 or 120 $000m^3$.

Allowing for 50% utilization, this amounts to a loss of more than $1M in sawlog royalty each year. These figures could be made more precise if the volume of wood produced/ha/yr by codominant and subdominant jarrah in high quality stands in the SJF was known.

Following Mazanec's short-term study (1968-71), the leafminer seems to have attained some sort of equilibrium in the SJF. Since 1984, the only year when there was extensive moderate-severe defoliation by JLM was 1986 but even this infestation was extremely patchy south of Bridgetown. In contrast, moderate-severe infestation has been prevalent each year in Kirup and Collie Districts. Research into the effects on wood growth of the recent (1975-83) expansion of infestation into these Districts will be initiated late in 1987.

Long-term effects could be measured by locating pairs of resistant/susceptible poles or piles anywhere in the SJF, felling them, and counting growth rings. This study would allow 30 + year estimates of the effect of JLM infestation on wood growth, and would also permit precise dating of when and where the outbreak began.

RECOMMENDATION 4 : Forest Resources Division (Inventory Section) should take over and expand the current inventory plot study on medium-term effects of JLM infestation on wood growth. Research Division should initiate a study of long-term effects of JLM on wood growth by counting and measuring growth rings in paired samples of adjacent resistant and susceptible jarrah.

(c) Evidence for a threshold level of leaf damage below which there is little effect on wood growth.

This is an extremely important research question which we have pursued since 1984. The data collected suggest but do not prove that this threshold is c.40% of leaf area.

In the scientific literature three types of relationship between plant growth and % defoliation have been described. The commonest is monotonic decreasing linear (No. 1, Fig. 1), No. 2 represents a threshold, and No. 3 stimulation of growth with low-moderate levels of defoliation.

In October 1984 25 ground coppice were selected in Yanmah and in Cardac blocks, and all the leaves present counted. These plants were assigned randomly to one of five treatments :

- T25 : distal 25% of every leaf on five ground coppice was clipped off;
- T50 : distal half of every leaf on five ground coppice was clipped off;
- T75 : distal 75% of every leaf on five ground coppice was clipped off;

T100 : each leaf was cut off.
C : control (no clipping)

One year later all leaves belonging to the cohorts present in October 1984 were counted. Leaf survival was similar in the control, T25 and T50 treatments, but much less in the T75 treatment. This suggests a threshold exists between 50% and 75% loss of leaf area.

A second experiment begun in January 1986 in Yardup and Quininup blocks involved T25, T50, T75, and C treatments except that only five new leaves (i.e. November 1985 cohort) on each of 10 ground coppice were clipped (i.e. a very small minority). One year later, there was no difference in survival of these tagged leaves among the four treatments. This experiment indicates that severe damage to a small number of leaves does not affect their survival.

The height of the ground coppice in the Yanmah / Cardac experiment was measured in October 1986 (before clipping of leaves) and then one year later. The Cardac plants showed no height growth, but the relationship for the rather more dynamic plants at Yanmah is shown in Fig. 2. The control, T35 and T100 treatments have very similar height growth, whereas the T54 and T82 treatments show a reduction in height growth of about 30%. These data suggest that a threshold exists between 35% and 54% of leaf loss.

A further assessment of the impact of insect defoliators on growth was attempted by spraying saplings in Cardac block with insecticide (concentration 1ml/l). A pilot trial showed that the recommended concentration of 3ml/l resulted in some leaf browning. There were four treatments, each with 15 saplings, and DOB was measured 1m above ground level in January 1986 and then again one year later. The treatments were :

I: Insecticide application once in April and once in May [This is when JLM moths oviposit].
II: Application once each month from June to November inclusive [This is when the leaf miner caterpillar within the leaf is feeding]
III: Application once each month from November to March inclusive [This is when many leaf-feeding beetles are most active].
IV: Control, unsprayed.

Unfortunately the level of insecticide used was only slightly effective, as the difference in % area of the average leaf damaged by insects averaged 18.6% in the three insecticide treatments compared with 24.3% in the control. The DOB increment averaged 1.22 cm (insecticide treatments) as against 1.25 cm in the control. The % total damage to leaves (i.e. insect + fungal causes) averaged 23.1% in the sprayed treatments and 28.1% in the control. These results are, however, consistent with the hypothesis that c.40% damage to a leaf represents a threshold, below which there is little effect on growth of jarrah.

Since July 1987, insecticide has been injected into stems rather than sprayed onto foliage following advice from Mr E. Taylor of the NSW Forestry Commission.

Research Division intends to pursue this question further later this year, when a complex experiment assessing the impact of repeated defoliations on wood growth of jarrah saplings will be initiated. The design is as follows:

Treatment	% Crown Removed	Number of Defoliations	No. Saplings
1 (control)	Nil	None	15
2	25	One	15
3	25	Two	15
4	25	Three	15
5	50	One	15
6	50	Two	15
7	50	Three	15
8	75	One	15
9	75	Two	15
10	75	Three	15
11	100	One	15
12	100	Two	15
13	100	Three	15

Treatments involving one defoliation : January 1988
Treatments involving two defoliations : January 1988, January 1989.
Treatments involving three defoliations : January 1988, January, 1989, January, 1990.

This experiment should indicate if repetitive low level defoliation has as much impact on wood growth as one or two severe defoliations.

(d) Search for jarrah resistant to GLS.

About one quarter of jarrah trees (poles, piles) and ground coppice are resistant to JLM (Sect.3). Casual observations have not yet revealed any similar situation with GLS, although Mazanec (pers. comm.) has noted that some jarrah resistant to JLM appears also resistant to GLS.

RECOMMENDATION 5 : Forest Resources Division (Inventory Section) should begin systematic searches for jarrah resistant to GLS. These searches would be best conducted in January within the GLS outbreak area, when plants with green crowns would be obvious.

(e) Effect of GLS on wood growth

About 118 000 ha of high quality jarrah forest was infested moderately-severely by GLS at the latest estimate (January 1986). Given that the proportion of jarrah resistant to GLS appears << 1%, then by analogy with JLM (Sect. 4b) the loss of wood growth due to GLS should be 118 000 x 0.38 or 45 000m^3/yr. This is equivalent to about $0.75M per annum in sawlog royalty.

5. INSECT ECOLOGY

(a) Synthesis of available data on life cycles of JLM and GLS.

The life cycle of JLM can be summarized as follows:

		J	F	M	A	M	J	J	A	S	O	N	D
pupa			X	X									
prepupa			X	X									
larva in case in soil		X	X							X	X	X	X
caterpillar	instar 4							X	X	X	X		
	" 3							X	X				
	" 2						X	X					
	" 1					X	X						
egg					X	X							
adult					X	X							

Moths emerge and fly during the day. They are weak fliers. At night or during cold wet days they seek shelter in the litter. Almost all eggs are laid on the lower surface of jarrah leaves (Wallace 1970), at 14-22 C in diminishing light or overcast conditions (Mazanec 1986). The longevity of moths averages 10 days in the laboratory.

The caterpillar stage (within the leaf) lasts 160 days. After feeding finishes (instar 4), the caterpillar falls to the ground within a case, generally around midnight to avoid predation by ants (Mazanec 1980). It then burrows 1-2 cm into the soil, where it remains in diapause for about 150 days (depending on latitude), until the end of February, when pupation begins. The prepupal stage lasts 2 days and the pupal stage another 35 days.

Most eggs are laid in leaves 6 months old (Wallace 1970, Mazanec 1986, Abbott unpubl.) but there is disagreement about whether females prefer tops of trees or the advance growth. Newman and Clark (1926) noted heaviest infestation nearer the ground and this was confirmed by Wallace (1970), with the exception of one stand lacking abundant advance growth. There infestation in the crowns > 12m above ground was extremely heavy. Mazanec and Justin (1986) found a statistically significant difference between infestation in upper canopy and lower canopy. Our studies in 12 stands have not detected any significant difference in infestation 12m above ground compared with 1-2m above ground (Table 1). This is probably because there is a shortage of leaves for oviposition in an outbreak. Where the female moths have a choice, lower levels are used first (Z. Mazanec, pers. comm.).

The life cycle of GLS can be summarized as :

		J	F	M	A	M	J	J	A	S	O	N	D
pupa		X	X										
caterpillar	instar 11 (S, 6 head capsules)	X	X										X
	instar 10 (S, 5 " ")	X	X										X
	instar 9 (S, 5 " ")	X	X									X	X
	instar 8 (S/G,3 " ")										X	X	X
	instar 7 (S/G,2 " ")									X	X	X	
	instar 6 (S/G,1 " capsule)								X	X	X		
	instar 5 (G)								X	X	X		
	instar 4 (G)							X	X	X			
	instar 3 (G)						X	X	X				
	instar 2 (G)					X	X	X					
	instar 1 (G)				X	X	X						
egg			X	X	X	X	X						
adult			X	X									

S = solitary phase
G = gregarious phase
S/G = some caterpillars are solitary, others are gregarious.

As in JLM, there is only one generation each year. The moth is nocturnal, does not feed, is a poor flier, and is probably shortlived. It mates in February and March and the female then lays her eggs in a series of parallel rows, usually on the underside of a leaf 1-4 months old. The eggs hatch from April to June and the small caterpillars feed together on the same leaf until about August. This gregarious phase lasts until about October when the caterpillars become largely solitary (2 or 3 per leaf) and more mobile, often using silken threads to cross to the other trees.

Caterpillars in the gregarious phase confine their feeding to the green leaf matter of the leaf, leaving patches of the brown network of veins. Those in the solitary phase are more voracious : they also eat smaller veins and frequently leave only the midrib and irregular portions of the lamina.

In stands of forest where GLS caterpillars are dense, browning of crowns begins in late November to late December (depending probably on weather). In any case crowns are at their thinnest by the end of January when nearly all caterpillars pupate. Pupation occurs in cocoons spun by the caterpillars ; these cocoons are placed on the branchlets near the leaves the caterpillars have been feeding on, in branch forks, or under bark flakes on large branches or the upper trunk.

Our observations indicate that very few GLS caterpillars occur on ground coppice.

(b) Development of methods of sampling insects.

Both Wallace (1970) and Mazanec (1980) used conical traps to sample JLM moths as they emerged from the soil ; when inverted, these traps could also be used to estimate the density of cells of instar 4 falling to the ground.

Our research has instead concentrated on measuring the damage that JLM caterpillars do to the leaf (Sect. 2c). This method is not suitable for use with caterpillars of GLS, as several other (albeit rare) insects skeletonize leaves and bite fragments from leaves. GLS caterpillars have therefore been sampled by both sweeping foliage and by clipping foliage. The latter method was more efficient, and has the advantage that the density of caterpillars can be expressed relative to the weight of leaves in the sample.

(c) Frequency of sampling.

Since January 1986 foliage from crowns of 45 jarrah poles, piles or trees (within a 50km radius of Manjimup) has been clipped each quarter. This frequency of sampling will terminate in January 1988. The foliage samples are sorted for all invertebrate species present, and the number of individuals of each is tabulated.

(d) Identification of parasitoids of eggs, larvae and pupae of JLM and GLS.

Mazanec (pers. comm.) is currently preparing his research on parasitoids of JLM for publication. The samples described under Sect. 5c are used to compile lists of invertebrates possibly parasitic or predatory on GLS caterpillars. Casual observations on predation/parasitism are also made. Van Heurck (pers. comm.) has been returning large samples of eggs and caterpillars of GLS to the Como Insectary, recording their survival and collecting emerging parasitoids.

RECOMMENDATION 6 : **Research Division should give major attention to the search for parasitoids and invertebrate predators of GLS by appointing a technical assistant to the entomologist shortly to be based at the Manjimup Research Centre and upgrading the insectary there. This type of research is best done close to the forest. The goals would be to identify parasitoids and predators, assess their abundance and distribution in the forest, select one or two of the more promising species for laboratory culturing, mass-rearing and subsequent release in the forest. It may also be necessary to investigate whether importation of parasitoids from South Australia (where GLS is not a pest) is practicable.**

(e) Identification of bird species eating JLM and GLS caterpillars.

Mazanec (pers. comm.) is currently writing up his research on bird predation of JLM mines.

Wardell-Johnson (pers. comm.) attempted to determine which bird species eat GLS caterpillars by mist-netting birds along a suitably overgrown disused track in Yanmah block in December 1986. Unfortunately only five birds were netted; faecal samples were collected from them in order to detect whether these birds had eaten GLS caterpillars.

This subject will be re-assessed in December 1987 when caterpillars are largest. Birds belonging to all insectivorous species of the SJF will be collected within outbreak areas of SJF and their stomach contents preserved for later analysis.

RECOMMENDATION 7 : **Research Division should determine which bird species in the jarrah forest eat GLS caterpillars.**

(f) Annual quantification of density of GLS caterpillars and GLS parasitoids and invertebrate predators.

From January 1988 it is planned to sample GLS caterpillars every January. The best time for sampling for parasitoids and invertebrate predators will be determined when the samples collected each quarter during 1986 and 1987 (Sect. 5c) are analysed.

RECOMMENDATION 8 : **Research Division should continue sampling of GLS caterpillars, GLS parasitoids and invertebrate predators at least once each year.**

(g) Correlation of density of GLS caterpillars with environmental and stand characteristics.

Data on variables describing each of 45 jarrah trees and their immediate environment were assembled. They were : Stand basal area, proportion of jarrah stems in the stand, DOB of tree at breast height, altitude, distance to private property, number of years since the most recent fire, number of years since the stand was logged, and average annual rainfall. Significant correlations between four of these variables and number of GLS caterpillars/kg oven dry leaf weight were found : rainfall (r_s = 0.38, P = 0.005) altitude (r_s = -0.33, P = 0.014), DOB (r_s = -0.30, P = 0.025) and distance to private property (r_s = 0.29, P = 0.025). Unlike JLM, GLS caterpillars are associated with stands in the higher rainfall zone. There were no significant statistical relationships between type of forest management and degree of infestation.

6. INITIATION AND CONTINUATION OF OUTBREAKS

(a) Assessment of factors that may have triggered the outbreak of JLM in the 1960's.

The outbreak of JLM that began more than two decades ago in the SJF had no historical precedent, at least since European settlement. Newman and Clark (1926) recorded that noticeable damage was confined to the 'coastal jarrah growing on the plains country', mainly near Fremantle, Bunbury, Busselton and Albany, but radiating inland 'for several miles to the base of the foothills'. They noted explicitly that no damage was recorded in the country between Torbay and Busselton or in the Darling Range forests. Outbreaks near Perth (Kings Park) were first recorded in 1914.

This historical perspective invites the question 'What initiated the 1960's outbreak in forest east of Manjimup?' Obvious perturbating factors include fire (a change in intensity, season of burning, frequency of burning or combinations of all three factors), logging, deforestation (for farming and settlement) and a subtle change in climate (rainfall, temperature).

Forests Department records were examined for details of areas of forest burned and season of burning, and of areas of forest logged. Unfortunately these records provide no information about intensity of burning or logging. Aerial photographs were used to address the role of deforestation in settled areas within the forest. Records held by the Bureau of Meteorology were examined for several locations near Manjimup and were analysed following White (1969).

Fire Records from the burning season of 1937/8 to 1983/4 show that the percentage of forest area experiencing fire has increased since 1960 (Fig. 3). This derives from a marked increase in Spring burning since 1960 (Fig. 4) and a parallel decline in areas burnt by wildfire since 1960 (Fig. 5). The implication is that since 1960 fires have become more frequent and less intense.

Logging Most logging took place during the 1950's and 1960's (Fig. 6).

Deforestation Clearing of jarrah forest on private property shows a marked increase since the 1960's (Fig. 7).

Climatic change The analyses of winter rainfall (April-September incl.) from 1921 to 1983 for Deeside (30km SE of Manjimup) and Wilgarup (15 km N of Manjimup) contradict the facts known about the expression of JLM outbreaks. The Wilgarup data suggest that winter droughts became normal after 1958 (Fig. 8) whereas the Deeside data (Fig. 9) show that winter droughts have occurred regularly since the 1920's. The Deeside station is close to where the outbreak of JLM is believed to have begun in the early 1960's whereas the JLM outbreak did not reach the Wilgarup area until 1970 (Appendix (a)).

In conclusion, the 1960's was a period when an increase in several kinds of disturbance occurred. Burning became more frequent and more widespread, as did logging and clearing of forest on farms. At this stage it cannot unequivocally be asserted that any one of these factors has primacy. The evidence for climatic change influencing JLM outbreaks is weak.

Many of the interpretations made by Newman and Clark (1926), Wallace (1970) and Mazanec (1980) about the factors promoting or limiting the spread of JLM prove, in hindsight, incorrect. Newman and Clark (1926) suggested that the habit of the larvae of JLM in burying themselves in the soil, just below the surface, renders them liable to destruction in large numbers by the application of fire. The fire passing over the surface of the ground 'roasts the hibernating (sic) larvae'. Wallace (1970) quoted A.C. Harris (1966) that controlled spring burning kills many leafminer in the ground during summer. This would be more true of an Autumn fire which is generally of higher intensity than a spring fire. Mazanec (1980) found that a 'severe' prescribed fire in November 1968 killed 95% of larvae diapausing in the soil. Prescribed (low intensity) fires do not elevate soil temperatures because they pass over the surface too quickly because the litter is relatively moist. Newman and Clark's point could be reversed : the switch to spring burning in the mid 1950's could be used to explain the outbreak of JLM in the 1960's. This cannot, however, be the whole reason because before the 1950's the general policy in jarrah forest since the 1930's was no burning at all. Mazanec (1981) stated that the flush of new leaves following fire leads to immigration of female moths from outside the burning area and heavy oviposition on leaves.

Wallace (1970) gained the dominant impression from broad scale surveys that 'severe infestations were usually associated with open country, or with natural or artificial clearings'. He then suggested that logging and other silvicultural practices which tend to open up the forest may require modification. Mazanec (1980) examined this hypothesis more closely by measuring stand basal area at 42 places within the JLM outbreak zone and at 38 places in non-outbreak areas in November 1978. The averages were 30 and 38 m^2ha^{-1} respectively, a statistically significant difference. However, recent research by CALM has shown that neither stand basal area nor time since logging are significant predictors of JLM leaf damage, but that rainfall zone is significant. These discrepancies can be reconciled because the difference between outbreak and non outbreak areas in stand basal area very likely describes the difference between stands experiencing low or high average annual rainfall. Rainfall was not considered by Wallace or Mazanec.

Wallace (1970) thought that soil type was influential in JLM outbreaks, with sandy sites favouring outbreaks. In the CALM study, which involved a contrast of sandy sites and lateritic sites, this factor was not significant.

The attached maps (Appendix (a)) document the spread of moderate-severe infestation of JLM in 1964, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1980 and 1983. The 1986 map represents infestation in Collie District. The latest maps show that 56% of high quality jarrah forest (420 000 ha) is infested by JLM.

These maps provide an excellent baseline for a study making associations between climatic variables at different meteorological stations and other hydrological records (groundwater level, stream flow) and the spread of the outbreak. This analyses would need to examine relationships between rainfall and minimum/maximum temperature and expansion of the outbreak for (i) the period of oviposition; (ii) the period when the larva feeds within the leaf.

