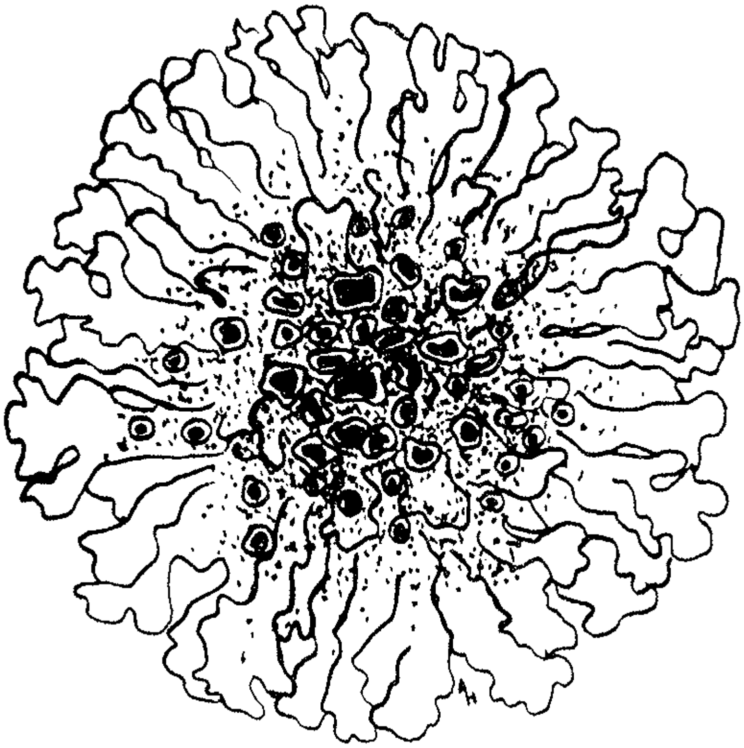
BASELINE SURVEY

OF

LICHENS AND HIGHER PLANTS

PINJARRA, W.A.



A REPORT PREPARED FOR

ALCOA OF AUSTRALIA (W.A.) LTD.

SEPTEMBER, 1979

FERMCO PTY. LTD.

VOLUME 2 : APPENDICES

(FIGURES & TABLES)

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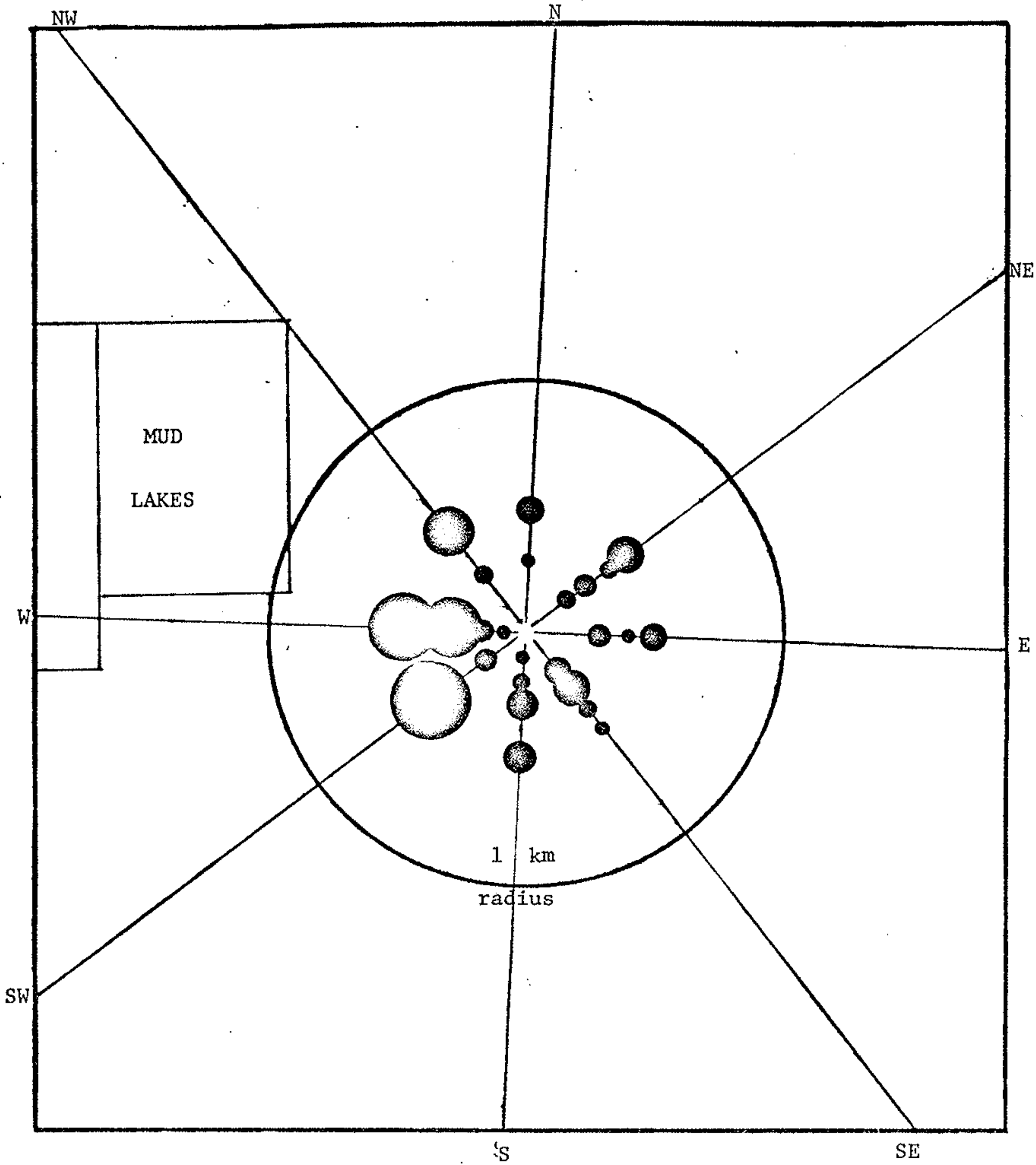



FIG. 2.1-1 : Frequencies and distances of observed ground contact by stack plume for the period May to September, 1978. The number of observations equals the circle diameter in millimetres. Compass points refer to the direction taken by the plume. Morning and afternoon observations are aggregated.

1978

FIG. 2.2.2-0: MAP OF STUDY AREA SHOWING RELATIONSHIPS BETWEEN MAPS 1, 2, 3 AND 4. CONCENTRIC CIRCLES MARK ONE KM INTERVALS.

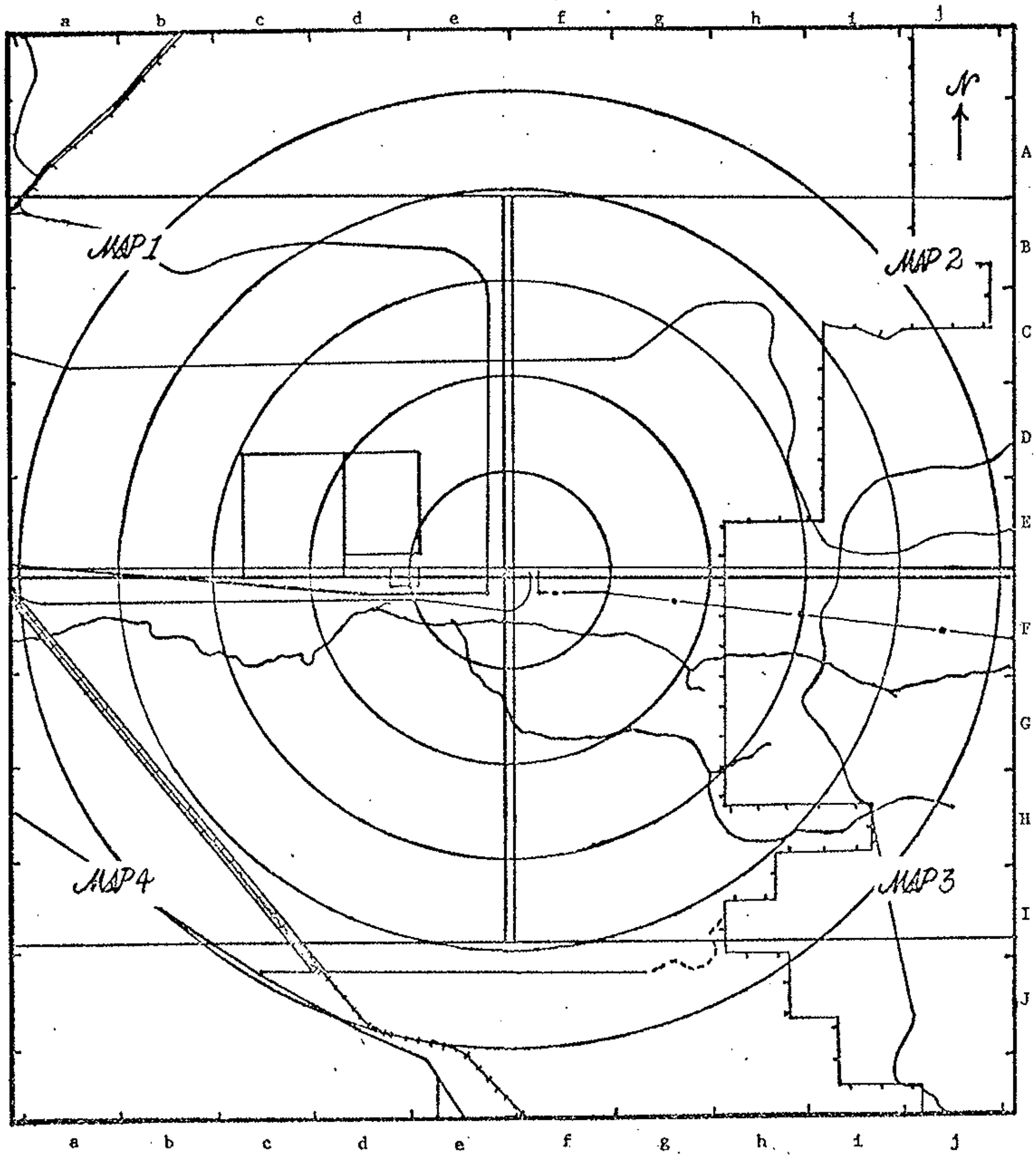


FIG. 2.2.2-1 : Distribution of total sulfur levels in proximal and distal leaf sections of *Xanthorrhoea preissii:* North West quadrant of study area.

Key : (i) Proximal, left bar; distal, right bar.
(ii) One mm bar length equals 100 ppm total elemental sulfur.
(iii) Concentric circles mark 1 km intervals from emission source.