RECOMMENDATION 9 : Research Division should investigate whether there is a climatic basis to the JLM outbreak by obtaining appropriate information held in computer by the Bureau of Meteorology and WAWA. Annual expansion of the outbreak area should also be related to the logging and fire records held by CALM.

(b) Assessment of factors that triggered the outbreak of GLS in 1982/3.

The only previously recorded outbreak of GLS occurred in Spring of 1947 between Calingiri and Cowaramup. So few details are now available that it is uncertain whether the NJF was affected by this outbreak.

every where else I have used the figure of 120,000

The current outbreak in the SJF began in 1982, resulting in widespread browning of crowns in January 1983. Some 90 000 ha of jarrah forest between Nannup, Greenbushes and Walpole were affected. One year later the infested area covered 230000 ha. In January 1985 and 1986 the extent of outbreak was 300 000 ha and 240 000 ha respectively. Maps showing the extent of the outbreak each January have been produced for 1983, 1984, 1985 and 1986 (Appendix (b)).

Because the initiation of the 1982/3 GLS outbreak is very well documented, it should be possible to relate this to the factors already discussed under Sect. 6a (namely, fire, logging, deforestation, climatic change). In addition, the Manjimup Research Centre has records of the daily SDI (soil dryness index) and WAWA has daily records of rainfall throughout the forest area. These data are much more detailed than those of the Bureau of Meteorology.

RECOMMENDATION 10 : Research Division should undertake computer modelling studies linking the expansion (and contraction) of the outbreak area of GLS with SDI, WAWA and Bureau of Metereology data and logging and fire maps held by CALM.

(c) Annual mapping of outbreak areas of JLM and GLS.

In the 1960's and 1970's, Mazanec and associates mapped JLM outbreak areas by traversing the forest by car. Since then the area affected has doubled and aerial mapping is the only alternative.

Aerial mapping of the zones of moderate-severe infestation of both insect pests should no longer be the task of Research Division. With proper training from Research personnel, it could be accomplished by the Forests Resource Division (Inventory Section). At present, these surveys require too many resources from Research Division at a critical time (Spring and Summer) when staff are overloaded with more specialized duties.

Aerial surveys must be done in late Spring (JLM) and mid summer (GLS) because they depend on the recognition of brown crowns ; if deferred the flush of new green leaves in late summer obscures the damage caused by the insects.

RECOMMENDATION 11 : Forest Resources Division (Inventory Section) should take over the annual mapping of brown canopies caused by JLM and GLS. They should also investigate if LANDSAT and other modern techniques allow an unequivocal basis for mapping forests damaged by defoliating insects.

(d) Investigation of whether particular site-vegetation types are prone to infestation.

G. Strelein has recently completed a study which subdivided the SJF into 17 site-vegetation types (using an approach similar to that of Havel 1975 in the NJF). The next step is to map the occurrence of these and assess if any of them associate strongly with their susceptibility to infestation by JLM or GLS. This task is more properly considered as an Inventory one and not Research. This task is important because it would allow Operations Division to plan to manage certain site-vegetation types differently from others.

RECOMMENDATION 12 : Forest Resources Division (Inventory Section) should examine the degree of association between site-vegetation types and outbreak areas of JLM and GLS.

(e) Estimation of likely future distribution of outbreaks of JLM and GLS.

The known distribution of JLM and GLS is shown in Figs 10 & 11. In the NJF, JLM currently occurs extensively in Narrogin (not in outbreak) and Collie (in outbreak) districts and in the southern half of Harvey District (not in outbreak). North of Dwellingup, JLM has been recorded (not in outbreak) in Randall, Lesley and Flynn blocks (CALM records) and in Victoria block (Mazanec, pers. comm.).

The only records of GLS in the NJF are from Illawarra, Lesley and Clarke blocks (not in outbreak). A survey of forest blocks on both sides of the Blackwood River between Nannup and Mayanup is planned for September 1987.

7. CONDITION OF JARRAH CROWNS

(a) Assessment of whether jarrah crowns are deteriorating in width, depth and leaf density.

M. Wallace circulated a questionnaire in 1970 to certain foresters stationed at Manjimup. One question asked "Has JLM attack affected the forest canopy and general tree vigour in any viable way?" and another asked "Is this visible change, if any, definitely confined to JLM infested areas only?"

Most foresters believed that permanent damage resulted from JLM infestation. They noted that where defoliation had only begun recently, crown deterioration had not reached the severity of old infestations. Deterioration appeared rapidly within 5-10 years.

These conclusions are supported by studies on inventory plots rating the condition of the crown of selected codominant and subdominant jarrah resistant or susceptible to JLM (The same trees were studied as mentioned in Sect. 4b). C. Ward (Manjimup Research Centre) used a modified version of Grime's Index based on visual estimates of leaf density, contribution of epicormic branches to foliage and the incidence of dead branches. The index ranges from 0 (tree dead) to 24.

Resistant poles in high and low quality jarrah forest had above average (=12) indices of crown condition (Table 5). The deterioration in crown condition caused by JLM was greatest in codominant poles in low quality forest (44%), followed next by codominant poles in high quality forest (35%). Crowns of subdominant poles deteriorated least (19%).

These data, when combined with those in Table 4, indicate that DUB increment is zero when the crown condition index has a value of 9-10 or below.

Photographs of a group of trees in Boyicup block, east of Manjimup taken by Z. Mazanec in November 1967 and December 1985 show a marked thinning out of crowns following repeated infestation by JLM (Fig. 12). Mazanec has also kindly made available many other photographs of stands taken in the late 1960's. We plan to relocate these stands and rephotograph the crowns.

C. Ward (Manjimup Research Centre) has recently begun photographing branches with foliage in good condition in several plots within the GLS outbreak area.

8. MORTALITY OF JARRAH

(a) Assessment of whether chronic infestation by JLM kills jarrah.

Data made available by Mazanec allow me to conclude confidently that JLM has not yet killed jarrah trees. The evidence comes from 11 plots kept under long-term investigation by Mazanec. In six plots (Cessna, Boyicup, Boyicup East, Marranup, Diamond and Dingup) established in 1969, only three out of 120 trees had died by 1987; one of these trees had never experienced much JLM damage (Mazanec, pers. comm).

In four other plots (Gold Gully, Stallard, Easter and Jubilee) established in 1980, none of the 80 trees had died up to 1987.

Combining these data, mortality due to JLM is 0.11% p.a., i.e. 11 trees die per 10 000 trees per annum.

(b) Investigation of impact of repeated defoliation on nutrient levels in, and physiological condition of, jarrah.

It is desirable to obtain detailed knowledge about the effects of defoliation on the nutrition and physiology of jarrah. The kinds of information required include determining when jarrah has the least carbohydrate reserves and how defoliation interacts with transpiration during summer. Dr S. Crombie, currently employed by CALM on contract to study the physiological effects of Phytophthora cinnamomi invasion on the jarrah tree, would be an obvious person to invite to undertake this study. His present funding expires in March 1988.

RECOMMENDATION 13 : **Research Division should appoint a physiologist to study the effects of various degrees of defoliation by JLM and GLS on the physiological condition of jarrah and how jarrah responds nutritionally to such leaf damage.**

9. POSSIBLE ENVIRONMENTAL CONSEQUENCES OF INSECT OUTBREAKS

(a) Monitoring of stream salinity in IRZ and LRZ of jarrah forest.

The intermediate (900-1100 mm p.a.) and low (<900 mm p.a.) rainfall zones cover the parts of the jarrah forest most favoured by JLM. CALM needs to liaise with WAWA to ensure that all streams in these areas are adequately monitored so that any increase in salinity due to JLM will be detectable. The relevant water courses include the Helena, Canning, Serpentine, Harvey, Collie and Donnelly Rivers and Bell Brook, Bingham R., Harris R., Beraking Brook, Darkin R., Nockine Brook and Bannister R.

Several of these streams feed into the reservoirs serving the water requirements of Metropolitan Perth. As the JLM outbreak area expands into the NJF, crown condition of the forest should decline over a 20 year period and this may lead to a rising water table and risk of increasing salinity in streams draining affected stands. Recent research, however, suggests that this is unlikely (Stokes and Batini 1986).

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Historical records of salinity levels in various southern forest subcatchments need examination in order to determine if JLM infestation has produced a measurable change in salinity.

RECOMMENDATION 14 : **Research Division should liaise with WAWA and conduct joint historical research into the impact of past insect infestation on water quality in various subcatchments.**

(b) Impact on aesthetic and recreational values.

It is rather curious that both JLM and GLS cause browning of crowns. Many other insect folivores remove sections of leaves but do not alter the colour of the piece of lamina remaining. It is very doubtful that the general public would ever be aware of this latter type of crown damage.

Stands with brown canopies resemble forest scorched by wildfire, and are generally perceived as unattractive. Indeed, it is likely that many members of the public confuse the appearance of insect-damaged brown crowns with fire or possibly with fungal dieback.

The caterpillars of GLS are covered with numerous long, urticating bristles. Some humans have skin sensitive to these, so picnic areas within stands damaged by GLS would be undesirable places for allergic people to recreate in.

(c) Impact of defoliated crowns on the abundance of other insects.

Stands with insect-damaged crowns should offer less food and fewer oviposition sites for other insects than stands in which most of the foliage comprising the canopy is green. In other words, both JLM and GLS could cause the microhabitat of the hundreds of other indigenous insects and other invertebrates living in jarrah crowns to deteriorate. Many of these species are likely to be endemic to South-Western Australia, so this problem is important for the conservation of native species of foliage-dwelling invertebrates.

The data currently being collected from both unaffected and affected trees (Sect. 5c) will be used to address this matter and then decide if more detailed investigations are warranted.

(d) Comparison of bird populations within and outside the insect outbreak areas.

As mentioned above (Sec. 9c), extreme browning of crowns may reduce the abundance of other invertebrates. Many of these constitute the food supply of most of the bird species present in the jarrah forest. Therefore, expansion of outbreak areas of JLM and GLS may result in some bird species declining in distribution and abundance within the jarrah forest. Wardell-Johnson (pers. comm.) in December 1986 conducted a census of birds in Yanmah block which is within the GLS outbreak area. He found unusually low numbers of birds present.

RECOMMENDATION 15 : Research Division should conduct a series of censuses of bird populations within outbreak and non-outbreak forest stands in the SJF. This study should establish if birds are less abundant and less widespread within stands experiencing outbreaks of defoliating insects.

10. <u>INSECT CONTROL</u>

(a) Rigorous experimental evaluation of the efficacy of fire, thinning, birds, spiders, parasitoids, bacteria, fungi and viruses in suppressing insect outbreaks.

There seems little merit in seriously considering the use of insecticides because of the possible environmental and evolutionary consequences : These include water pollution, contamination of birds and mammals feeding on affected insects, and the development of resistance by pest insects to insecticides, counteracting their effectiveness.

An experiment was set up in January 1987 in Thornton, Carter and Yanmah blocks to investigate the effect of no fire, a recent (November 1986) low intensity (spring) fire and a moderate intensity (Autumn) fire (planned for 1987 but rescheduled to Autumn 1988 because of unfavourable weather) on density of GLS caterpillars and damage caused by JLM to leaves in pole crowns. The areas of forest (c. 100 ha) set aside for each treatment are quite large. This is because it is planned to thin (using prescriptions of Bradshaw 1987) half of each stand so as to examine if thinning affects the density of insect pests.

Our method of sampling GLS caterpillars (described in Sect. 5b) allows concurrent sampling of spiders, parasitoids, and other insects. This should provide valuable data on the response of these invertebrates to fire and subsequent thinning.

At present there is no one in CALM with expertise to study the usefulness of bacteria, microfungi or viruses in controlling populations of pest insects. Van Heurck (pers. comm.) has recently collected dead GLS caterpillars which appear to have been killed by a nuclear polyhedrosis virus. There is also a need to examine whether spraying of foliage with commercially available <u>Bacillus thuringiensis</u> would contribute to control of JLM and GLS, without reducing the abundance of other invertebrates living in jarrah crowns.

Apart from such limitations, each of these possible methods of treatment needs to be properly costed.

RECOMMONDATION 16 : Research Division should appoint a microbiologist or insect pathologist with expertise in bacteriology, mycology and virology to undertake a study of the natural importance of bacteria, fungi and viruses in killing pest insects, and to evaluate if other bacteria, fungi or viruses should be introduced to control pest insect populations (Note: This scientist possibly could contribute to research on controlling foxes and feral cats).

(b) Field trial involving retention of jarrah resistant to JLM and removal of susceptible jarrah.

The fact that a minority of jarrah plants in the forest are resistant to JLM should be used to reduce the abundance of susceptible saplings, poles and piles in the forest. Current policy concerning thinning is that all resistant trees are retained regardless of size, position or quality (Bradshaw 1987).

RECOMMENDATION 17 : Forest Resources Division and Research Division should survey and determine the adequacy of resistant jarrah regeneration and evaluate the feasibility of encouraging the development of resistant individuals and increasing their abundance by selective breeding and propagation.

11. ADVICE TO OPERATIONS

The intention of the foregoing has been to synthesize the factual data available and to suggest which data should be collected in the future so that definite recommendations can be made to the Operations Division on three important subjects. These are :

* which stands are most at risk to chronic infestation by insects;
* how such stands should be treated in the short-term and long-term in order to reduce infestation and thereby promote more rapid wood growth (in production priority forest) or improve aesthetics and conservation values (in conservation/recreation priority forest);
* how stands currently not infested by insects can continue to be kept free of infestation.

12. CONCLUSION AND FINAL RECOMMENDATION

The general conclusion of this review of past and present research is that a large scale problem exists, it will not go away, it could get worse and the future of the whole jarrah forest could be in jeopardy.

If the 17 recommendations are accepted, their implementation would involve

* improving the co-ordination of CALM's collective effort and expertise;

* rationalizing which Divisions are best equipped to collect and analyse which data. It is suggested that Research Division implement Recommendations 1,2,6,7,8,9,10,12,13,14,15 and 16, and Forest Resources Division implement Recommendations 3,4,5,11 and 12, and both Divisions jointly implement Recommendation 17. The role of the Services Division (Environmental Protection Section) in implementing some of these Recommendations requires clarification.

* supervising CALM's response to the insect problem in the jarrah forest, and ensuring that projects are adequately funded and staffed. Forest Resources Division may not wish to involve their current staff; if this is accepted then they need to re-allocate some of their resources to allow another Division to do the work.

The above goals could be best accomplished by forming a task-force.

RECOMMENDATION 18 : **Policy Directorate should consider appointing a task force to investigate the insect problem in the jarrah forest. Forest Resources, Operations, Research and Services Divisions within CALM, a CSIRO entomologist and a WAWA scientist should be represented on this task force. The duties of the task force would be to co-ordinate, supervise and implement the 17 recommendations made in this report. The Policy Directorate should ensure that sufficient resources are made available. In view of the gravity of the situation, it is also suggested that the Minister for CALM be briefed to present a case to Cabinet for special consideration.**

13. REFERENCES

Nearly all of the references to published entomological research will be found listed in

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14. ACKNOWLEDGEMENTS

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Table 1. Damage (% leaf area) to jarrah leaves (November 1984 cohort)

Damage		Ground Coppice (600 leaves) February 1986	Pole crown (360 leaves) January 1986
Insect	JLM	3.6	5.1
	Rasping (either surface of leaf)	0.6	0.8
	Biting	6.6	10.9
		10.8	16.8
Fungus (*Mycosphaerella*)		17.2	1.1
Wind		0	10.3
Unknown cause		0	2.4
TOTAL		28.1	30.7

Table 2. Damage (% leaf area) to leaves (November 1985 cohort) on ground coppice or saplings of eight eucalypt species in the SJF.

Species	Damage (November 1986) Insect	Fungus	Other or unknown	Total
E. calophylla	7.0	3.4	0	21.2
E. decipiens	8.5	1.9	5.8	16.3
E. diversicolor	2.9	4.5	6.1	13.6
E. marginata	12.6	13.3	1.0	26.8
E. megacarpa	5.1	4.3	8.8	18.1
E. patens	14.0	6.1	8.2	28.4
E. rudis	6.5	26.0	25.5	58.0
E. wandoo	6.3	3.8	0.8	10.8

Table 3. Damage (% leaf area) to leaves (November 1985 cohort) on jarrah ground coppice in the NJF and SJF.

Damage		NJF (600 leaves) November 1986	SJF (600 leaves) November 1986
Insect	JLM	0	2.6
	Rasping (either surface of leaf)	1.0	0.5
	Biting	11.6	8.0
		12.6	11.1
Fungus (*Mycosphaerella*)		1.4	13.9
Unknown cause		4.3	1.0
TOTAL		18.4	26.0

Table 4. Mean DUB increment (cm/yr) shown by codominant and subdominant jarrah poles in high and low quality stands in the SJF.

Stand quality	Codominant		Subdominant	
	Resistant	Susceptible	Resistant	Susceptible
High (9 plots)	Ø.23	Ø.11	Ø.19	Ø.15
Low (6 plots)	Ø.16	Ø.Ø4	Ø.14	Ø.Ø6

Table 5. Mean index of crown condition for codominant and susceptible jarrah poles in high and low quality stands. Index ranges from Ø to 24.

Stand quality	Codominant		Subdominant	
	Resistant	Susceptible	Resistant	Susceptible
High (9 plots)	17.5	11.3	15.6	12.7
Low (6 plots)	17.Ø	9.5	16.2	13.1

FIGURE CAPTIONS

1. Three types of relationship between plant growth and % defoliation.

2. Relationship found between height growth of jarrah ground coppice and % defoliation at Yanmah in Manjimup District.

3. Percentage area of State jarrah forest in Manjimup District burnt each fire season from 1937-8 to 1982-3 (all types of fires combined).

4. Percentage area of State jarrah forest in Manjimup District burnt each fire season from 1937-8 to 1982-3 (prescribed low intensity fires only).

5. Percentage area of State jarrah forest in Manjimup District burnt each fire season from 1937-8 to 1982-3 (wildfires only).

6. Percentage area of jarrah forest logged each decade from 1911-20 to 1971-80 (37 blocks lacking Karri were analysed).

7. Percentage area of jarrah forest on a sample of private properties in Manjimup District cleared since the 1940's.

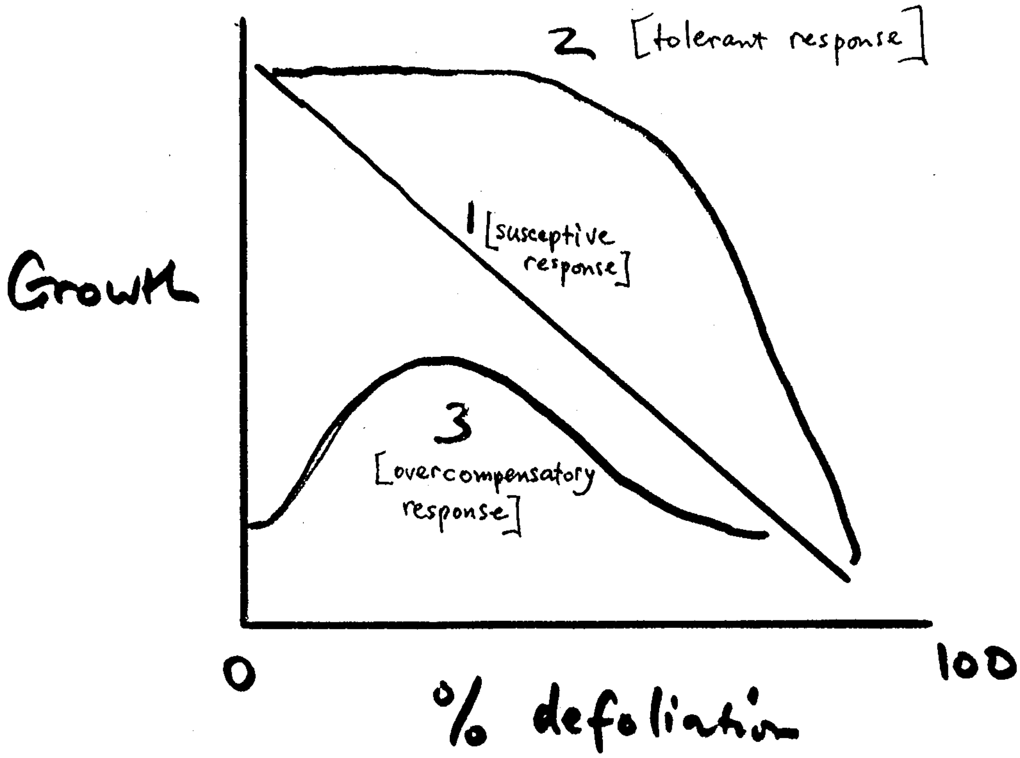
8. Analysis of annual variation in winter rainfall at Wilgarup, Manjimup District from 1921 to 1983, based on an index of White (1969). A positive Z-score indicates a year with above average winter rainfall.

9. Analysis of annual variation in winter rainfall at Deeside, Manjimup District from 1921 to 1983, based on an index of White (1969). A negative Z-score indicates a year with below average winter rainfall.

10. Distribution of JLM within the range of jarrah, showing current distribution (not necessarily in outbreak), occurrence of isolated populations, and likely future distribution.

11. Known distribution of Gumleaf Skeletonizer in Western Australia.

12. Deterioration in condition of the crown of a jarrah pole susceptible to JLM, Boyanup block, over 18 years.

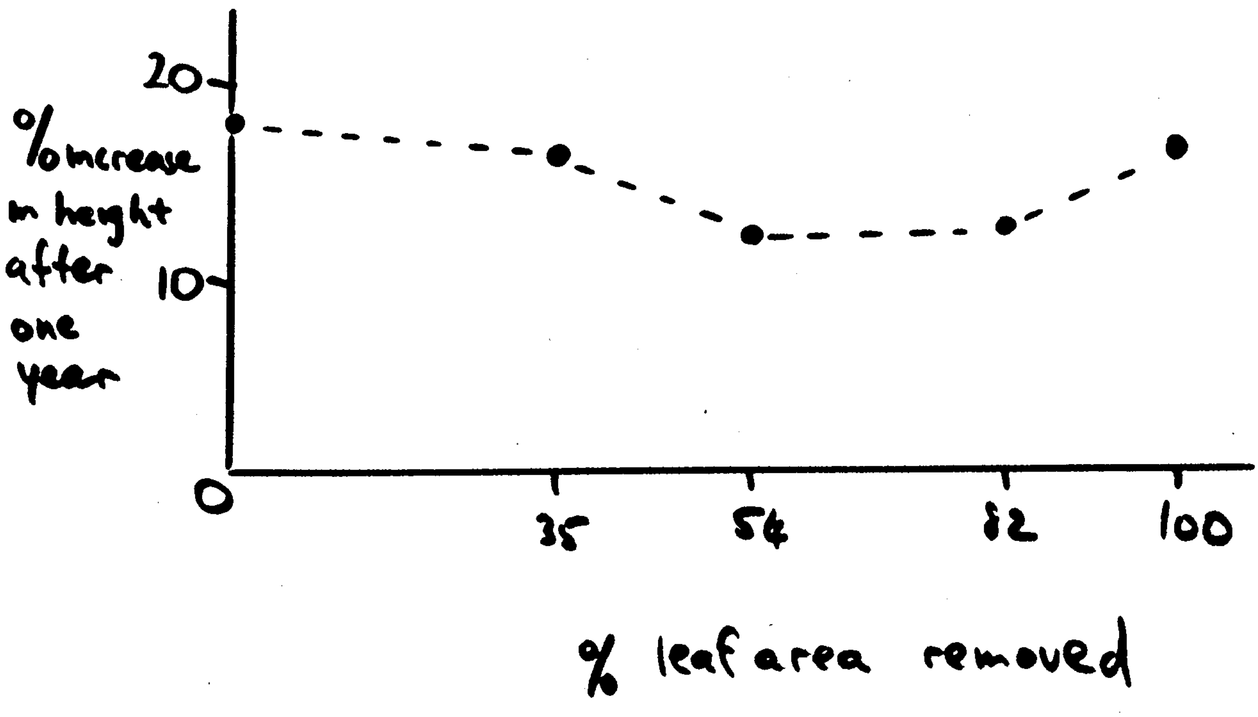


2 [tolerant response]
1 [susceptive response]
3 [overcompensatory response]
Growth
0
100
% defoliation

YANMAH

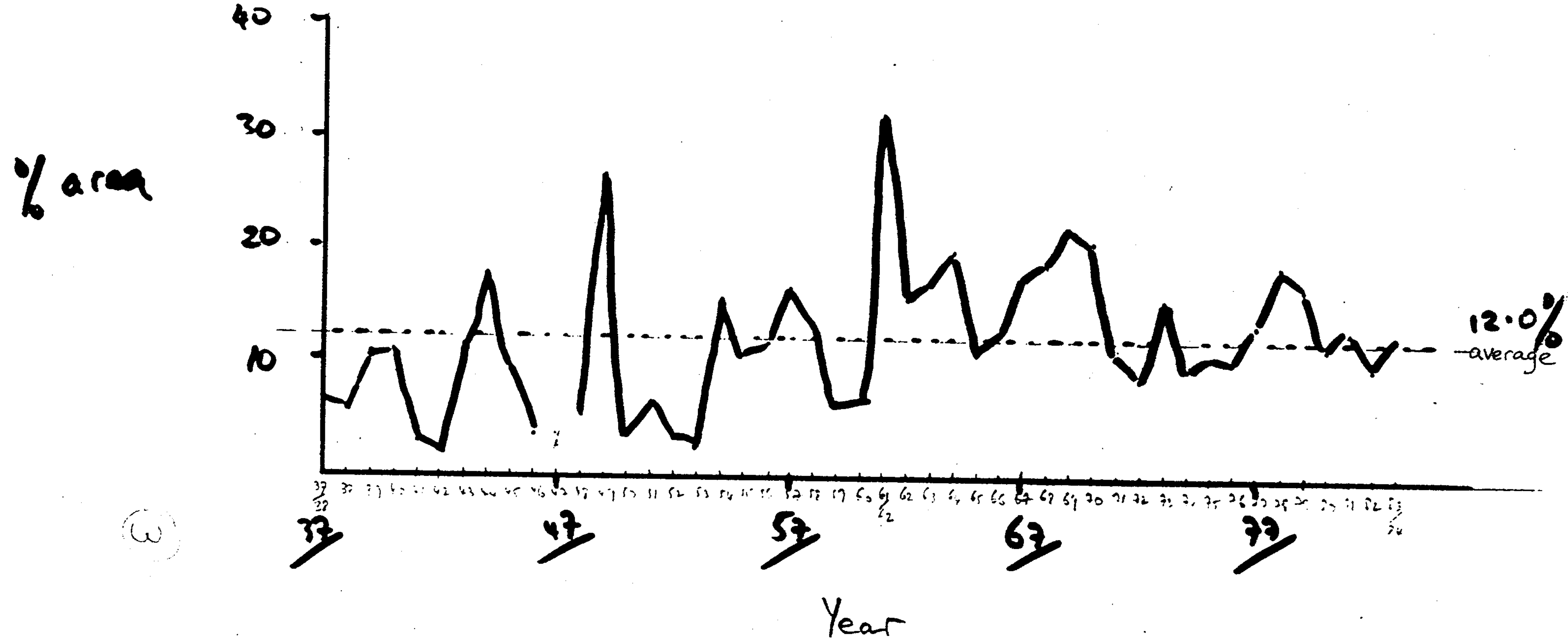
Jarrah ground coppice

Once-only manual defoliations Oct. 84.



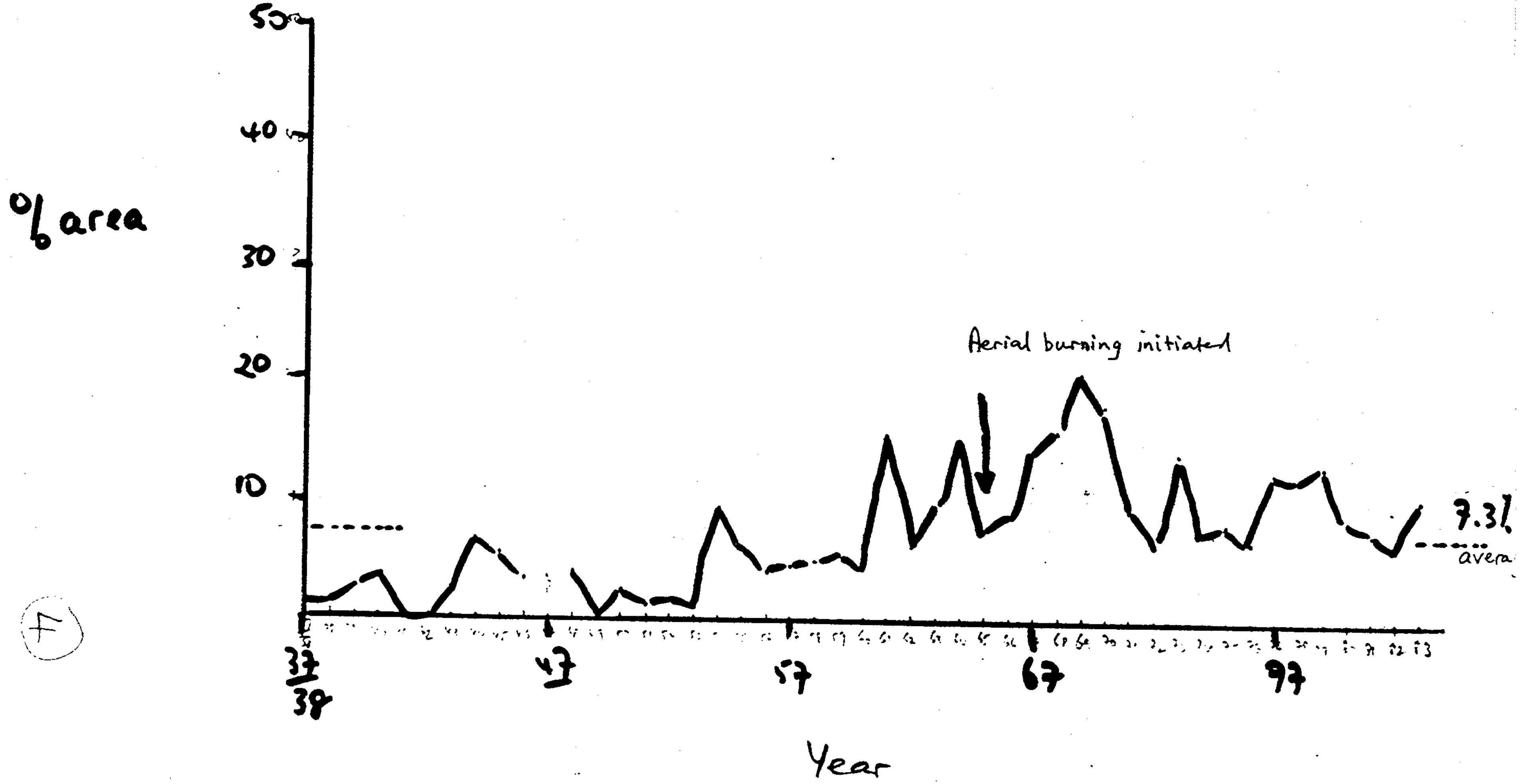
2

Manjimup Div.
all fires combined
46 yrs 281, 150 ha



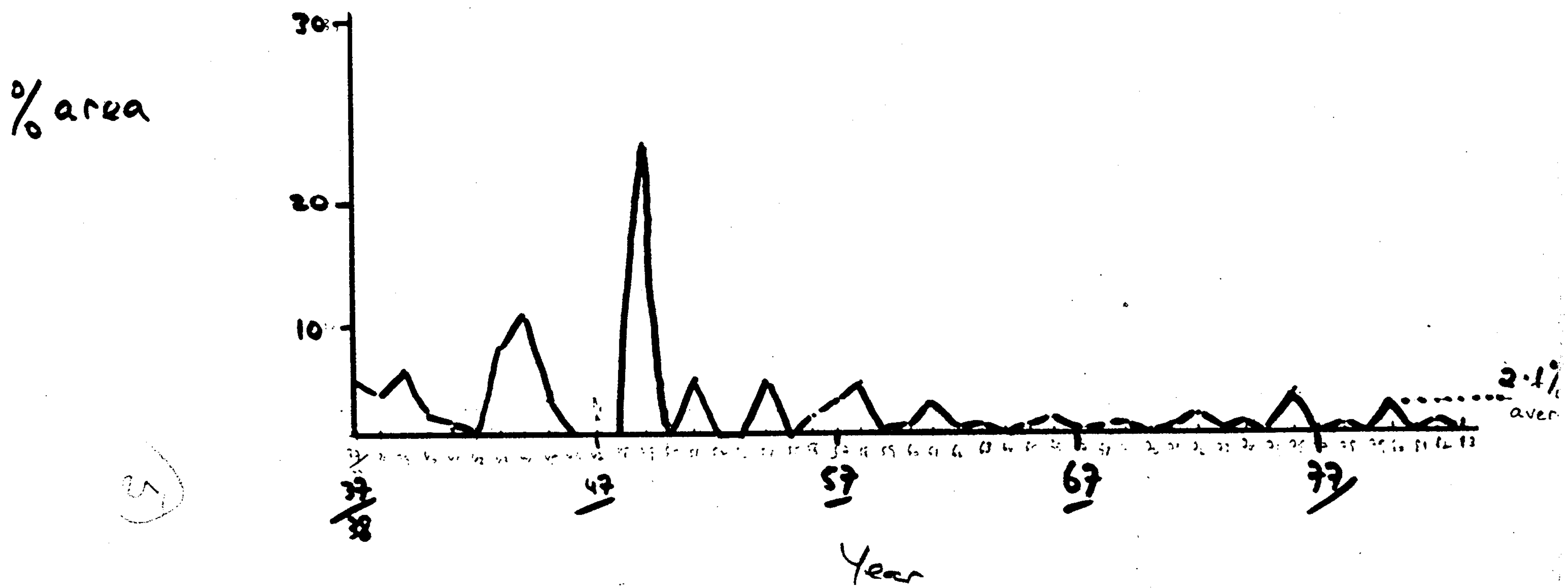
(3)

Manjimup Div.
Spring burning

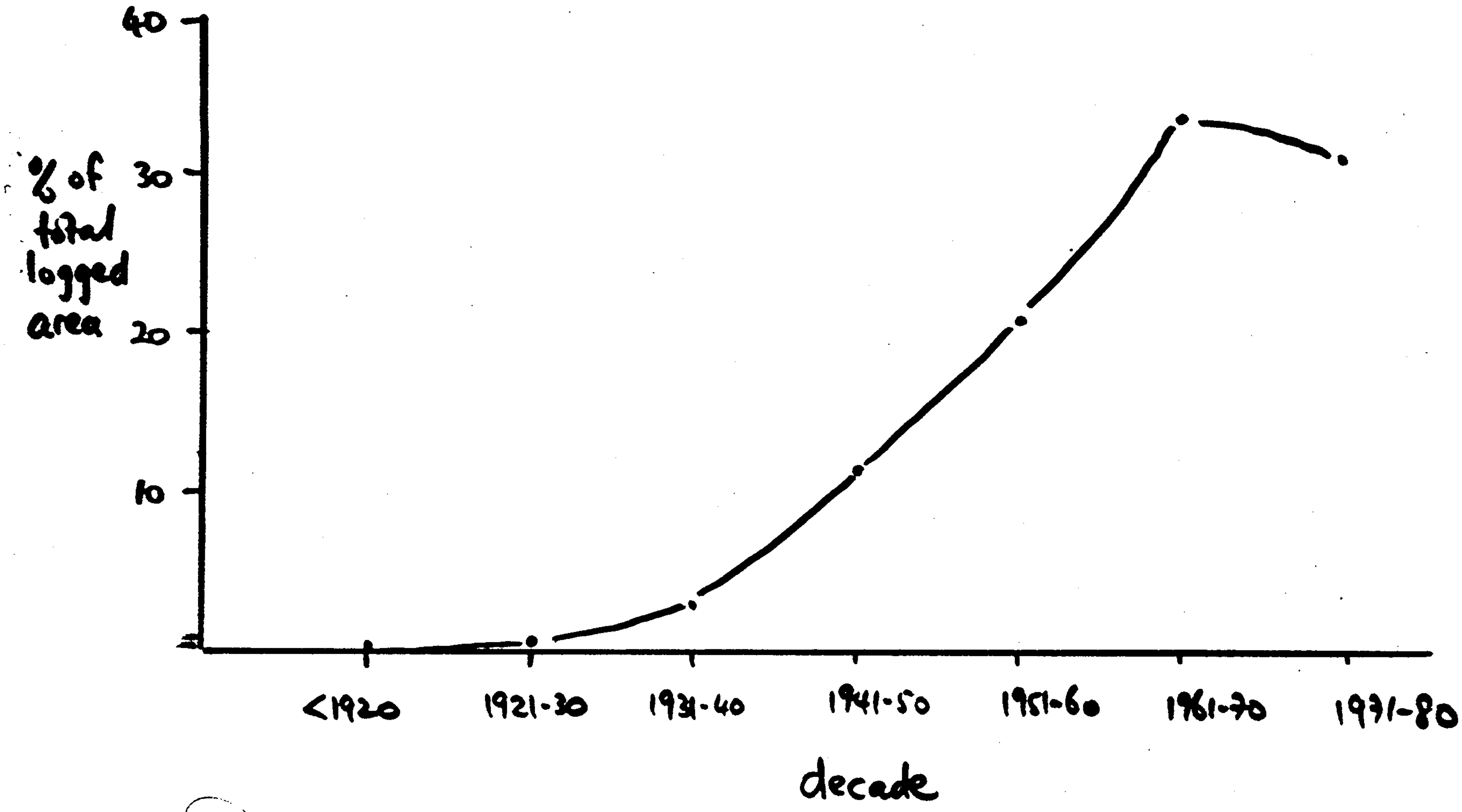


Manjimup Div.