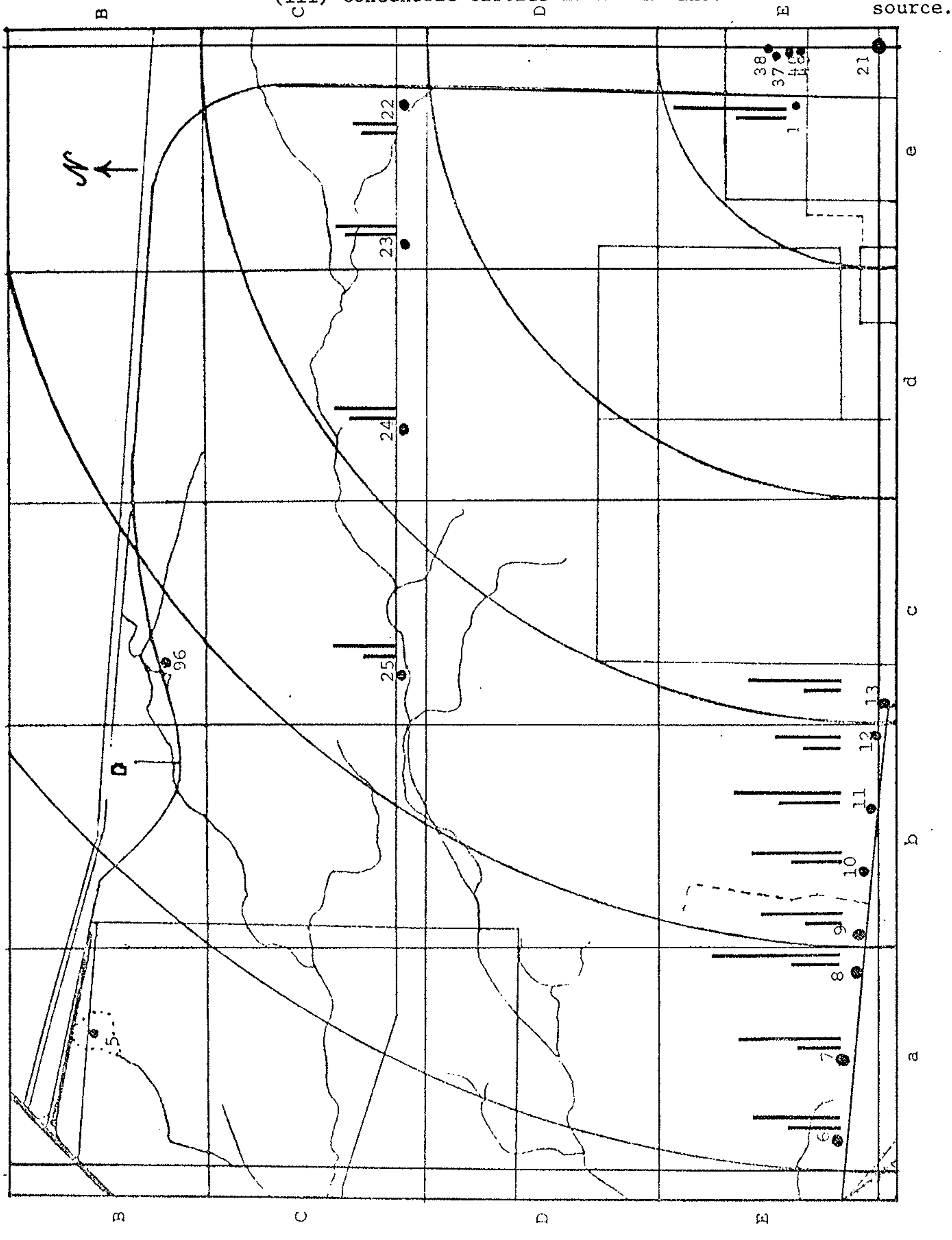


FIG. 2.2.2-2 : Distribution of total sulfur levels in proximal and distal leaf sections of *Xanthorrhoea preissii*: North East quadrant of study area.

Key : (i) Proximal, left bar; distal, right bar.
(ii) One mm bar length equals 100 ppm total elemental sulfur.
(iii) Concentric circles mark 1 km intervals from emission source.