Wildfires

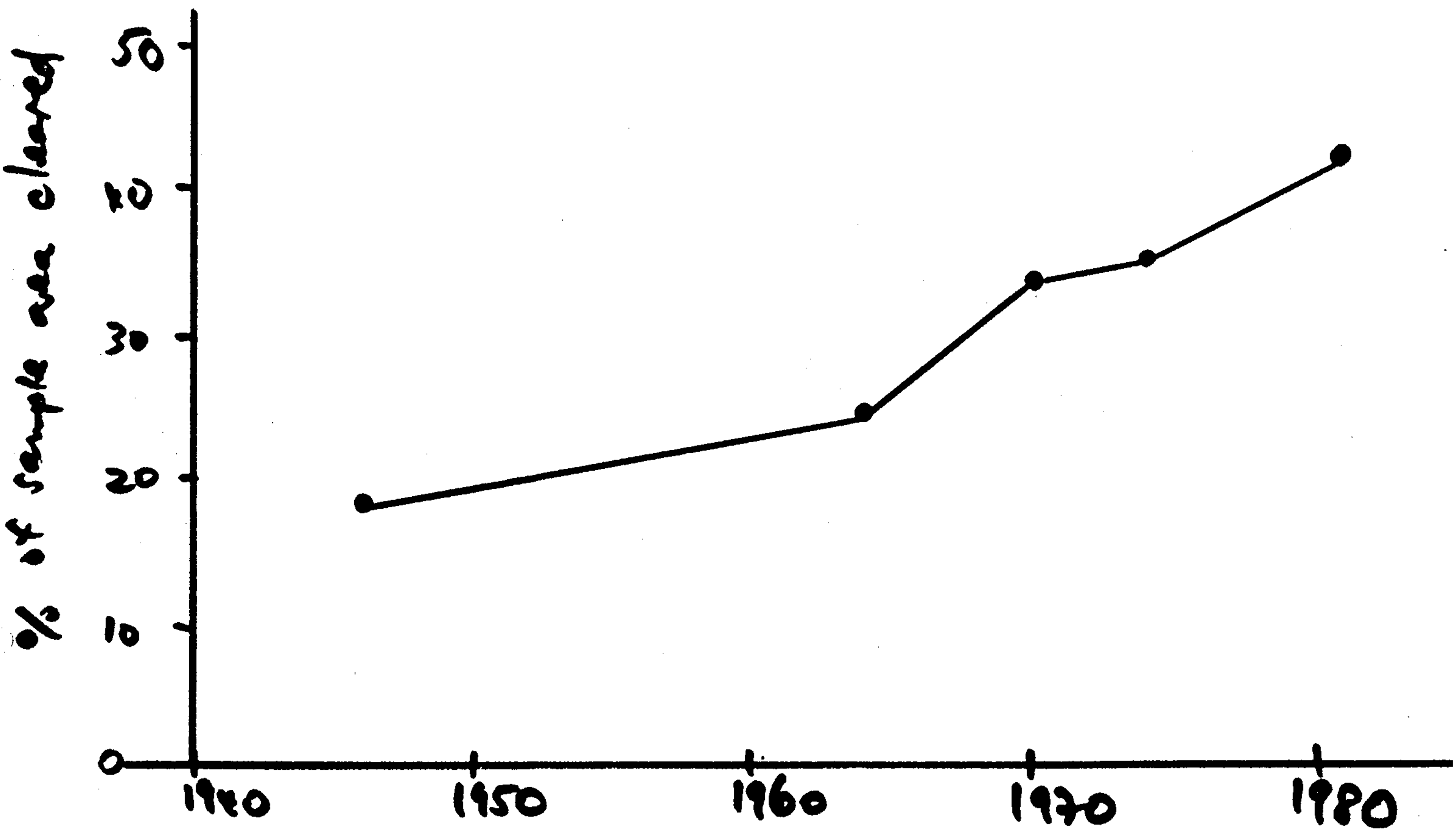


Total area of forest logged = 186,000 ha
(37 blks lacking karri,
mainly in MJP Div).

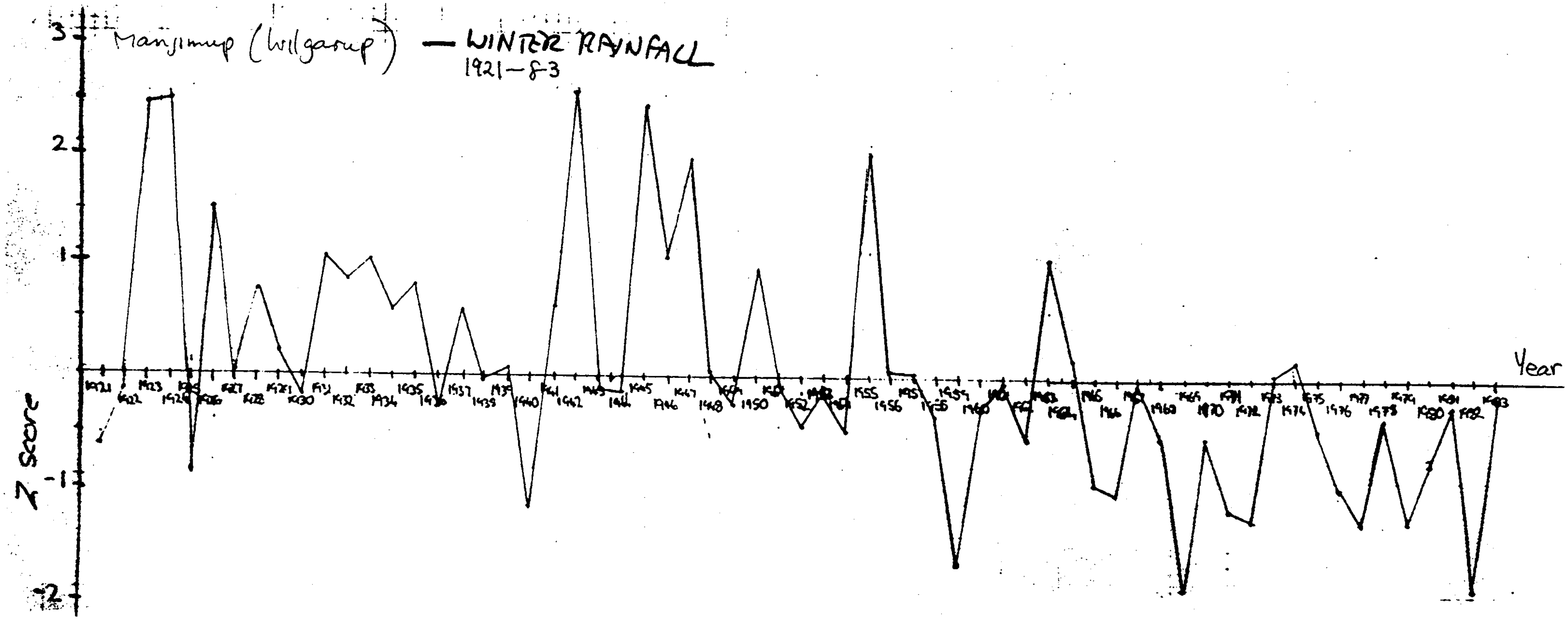


6

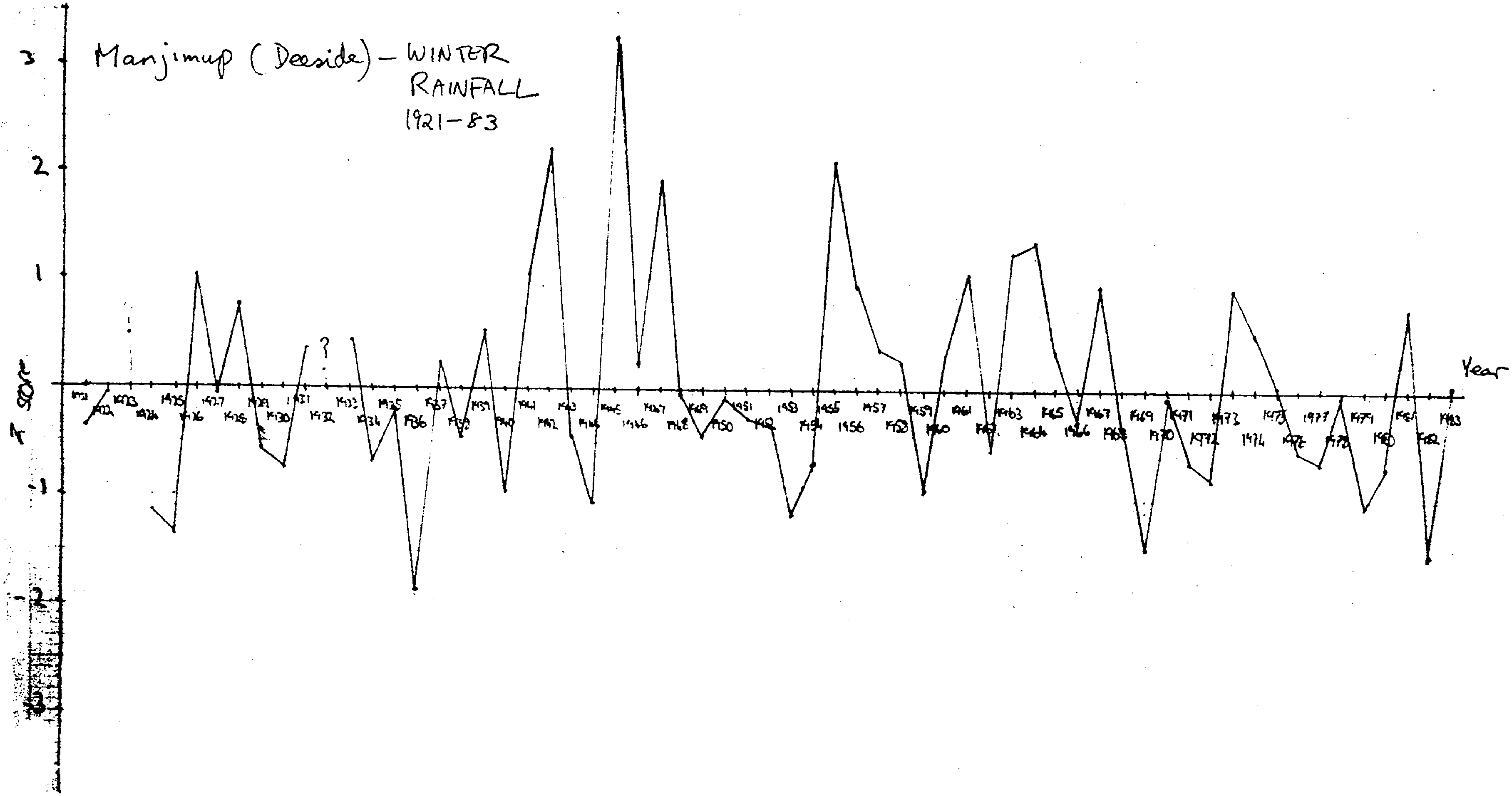
1330 ha sample of
private property surr. Manjimup

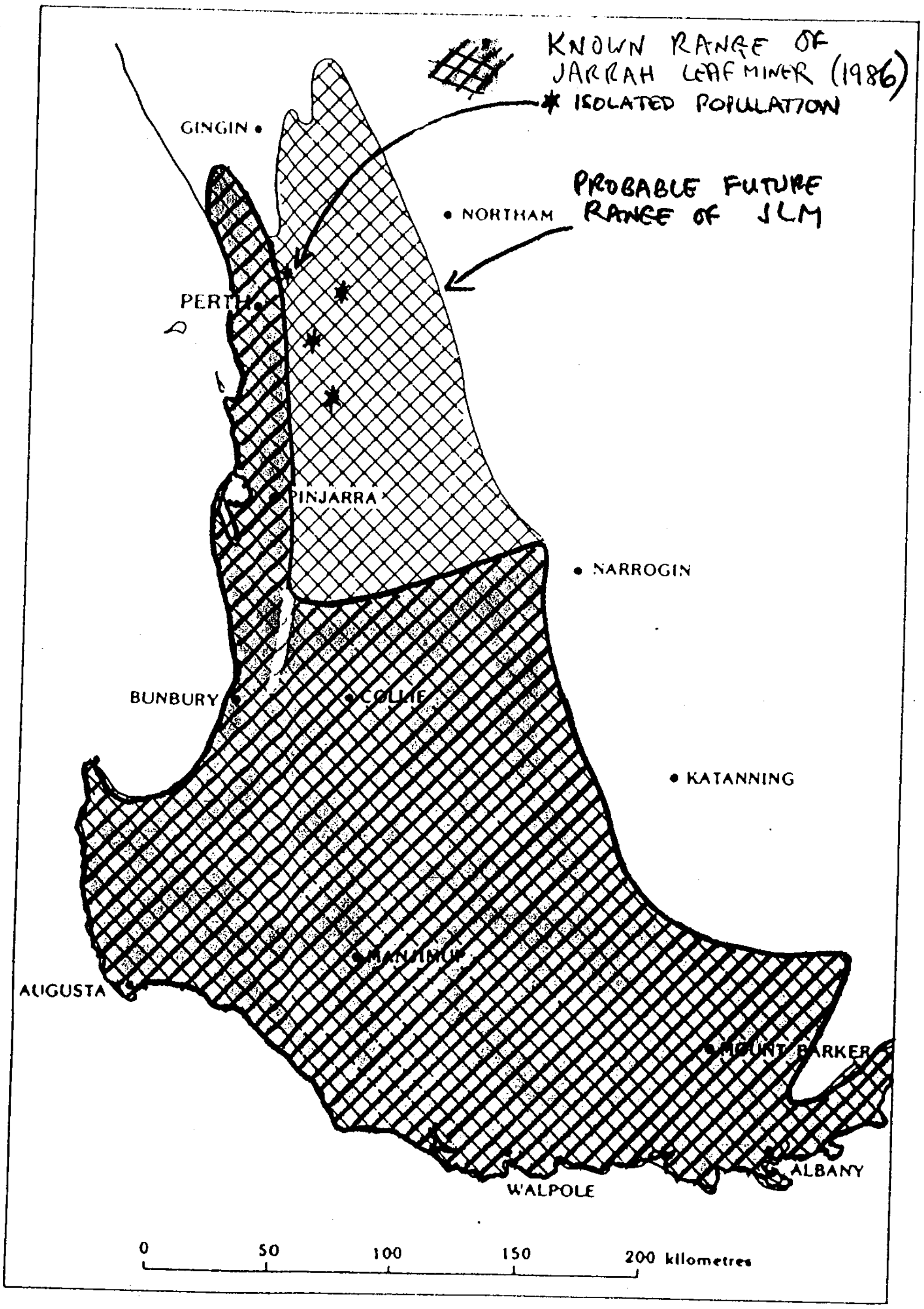


7

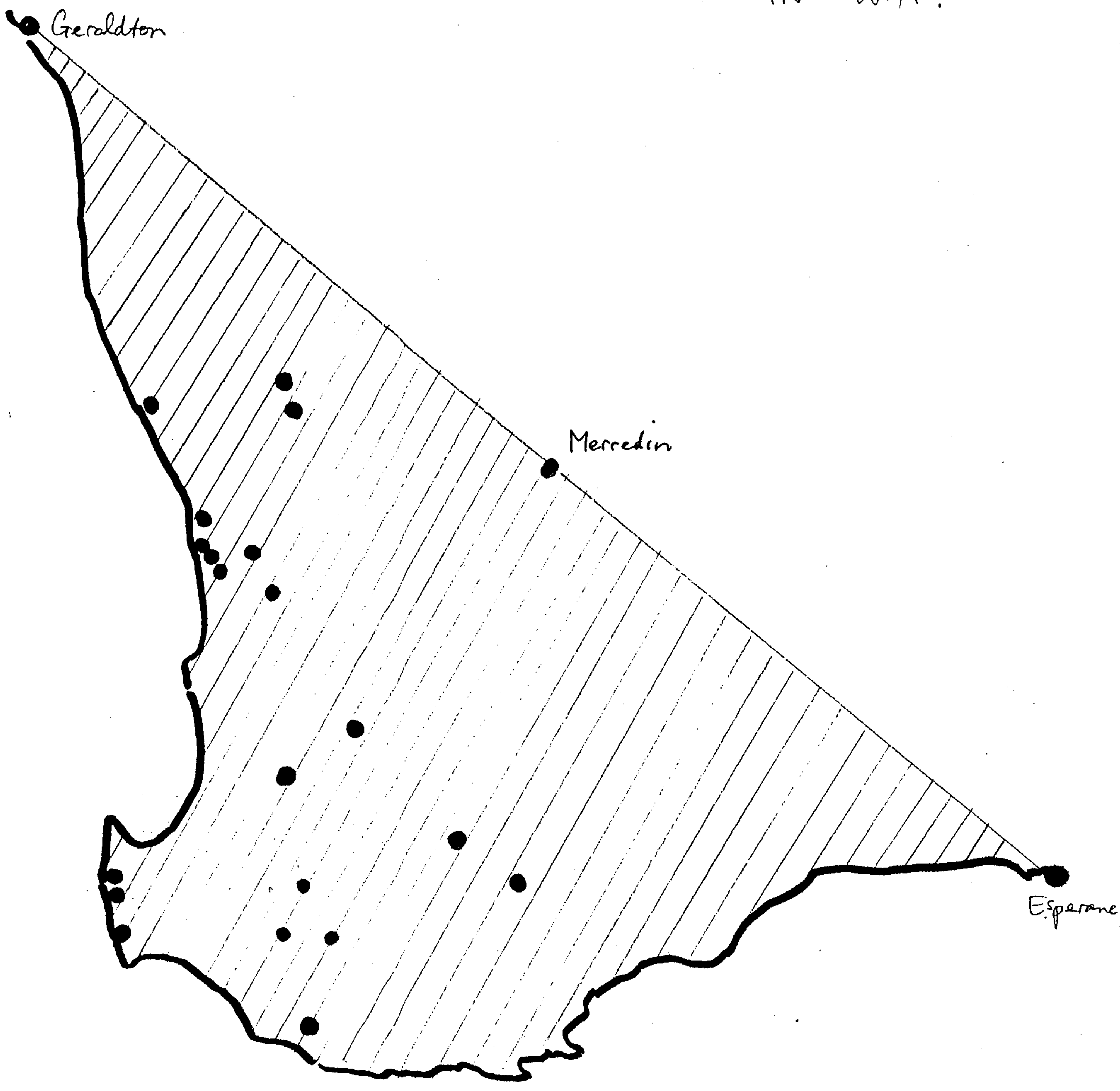

Manjimup (Wilgarup) — WINTER RAINFALL
1921–83
Z score
Year
3
2
1
-1
-2

(8)


Manjimup (Deeside) - WINTER RAINFALL 1921-83
3
2
1
-1
-2
score
Year


KNOWN RANGE OF JARRAH LEAF MINER (1986)
* ISOLATED POPULATION
PROBABLE FUTURE RANGE OF JLM
GINGIN
NORTHAM
PERTH
PINJARRA
NARROGIN
BUNBURY
COLLIE
KATANNING
AUGUSTA
MANJIMUP
MOUNT BARKER
WALPOLE
ALBANY
0
50
100
150
200 kilometres

KNOWN RANGE OF GUMLEAF SKELETONIZER IN W.A.



Boyicup block,
E of Manjimup

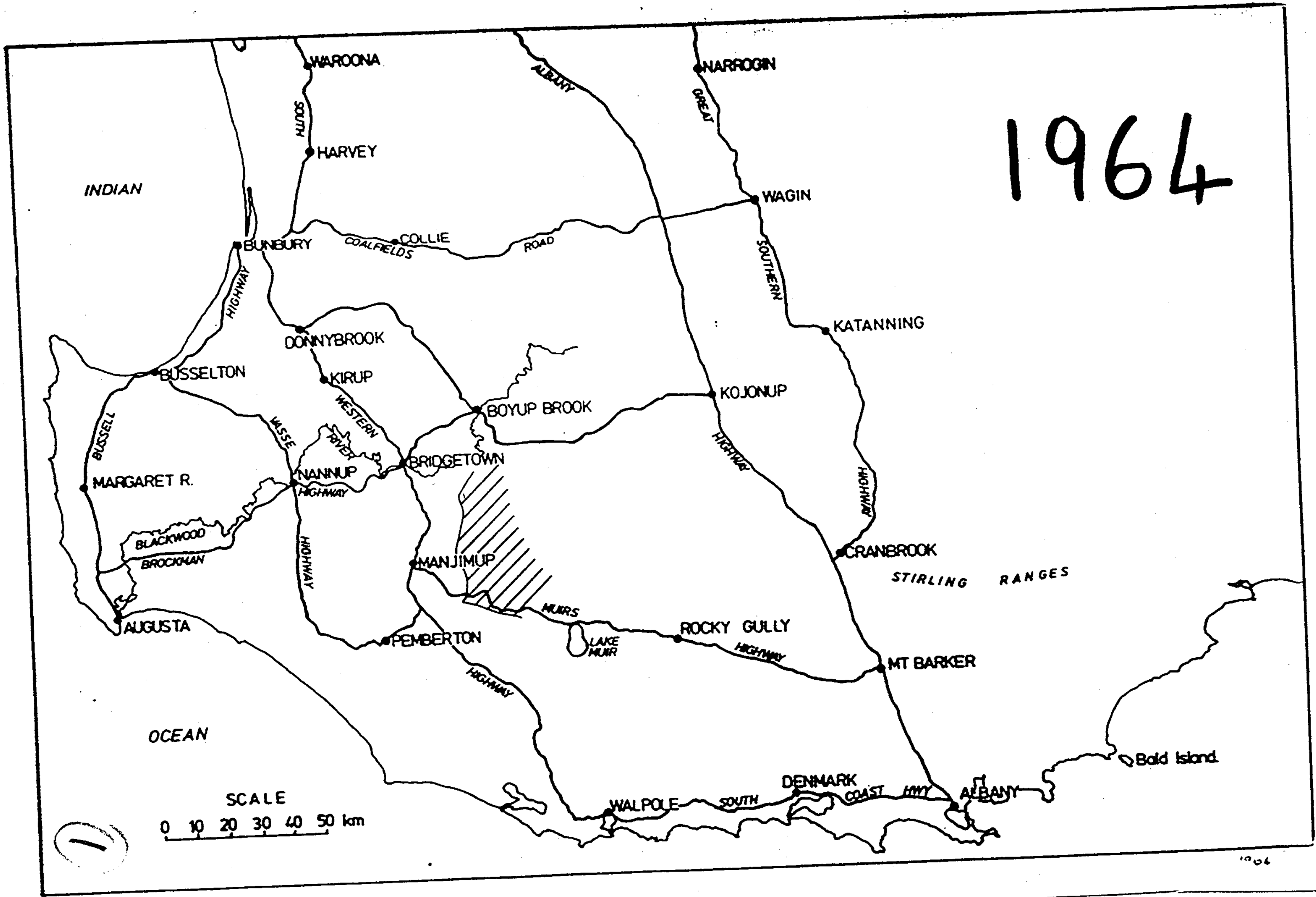
Nov. 1967

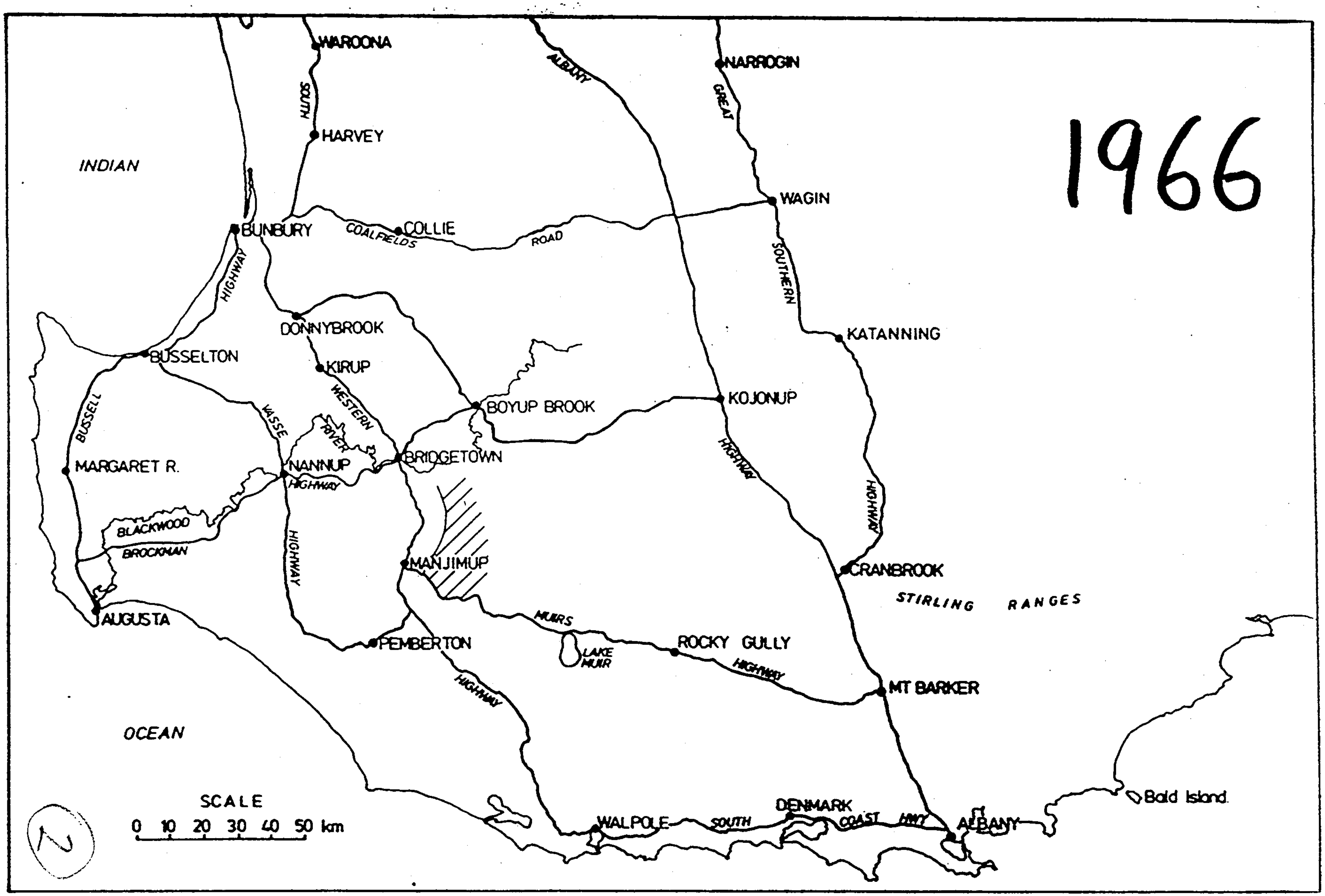
Dec. 1985

(photos courtesy Z. Mazanec)

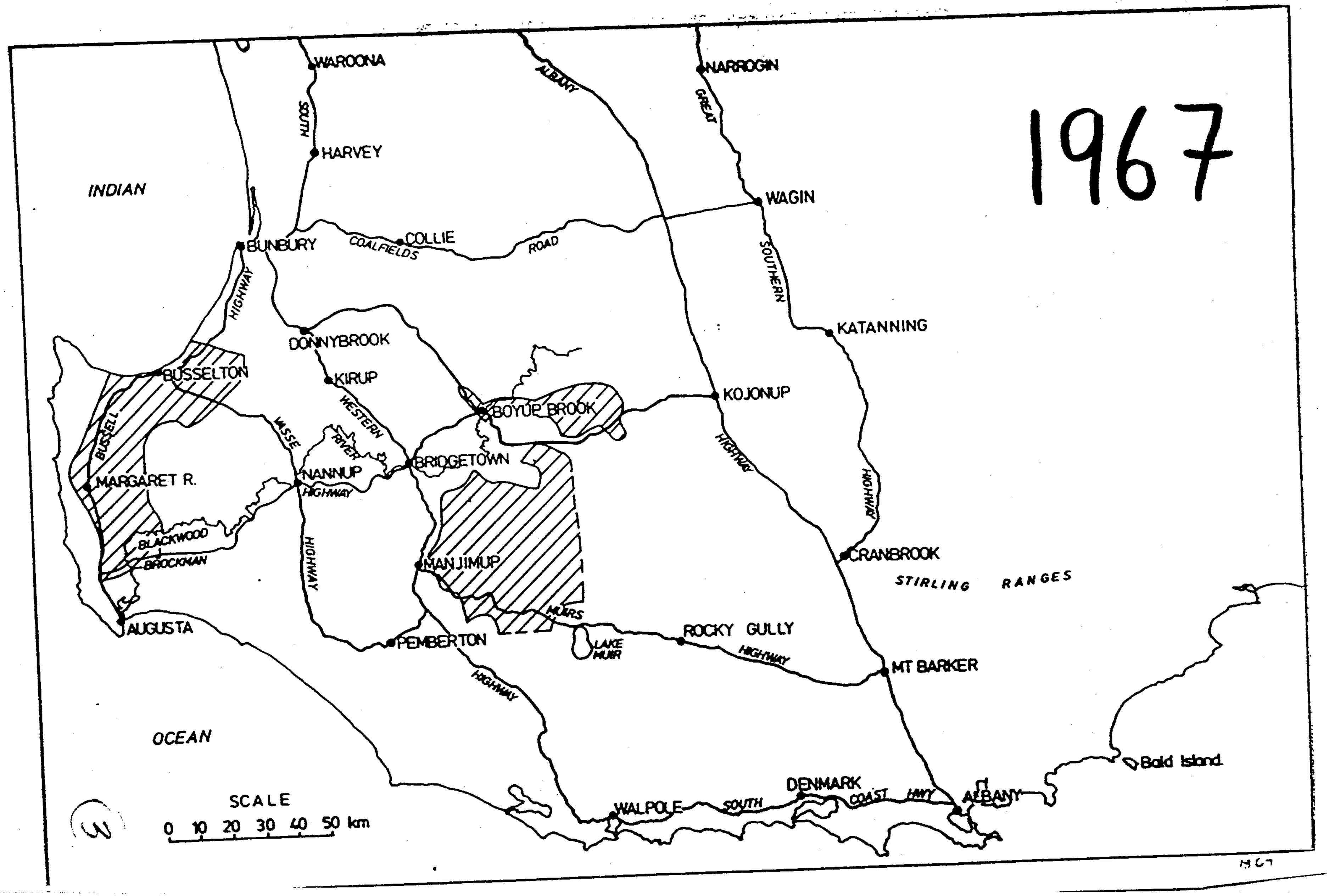
15. APPENDIX

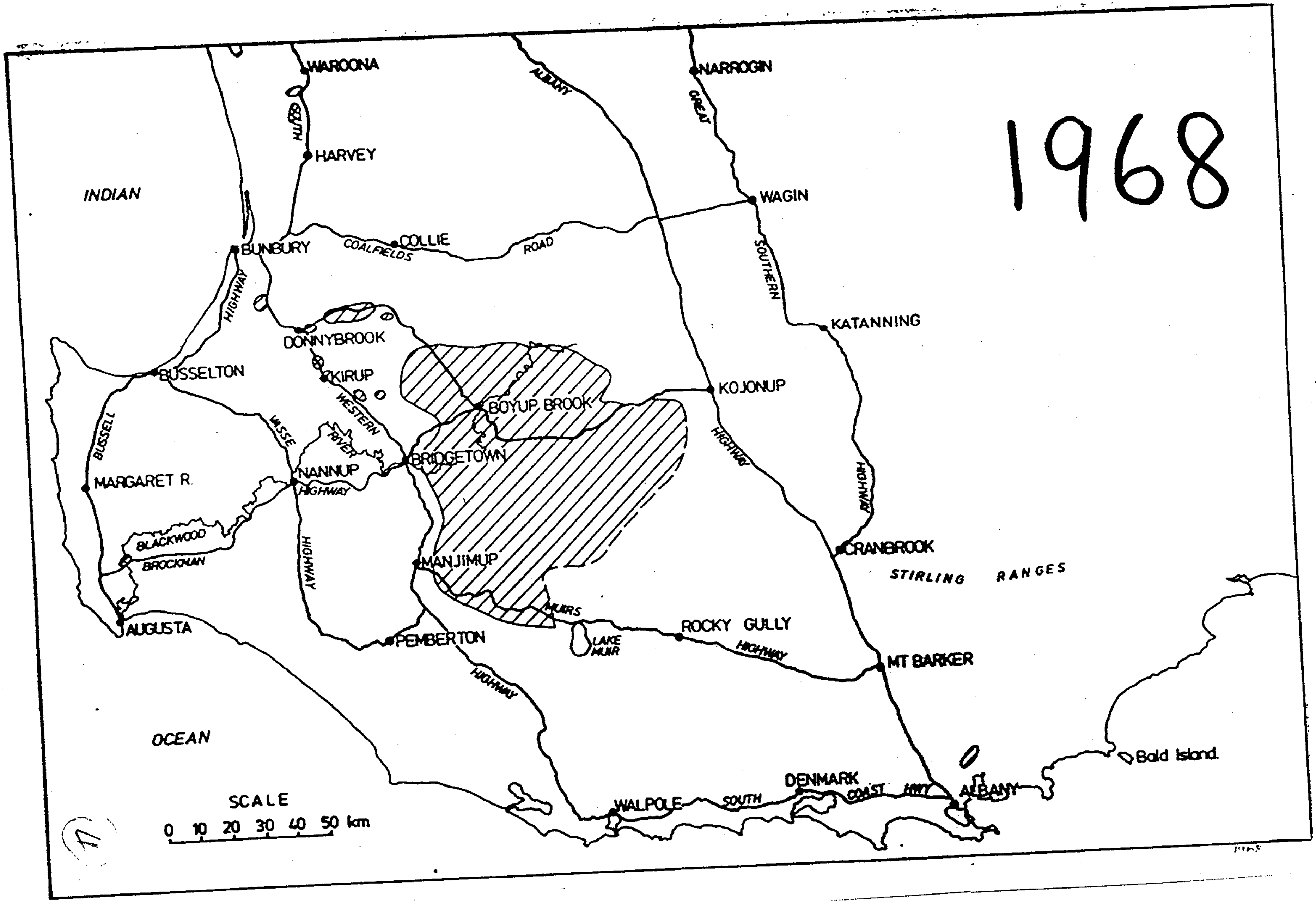
a) Maps of outbreak area of JLM.

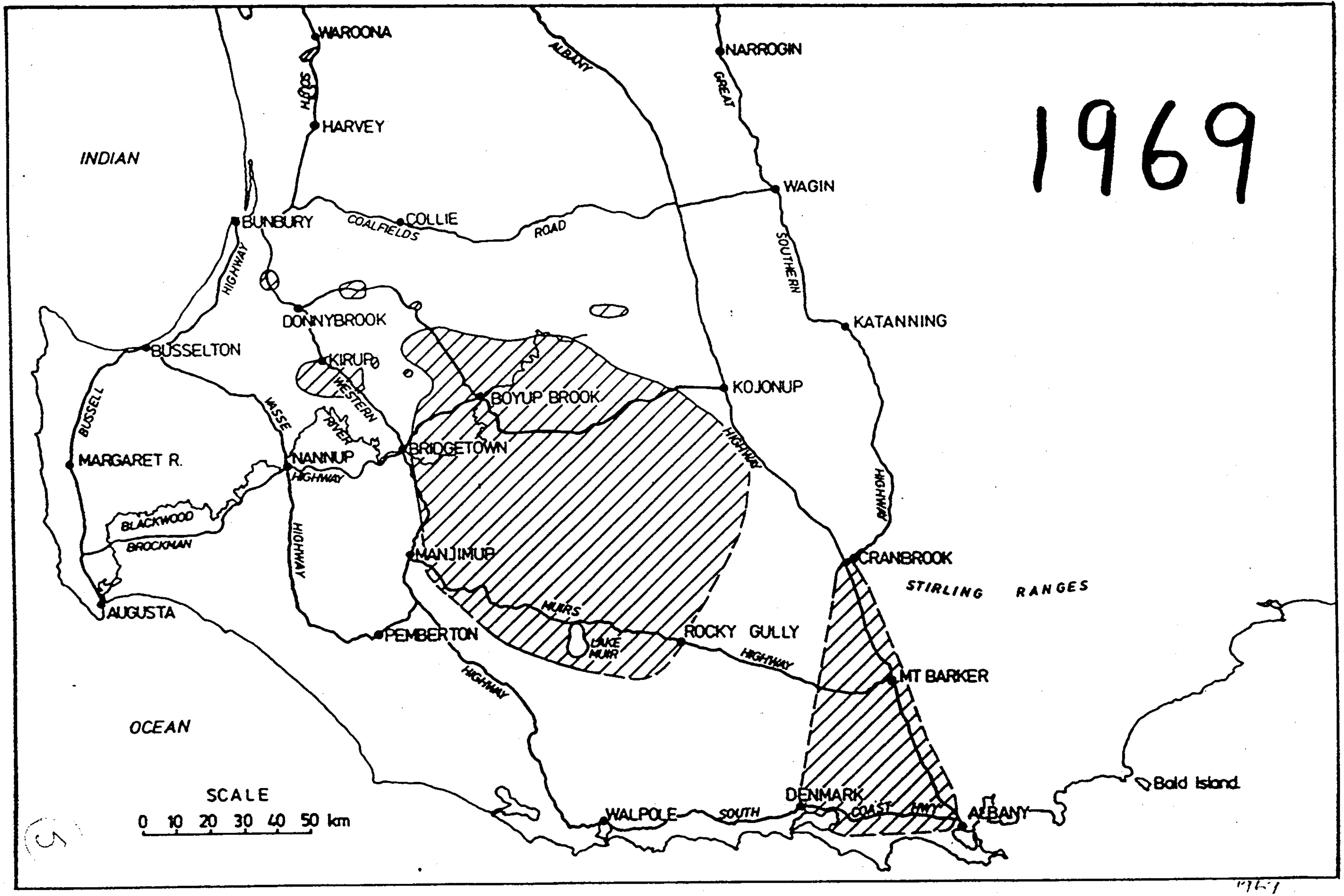

1964
INDIAN
OCEAN
WAROONA
SOUTH
HARVEY
NARROGIN
GREAT
ALBANY
WAGIN
SOUTHERN
KATANNING
BUNBURY
COALFIELDS
COLLIE
ROAD
HIGHWAY
DONNYBROOK
KIRUP
WESTERN
BUSSELTON
BUSSELL
VASSE
RIVER
BOYUP BROOK
KOJONUP
HIGHWAY
BRIDGETOWN
NANNUP
HIGHWAY
MARGARET R.
BLACKWOOD
BROCKMAN
HIGHWAY
MANJIMUP
MUIRS
LAKE MUIR
ROCKY GULLY
HIGHWAY
CRANBROOK
STIRLING RANGES
MT BARKER
AUGUSTA
PEMBERTON
HIGHWAY
WALPOLE
SOUTH
DENMARK
COAST
HWY
ALBANY
Bald Island
SCALE
0 10 20 30 40 50 km
1