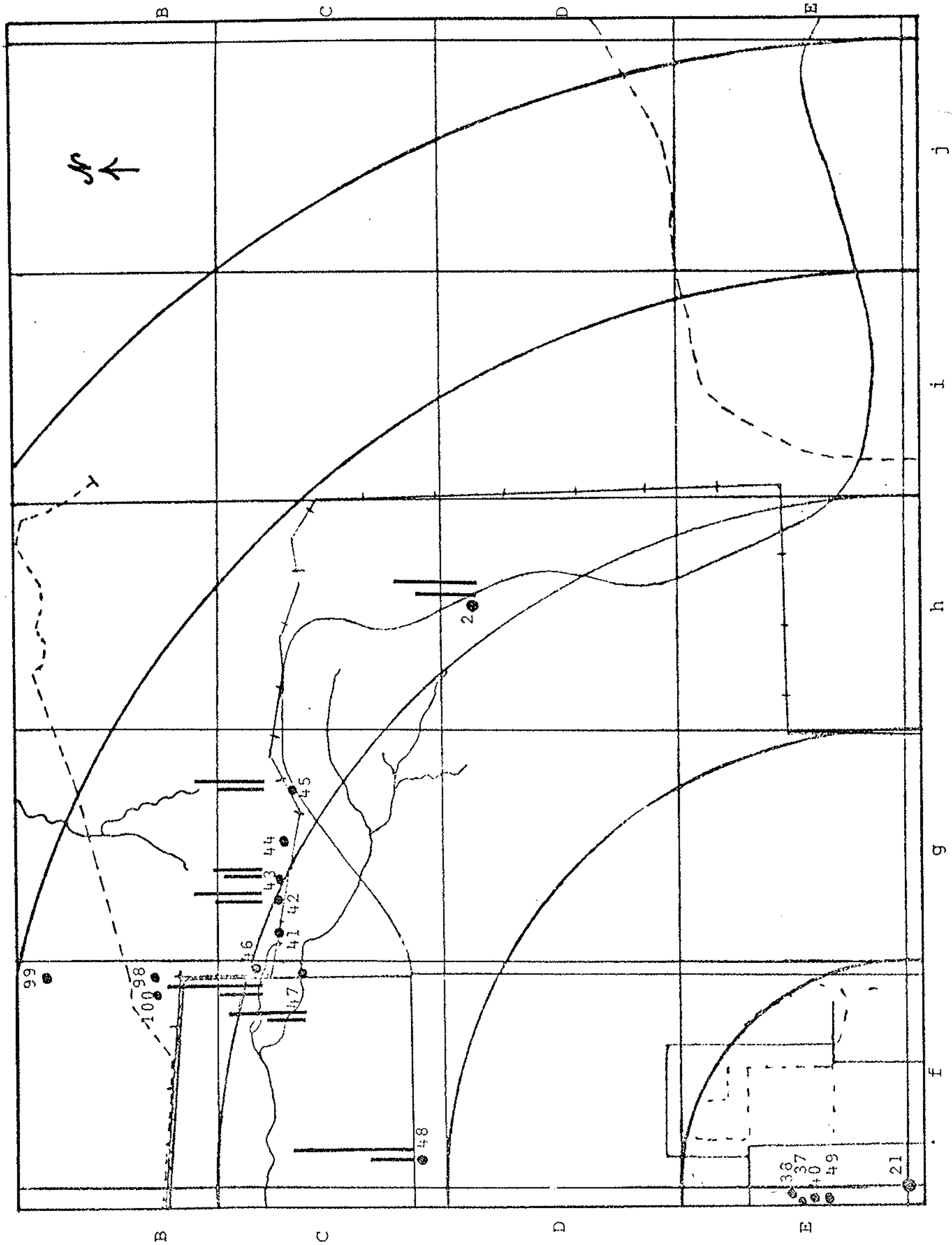


FIG. 2.2.2-3 : Distribution of total sulfur levels in proximal and distal leaf sections of *Xanthorrhoea preissii*: South East quadrant of study area.

Key: (i) Proximal, left bar; distal, right bar.
(ii) One mm bar length equals 100 ppm total elemental sulfur.
(iii) Concentric circles mark 1 km intervals from emission source.

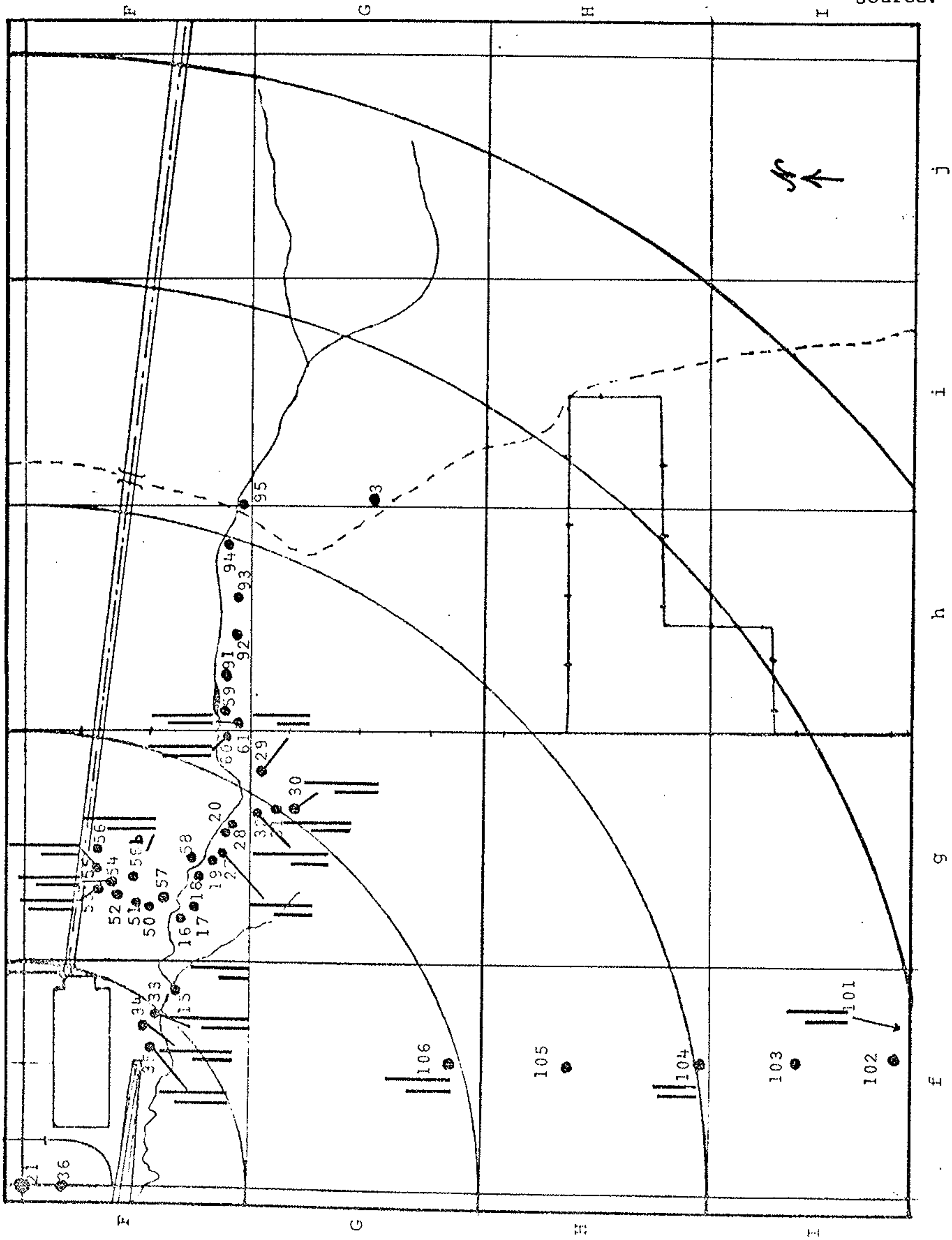


FIG. 2.2.2-4 : Distribution of total sulfur levels in proximal and distal leaf sections of *Xanthorrhoea preissii* : South West quadrant of study area.

Key: (i) Proximal, left bar, distal, right bar.
(ii) One mm bar length equals 100 ppm total elemental sulfur.
(iii) Concentric circles mark 1 km intervals from emission source.