1966
WAROONA
HARVEY
SOUTH
INDIAN
BUNBURY
COALFIELDS
COLLIE
ROAD
WAGIN
NARROGIN
GREAT
SOUTHERN
ALBANY
KATANNING
HIGHWAY
DONNYBROOK
BUSSELTON
KIRUP
WESTERN
BOYUP BROOK
KOJONUP
VASSE
RIVER
BRIDGETOWN
BUSSELL
MARGARET R.
NANNUP
HIGHWAY
BLACKWOOD
BROCKMAN
MANJIMUP
CRANBROOK
STIRLING RANGES
AUGUSTA
MUIRS
LAKE MUIR
ROCKY GULLY
PEMBERTON
MT BARKER
OCEAN
SCALE
0 10 20 30 40 50 km
WALPOLE
SOUTH
DENMARK
COAST
HWY
ALBANY
Bald Island

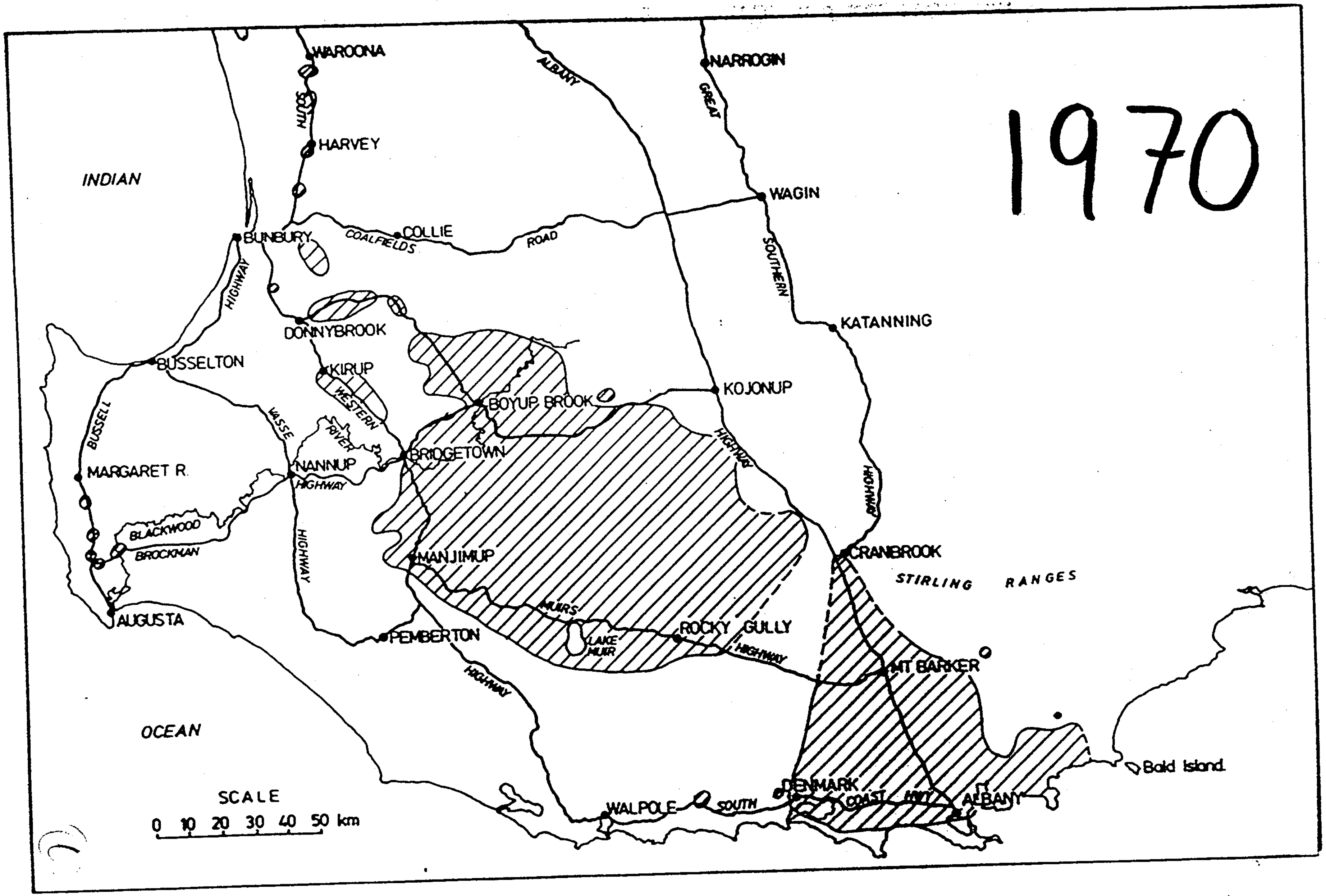
2

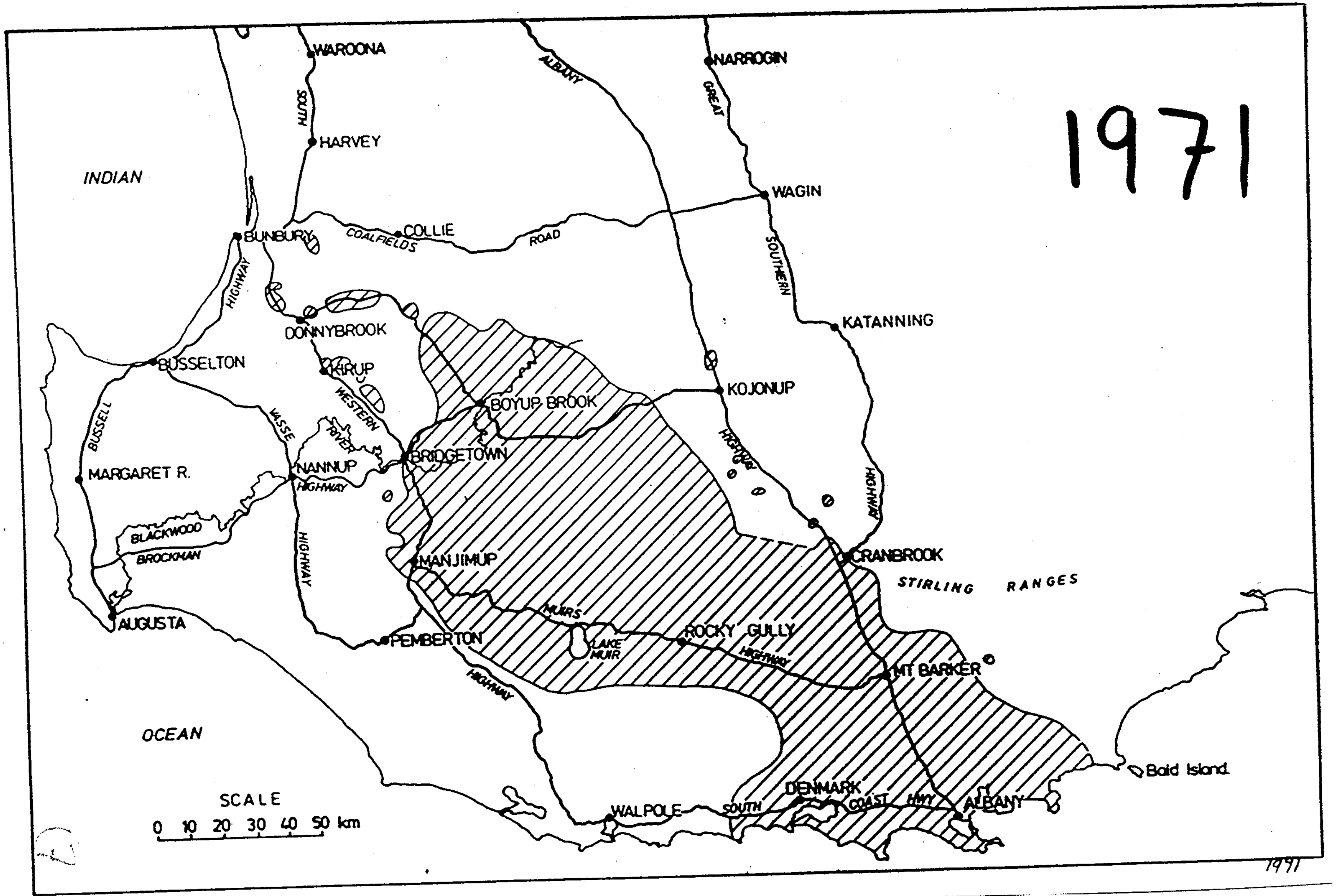

1967
INDIAN
OCEAN
WAROONA
SOUTH
HARVEY
BUNBURY
COALFIELDS
COLLIE
ROAD
ALBANY
NARROGIN
GREAT
WAGIN
SOUTHERN
KATANNING
HIGHWAY
DONNYBROOK
KIRUP
WESTERN
BUSSELTON
BUSSELL
VASSE
RIVER
BOYUP BROOK
KOJONUP
BRIDGETOWN
MARGARET R.
NANNUP
BLACKWOOD
BROCKMAN
MANJIMUP
CRANBROOK
STIRLING RANGES
AUGUSTA
PEMBERTON
MUIRS
LAKE MUIR
ROCKY GULLY
MT BARKER
Bald Island
WALPOLE
DENMARK
COAST HWY
ALBANY
SCALE
0 10 20 30 40 50 km
3

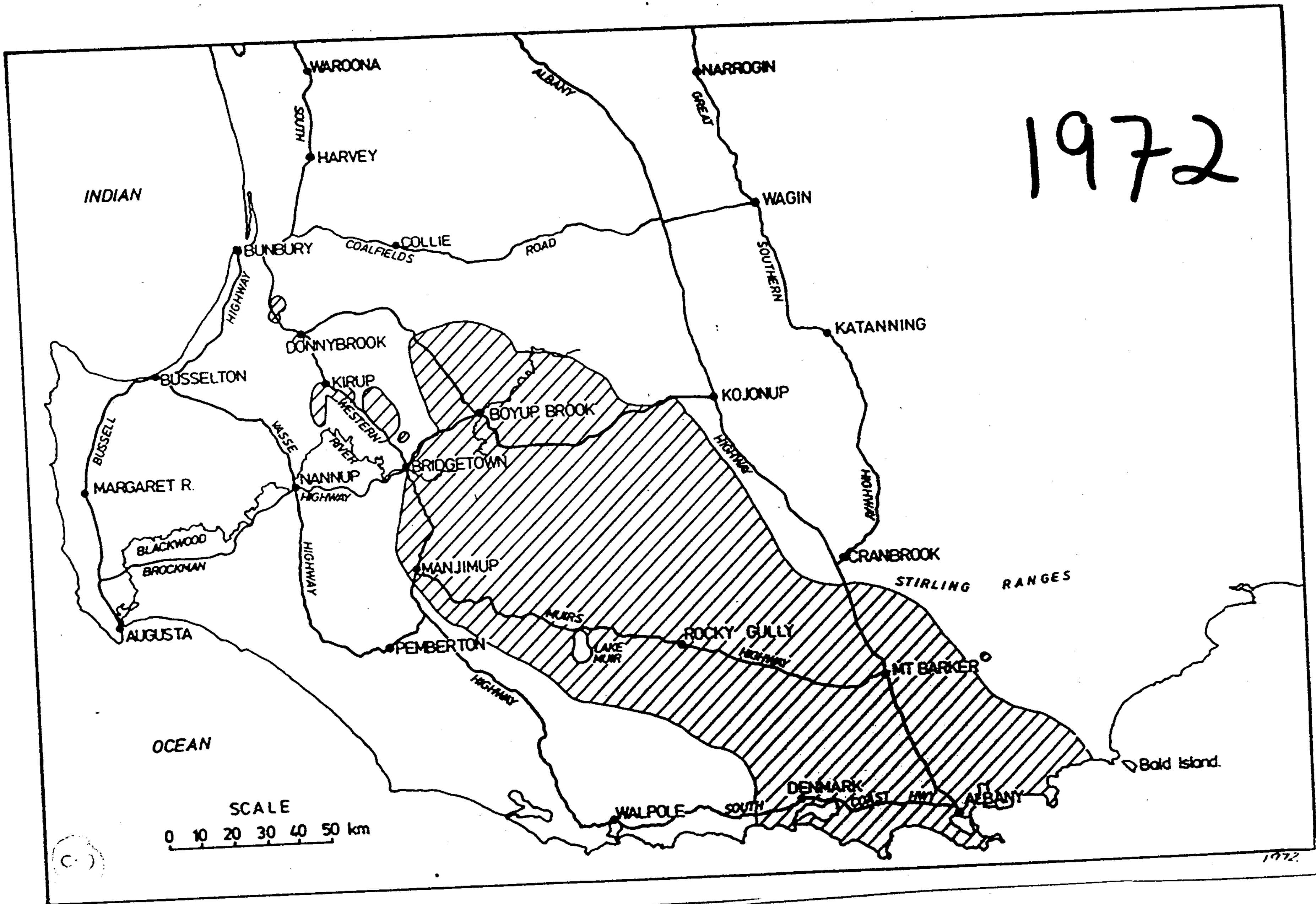

1968
WAROONA
HARVEY
SOUTH
INDIAN
BUNBURY
COALFIELDS
COLLIE
ROAD
HIGHWAY
DONNYBROOK
KIRUP
BUSSELTON
WESTERN
VASSE
RIVER
BOYUP BROOK
BRIDGETOWN
NANNUP
HIGHWAY
BUSSELL
MARGARET R.
BLACKWOOD
BROCKMAN
MANJIMUP
MUIRS
AUGUSTA
PEMBERTON
LAKE MUIR
ROCKY GULLY
HIGHWAY
ALBANY
NARROGIN
GREAT
WAGIN
SOUTHERN
KATANNING
KOJONUP
HIGHWAY
CRANBROOK
STIRLING RANGES
MT BARKER
OCEAN
Bald Island
DENMARK
COAST
HWY
ALBANY
WALPOLE
SOUTH
SCALE
0 10 20 30 40 50 km

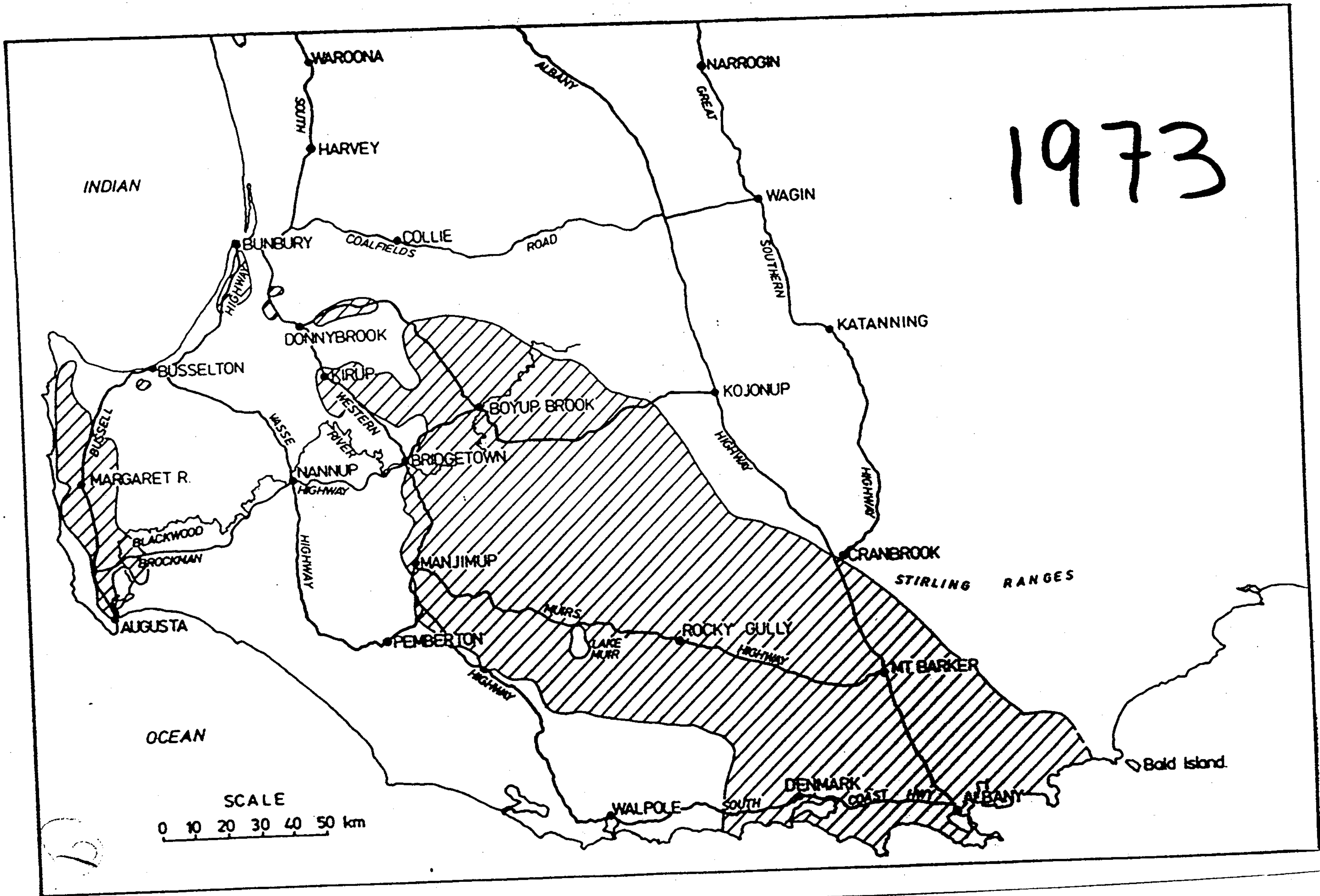

1969
WAROONA
NARROGIN
ALBANY
SOUTH
GREAT
HARVEY
INDIAN
WAGIN
BUNBURY
COALFIELDS
COLLIE
ROAD
SOUTHERN
HIGHWAY
DONNYBROOK
KATANNING
BUSSELTON
KIRUP
WESTERN
KOJONUP
BOYUP BROOK
BUSSELL
VASSE
RIVER
MARGARET R.
NANNUP
BRIDGETOWN
HIGHWAY
BLACKWOOD
BROCKMAN
MANJIMUP
CRANBROOK
STIRLING RANGES
AUGUSTA
MUIRS
PEMBERTON
LAKE MUIR
ROCKY GULLY
MT BARKER
OCEAN
Bald Island
SCALE
0 10 20 30 40 50 km
WALPOLE
SOUTH
DENMARK
COAST
HWY
ALBANY