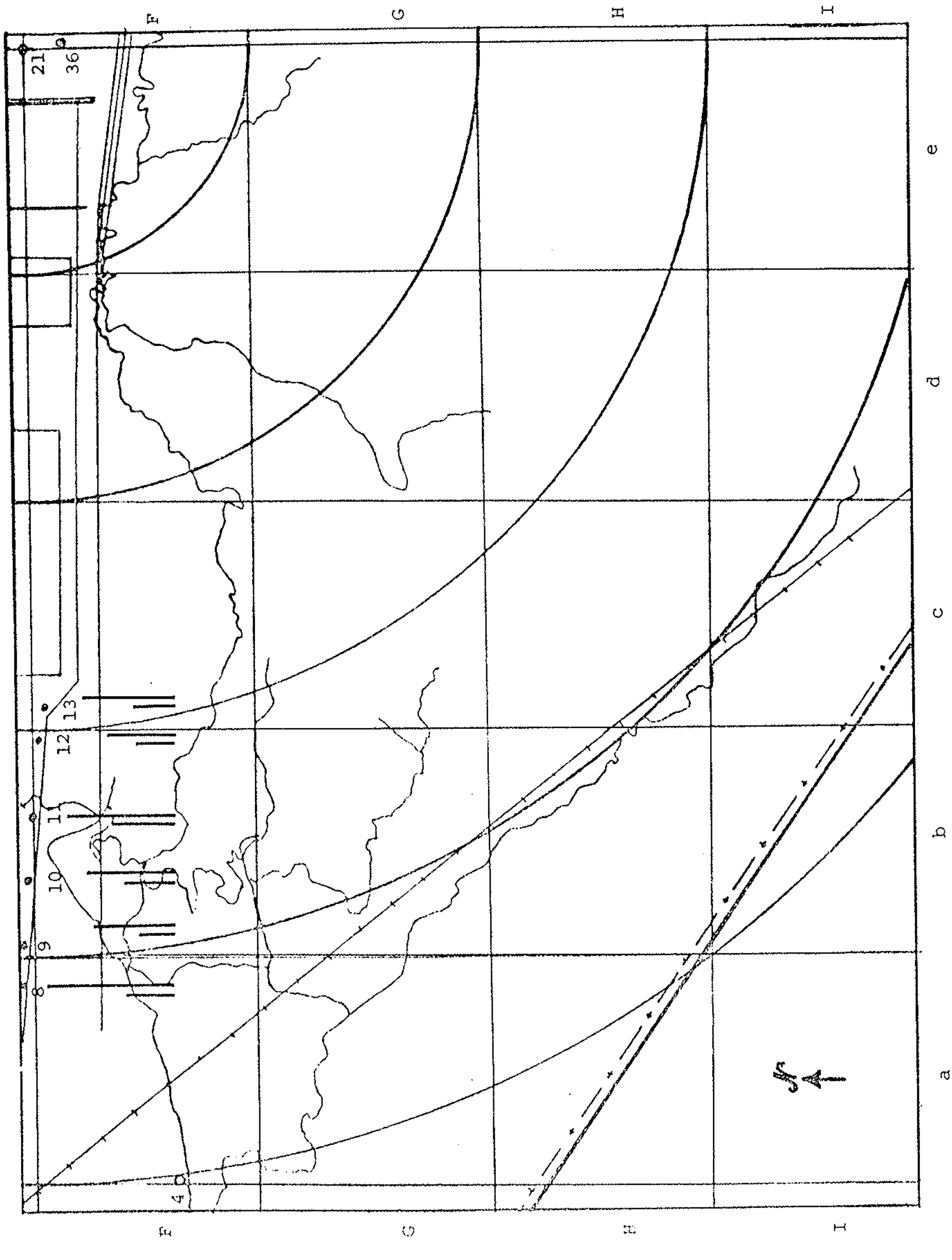


FIG. 2.2.2-5: TOTAL SULFUR (ppm) VARIATION ALONG THE LEAF OF *Xanthorrhoea preissi*.

KEY: △, site 2; ○, sites 6 to 13 (young leaf sample); ●, sites 6 to 13 (older leaf sample).

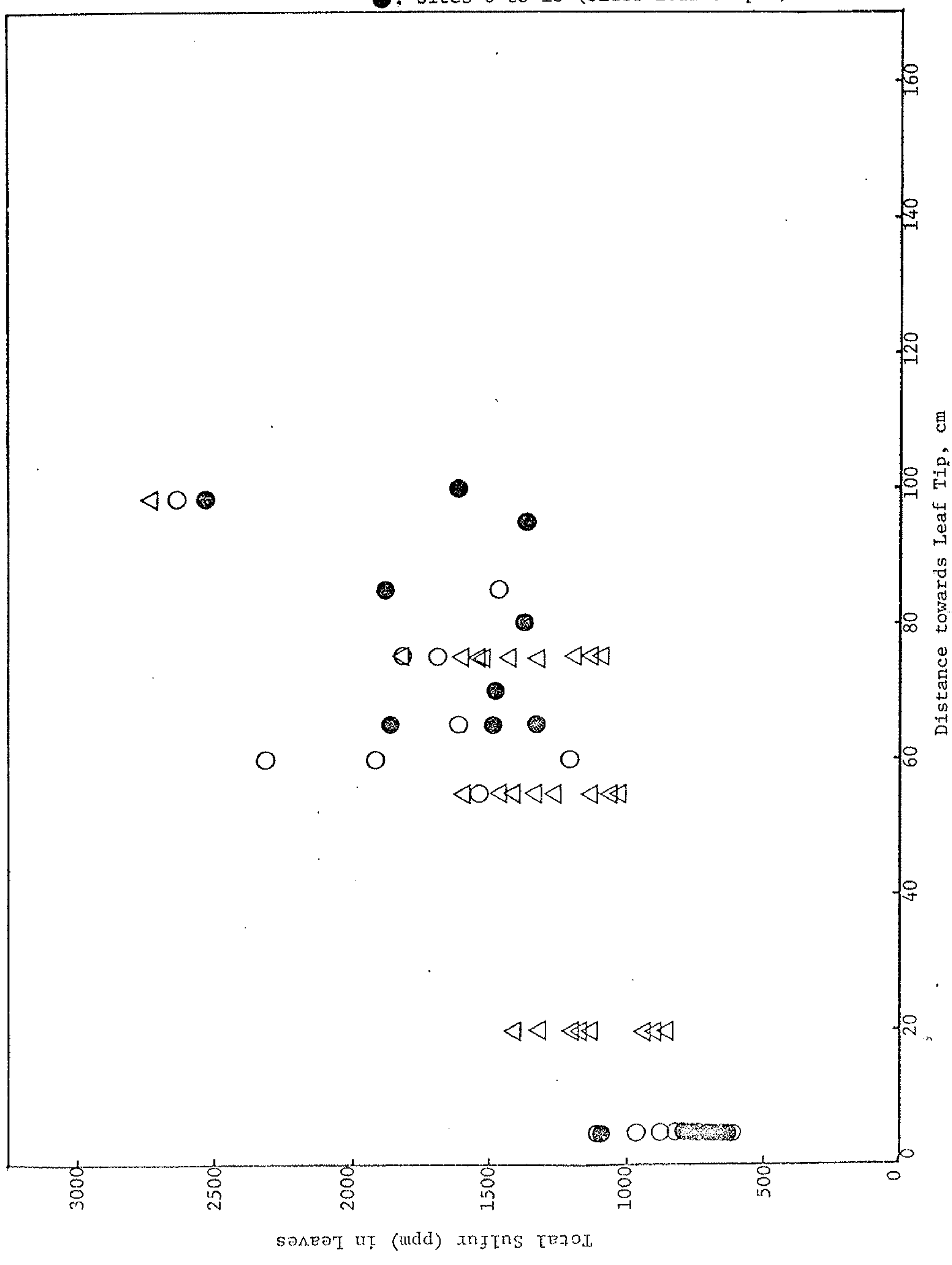


TABLE 2.2.2-0

LISTING OF SITE LOCATIONS

(Refer to Fig. 2.2.2-0)

| SITE NUMBER | LOCATION | MAP NUMBER(S) | GRID REFERENCE(S) |
|---|---|---|---|
| 0 | Manna Flat, York, W.A. | - | - |
| 1 | ALCOA, PINJARRA, W.A. | 1 | Ee |
| 2 | " " " | 2 | Dh |
| 3 | " " " | 3 | Gi |
| 4 | " " " | 4 | Fa |
| 5 | " " " | 1 | Ba |
| 6-13 | " " " | 1 | Eabc |
| 14 | Pine forest on Dwellingup Rd | - | - |
| 15-20 | ALCOA, Pinjarra, W.A. | 3 | Ffg |
| 21 | " " " | 1,2,3,4 | EFef |
| 22-25 | " " " | 1 | Ccde |
| 26 | South of Site 0, on Helena Rd | - | - |
| 27-32 | ALCOA, Pinjarra, W.A. | 3 | FGg |
| 33-35 | " " " | 3 | Ff |
| 36 | " " " | 3,4 | Fef |
| 37-40 | " " " | 1,2 | Ee |
| 41-47 | " " " | 2 | Cgf |
| 48 | " " " | 2 | Cf |
| 49 | " " " | 1,2 | Ee |
| 50-58 | " " " | 3 | Fg |
| 59-61 | " " " | 3 | Fgh |