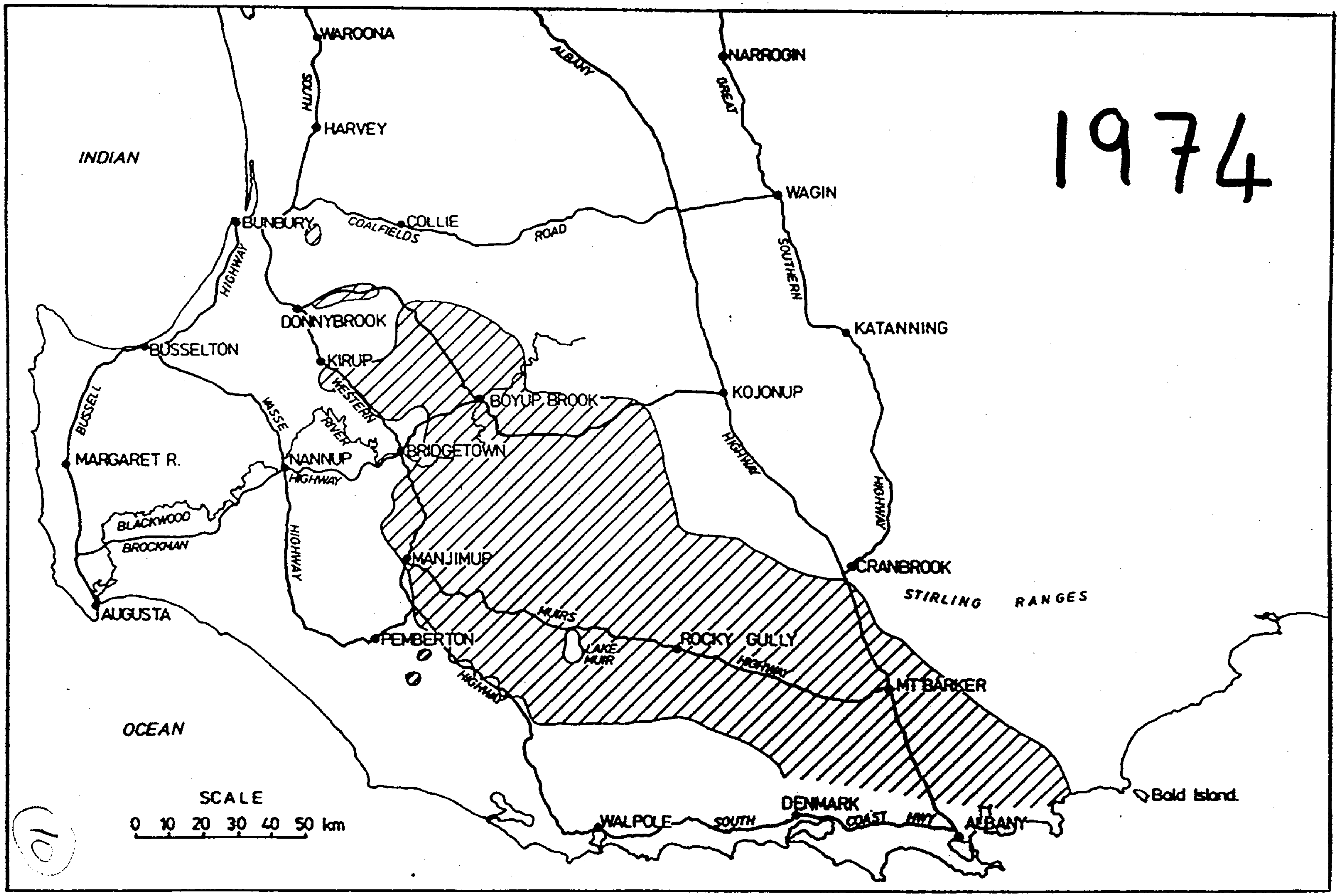
5


1970
INDIAN
OCEAN
WAROONA
HARVEY
SOUTH
BUNBURY
COALFIELDS
ROAD
COLLIE
NARROGIN
GREAT
WAGIN
SOUTHERN
KATANNING
ALBANY
HIGHWAY
DONNYBROOK
BUSSELTON
KIRUP
WESTERN
RIVER
VASSE
NANNUP
HIGHWAY
BOYUP BROOK
KOJONUP
BRIDGETOWN
BUSSELL
MARGARET R.
BLACKWOOD
BROCKMAN
MANJIMUP
AUGUSTA
PEMBERTON
MUIRS
LAKE MUIR
ROCKY GULLY
HIGHWAY
CRANBROOK
STIRLING RANGES
MT BARKER
Bald Island
DENMARK
COAST HWY
ALBANY
WALPOLE
SOUTH
SCALE
0 10 20 30 40 50 km

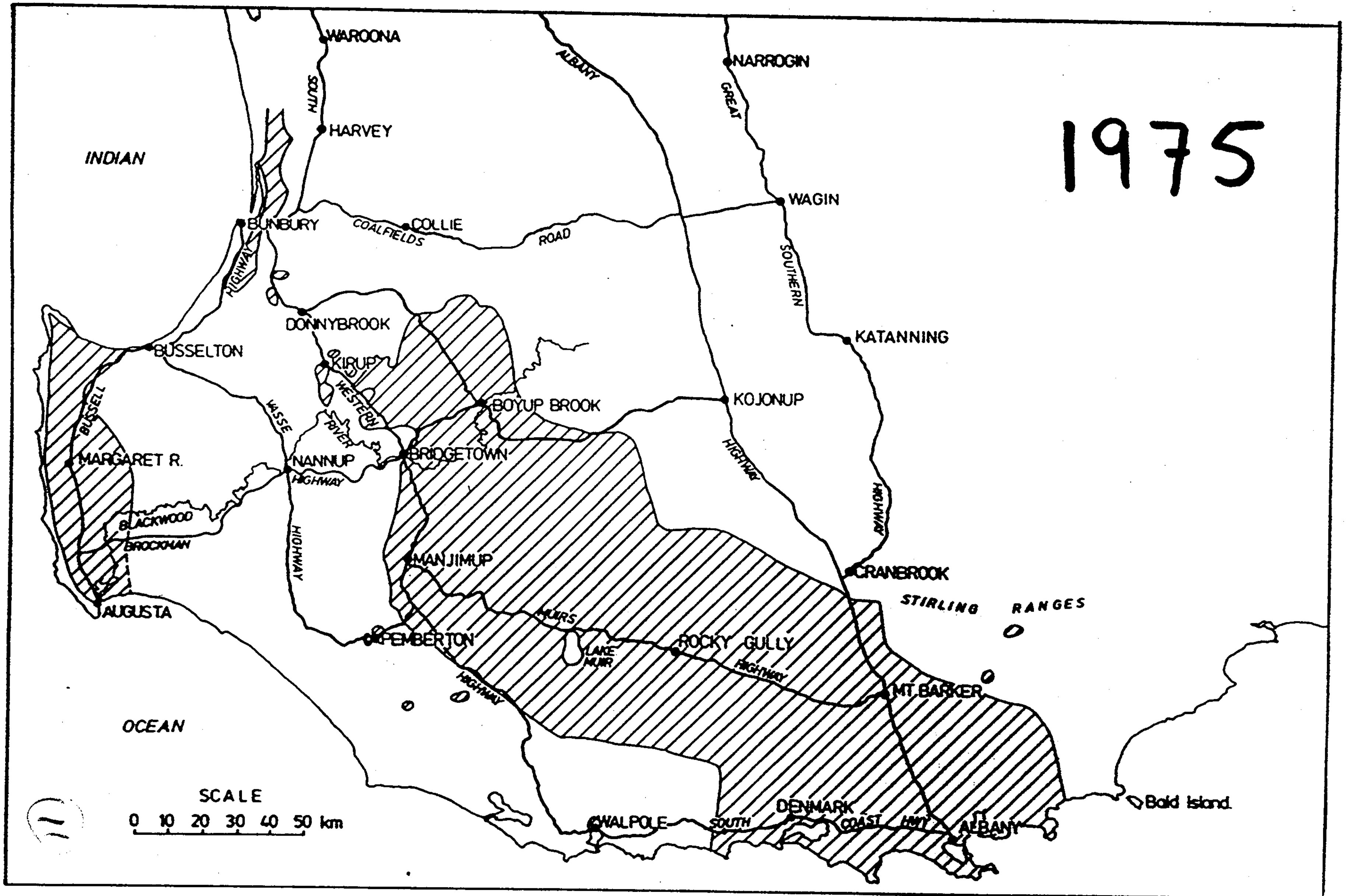

1971
WAROONA
HARVEY
NARROGIN
WAGIN
KATANNING
KOJONUP
CRANBROOK
STIRLING RANGES
MT BARKER
ALBANY
Bald Island
DENMARK
WALPOLE
ROCKY GULLY
LAKE MUIR
MANJIMUP
PEMBERTON
BRIDGETOWN
BOYUP BROOK
NANNUP
KIRUP
DONNYBROOK
COLLIE
BUNBURY
BUSSELTON
MARGARET R.
AUGUSTA
INDIAN
OCEAN
SOUTH
GREAT
SOUTHERN
ALBANY
HIGHWAY
COALFIELDS
ROAD
BUSSELL
VASSE
WESTERN
RIVER
BLACKWOOD
BROCKMAN
MUIRS
COAST
HWY
SCALE
0 10 20 30 40 50 km
1991

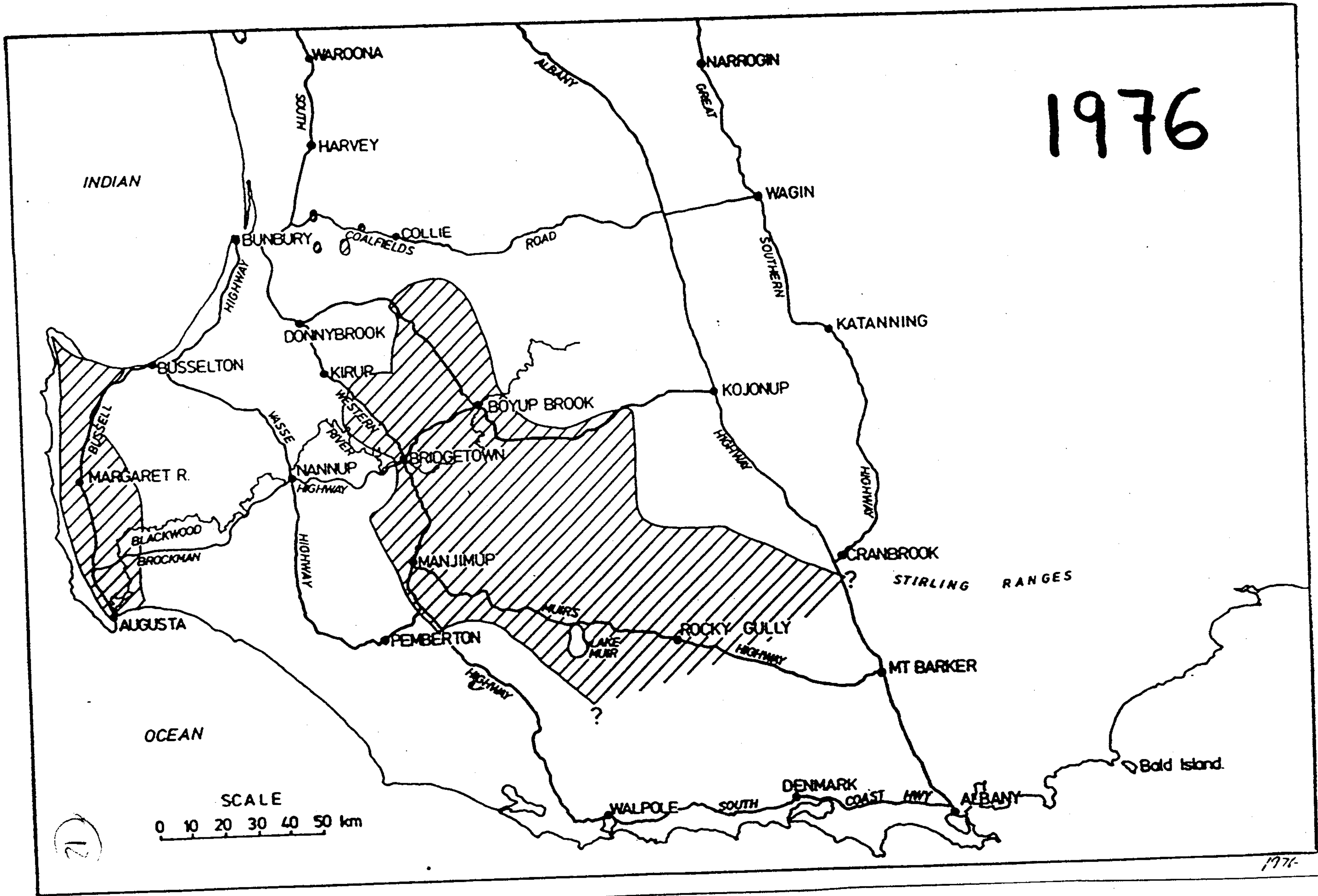

1972
WAROONA
NARROGIN
HARVEY
WAGIN
INDIAN
BUNBURY
COLLIE
COALFIELDS
ROAD
SOUTH
GREAT
SOUTHERN
ALBANY
KATANNING
DONNYBROOK
KIRUP
BUSSELTON
KOJONUP
BOYUP BROOK
WESTERN
RIVER
BUSSELL
VASSE
BRIDGETOWN
NANNUP
HIGHWAY
MARGARET R.
BLACKWOOD
BROCKMAN
MANJIMUP
CRANBROOK
STIRLING RANGES
MUIRS
LAKE MUIR
ROCKY GULLY
AUGUSTA
PEMBERTON
MT BARKER
OCEAN
Bald Island.
DENMARK
COAST HWY
ALBANY
WALPOLE
SCALE
0 10 20 30 40 50 km

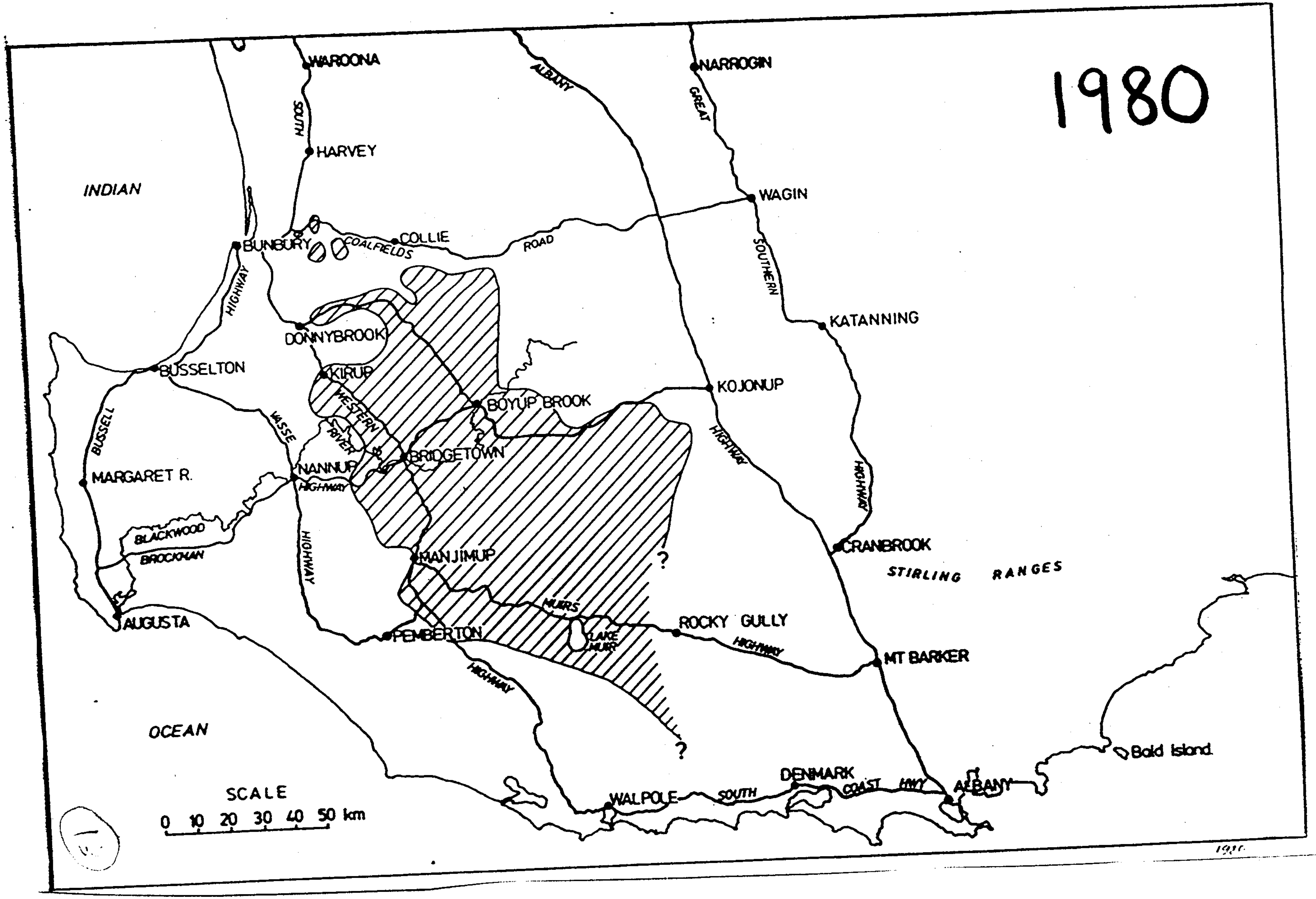

1973
WAROONA
HARVEY
SOUTH
NARROGIN
GREAT
WAGIN
SOUTHERN
KATANNING
ALBANY
INDIAN
BUNBURY
COALFIELDS
COLLIE
ROAD
HIGHWAY
DONNYBROOK
BUSSELTON
KIRUP
WESTERN
BOYUP BROOK
KOJONUP
HIGHWAY
BUSSELL
VASSE
RIVER
BRIDGETOWN
MARGARET R.
NANNUP
HIGHWAY
BLACKWOOD
BROCKMAN
MANJIMUP
HIGHWAY
CRANBROOK
STIRLING RANGES
MUIRS
LAKE MUIR
ROCKY GULLY
HIGHWAY
AUGUSTA
PEMBERTON
HIGHWAY
MT. BARKER
OCEAN
Bald Island
SCALE
0 10 20 30 40 50 km
DENMARK
WALPOLE
SOUTH
COAST
HWY
ALBANY

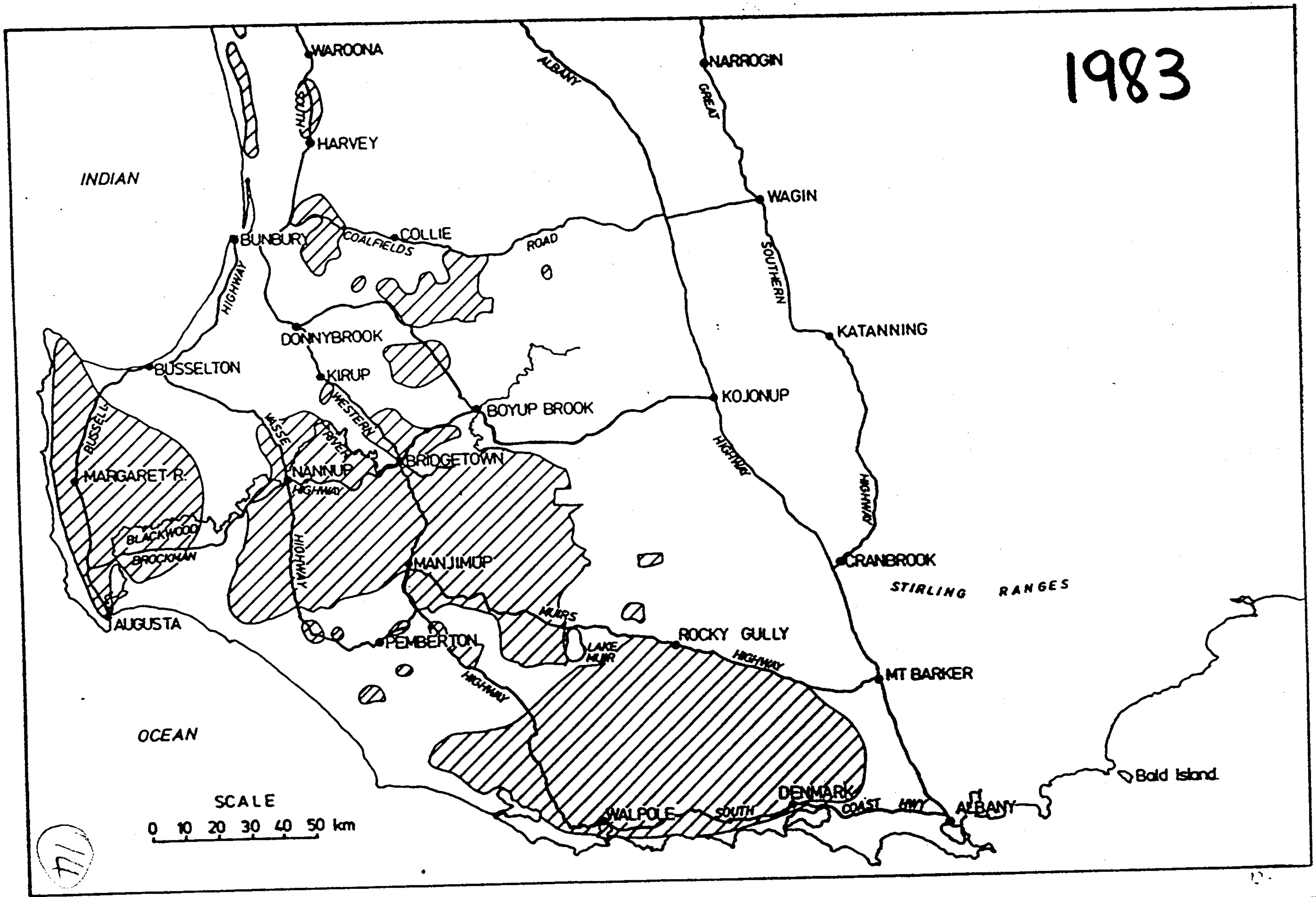

1974
WAROONA
HARVEY
SOUTH
INDIAN
BUNBURY
COLLIE
COALFIELDS
ROAD
ALBANY
NARROGIN
GREAT
WAGIN
SOUTHERN
KATANNING
KOJONUP
HIGHWAY
DONNYBROOK
KIRUP
BUSSELTON
BUSSELL
VASSE
WESTERN
RIVER
BOYUP BROOK
BRIDGETOWN
MARGARET R.
NANNUP
BLACKWOOD
BROCKMAN
MANJIMUP
CRANBROOK
STIRLING
RANGES
AUGUSTA
MUIRS
PEMBERTON
LAKE MUIR
ROCKY GULLY
MT BARKER
OCEAN
SCALE
0 10 20 30 40 50 km
DENMARK
WALPOLE
COAST
HWY
ALBANY
Bald Island

10


1975
WAROONA
SOUTH
HARVEY
NARROGIN
GREAT
ALBANY
WAGIN
SOUTHERN
KATANNING
INDIAN
BUNBURY
COALFIELDS
COLLIE
ROAD
HIGHWAY
DONNYBROOK
BUSSELTON
KIRUP
WESTERN
BOYUP BROOK
KOJONUP
BUSSELL
VASSE
RIVER
MARGARET R.
NANNUP
HIGHWAY
BRIDGETOWN
HIGHWAY
HIGHWAY
BLACKWOOD
BROCKMAN
HIGHWAY
MANJIMUP
CRANBROOK
STIRLING RANGES
AUGUSTA
MUIRS
PEMBERTON
LAKE MUIR
ROCKY GULLY
HIGHWAY
HIGHWAY
MT BARKER
OCEAN
SCALE
0 10 20 30 40 50 km
WALPOLE
SOUTH
DENMARK
COAST
HWY
ALBANY
Bald Island
11


1976
WAROONA
HARVEY
SOUTH
NARROGIN
GREAT
WAGIN
SOUTHERN
KATANNING
ALBANY
INDIAN
BUNBURY
COALFIELDS
COLLIE
ROAD
HIGHWAY
DONNYBROOK
KIRUP
BUSSELTON
WESTERN
RIVER
BOYUP BROOK
KOJONUP
BUSSELL
VASSE
NANNUP
HIGHWAY
BRIDGETOWN
MARGARET R.
BLACKWOOD
BROCKMAN
MANJIMUP
CRANBROOK
STIRLING RANGES
MUIRS
LAKE MUIR
ROCKY GULLY
MT BARKER
AUGUSTA
PEMBERTON
OCEAN
Bald Island.
SCALE
0 10 20 30 40 50 km
WALPOLE
DENMARK
SOUTH COAST HWY
ALBANY

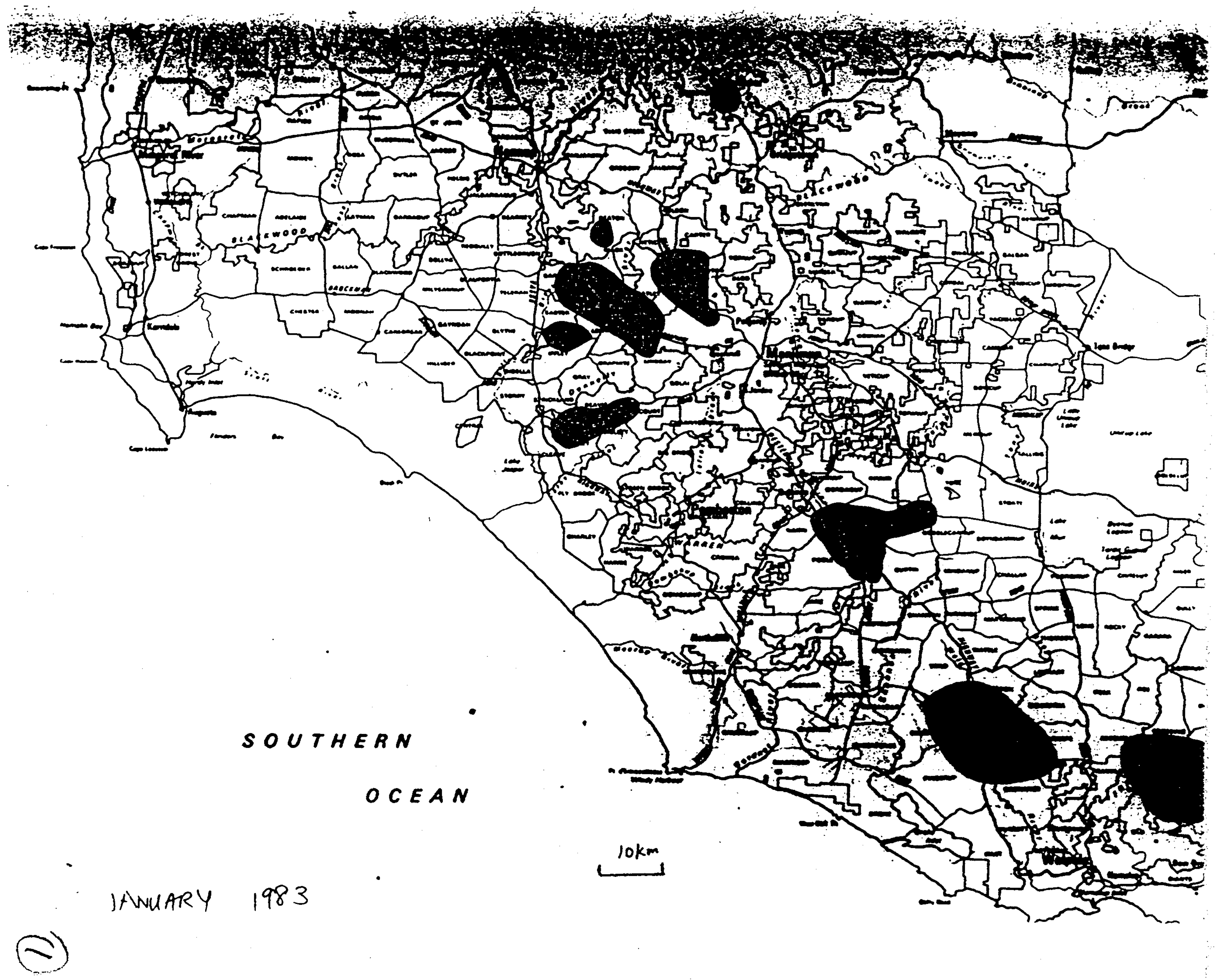

1980
WAROONA
HARVEY
NARROGIN
WAGIN
GREAT
SOUTHERN
SOUTH
ALBANY
INDIAN
BUNBURY
COLLIE
COALFIELDS
ROAD
HIGHWAY
KATANNING
DONNYBROOK
BUSSELTON
KIRUP
WESTERN
RIVER
BOYUP BROOK
KOJONUP
BRIDGETOWN
VASSE
NANNUP
BUSSELL
MARGARET R.
BLACKWOOD
BROCKMAN
MANJIMUP
CRANBROOK
STIRLING RANGES
MUIRS
LAKE MUIR
ROCKY GULLY
AUGUSTA
PEMBERTON
MT BARKER
OCEAN
Bald Island
DENMARK
WALPOLE
SOUTH
COAST HWY
ALBANY
SCALE
0 10 20 30 40 50 km

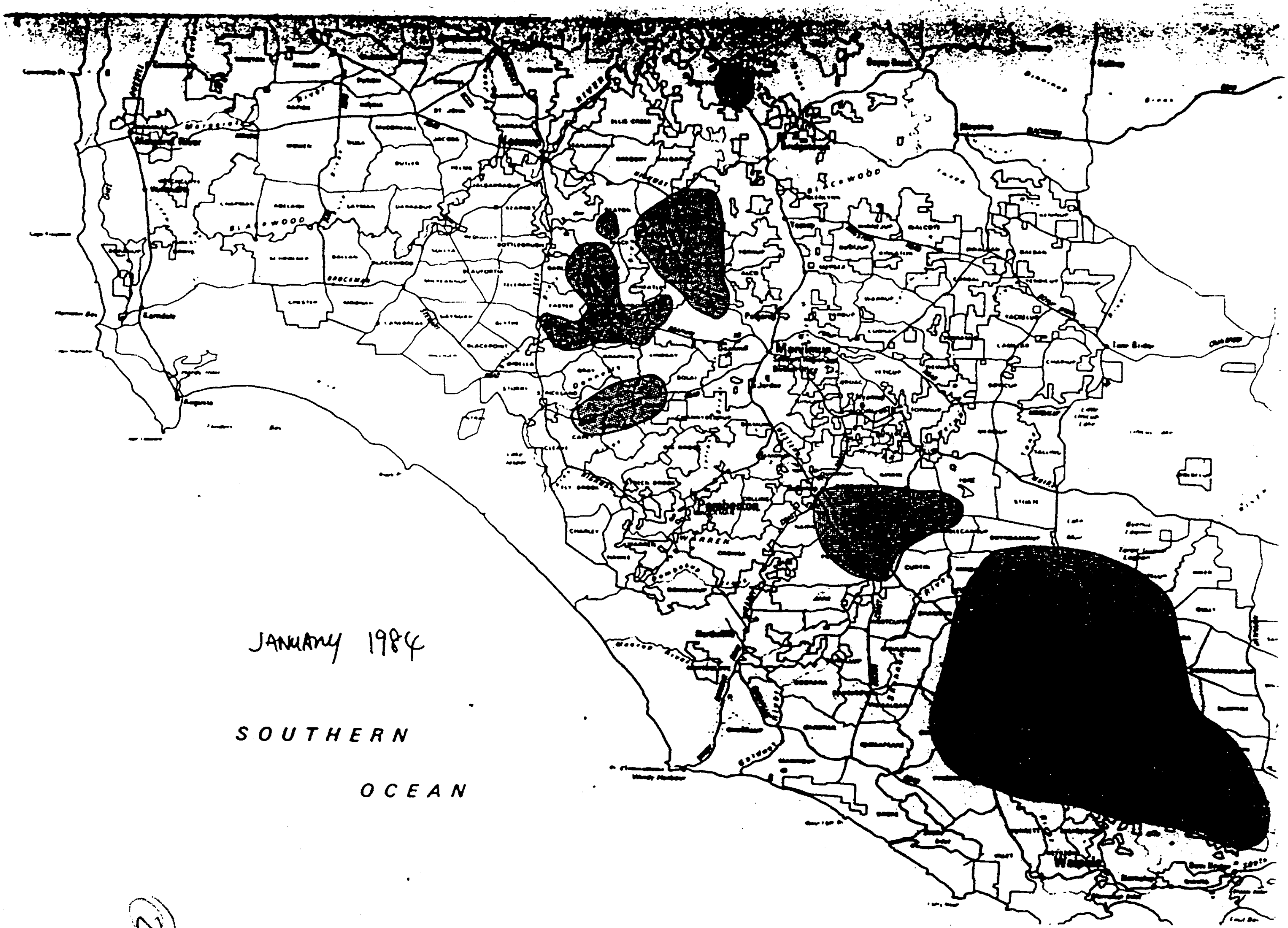

1983
WAROONA
HARVEY
SOUTH
INDIAN
OCEAN
BUNBURY
COALFIELDS
COLLIE
ROAD
HIGHWAY
DONNYBROOK
KIRUP
BUSSELTON
BUSSELL
MARGARET R.
BLACKWOOD
BROCKMAN
AUGUSTA
VASSE
WESTERN
RIVER
NANNUP
BRIDGETOWN
BOYUP BROOK
MANJIMUP
PEMBERTON
MUIRS
LAKE MUIR
ROCKY GULLY
WALPOLE
DENMARK
COAST HWY
ALBANY
Bald Island
MT BARKER
STIRLING RANGES
CRANBROOK
KATANNING
KOJONUP
WAGIN
NARROGIN
GREAT
SOUTHERN
ALBANY
SCALE
0 10 20 30 40 50 km

14

Appendix

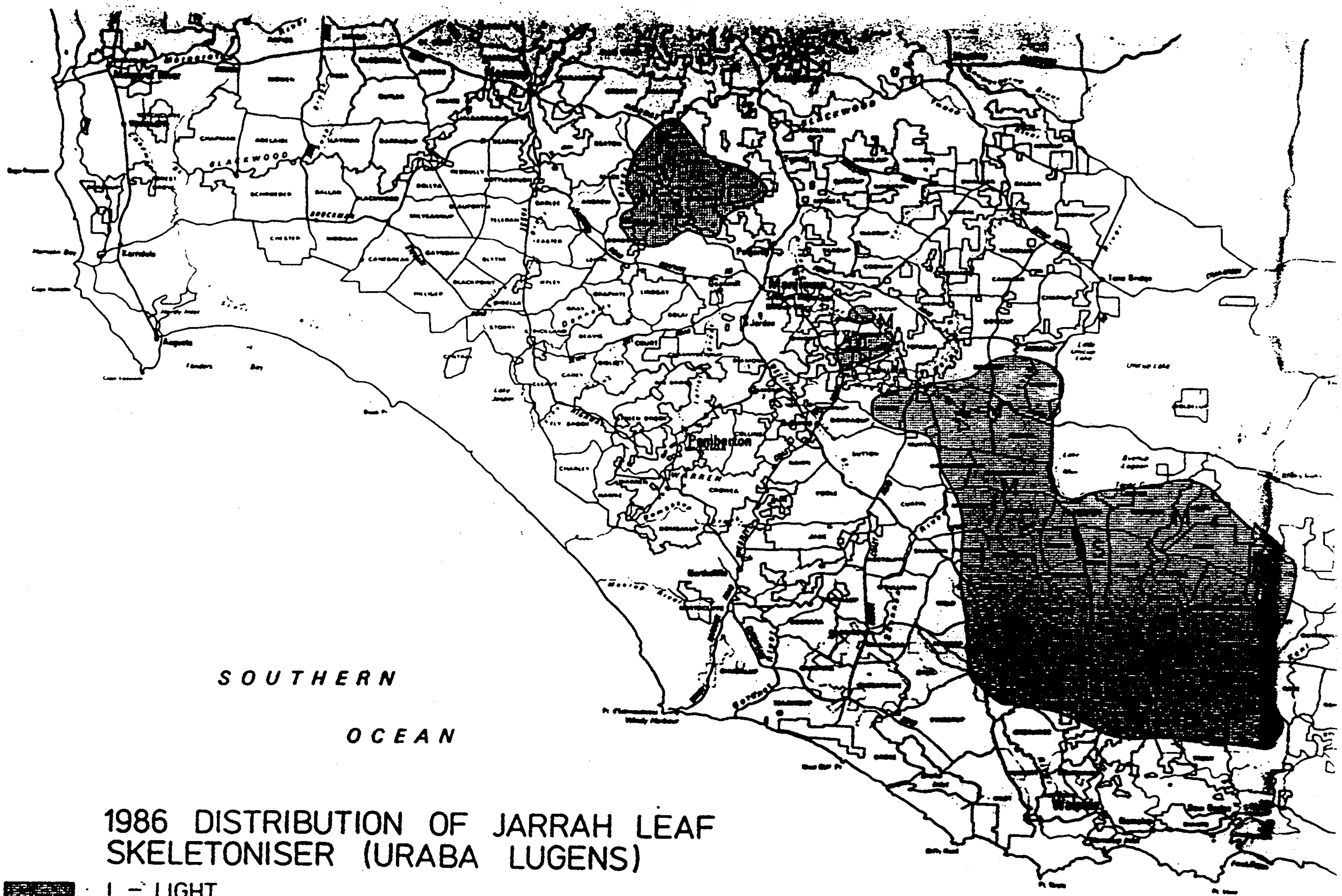
b) Maps of outbreak area of GLS.


SOUTHERN
OCEAN
10km
JANUARY 1983
1


JANUARY 1984
SOUTHERN
OCEAN

DISTRIBUTION OF JARRAH LEAF SKELETONISER (URABA LUGENS) 1985 JANUARY

(3)



1986 DISTRIBUTION OF JARRAH LEAF SKELETONISER (URABA LUGENS)

L - LIGHT
M - MODERATE
S - SEVERE