| 61b-90 | North West of W. Australia | - | - |
| 91-95 | ALCOA, Pinjarra, W.A. | 3 | Fh |
| 96 | " " " | 1 | Bc |
| 97 | Pinjarra cemetery | - | - |
| 98-100 | Fairbridge Farm, Pinjarra, W.A. | 2 | Bf |
| 101-106 | ALCOA, Pinjarra, W.A. | 3 | GHIf |
| 107 | Scarp area, near Dwellingup Rd | - | - |
| 108 | West Kulin | - | - |
| 109 | St. John's Churchyard | - | - |
| 110.1-11 | Pinjarra High School roof | - | - |
| 111.1-5-112 | Pinjarra street trees | - | - |
| 113-115 | East Perth | - | - |

TABLE 2.2.2.-1 TOTAL SULFUR LEVELS IN THE LEAVES OF *XANTHORRHOEA PREISSII* AND *KINGIA AUSTRALIS*

| SITE NO. | SAMPLE[1,5,6,7] | TOTAL MEAN LENGTH (cm) | SULFUR CONCENTRATION (ppm) | | |
|---|---|---|---|---|---|
| | | | PROXIMAL[2] | MEDIAL[3] | DISTAL[4] |
| 0 | P167 | 75 | 570 | | 1020 |
| | P168 | 84 | 510 | | 900 |
| 1 | P279 | 64 | 890 | | 1960 |
| | P280 | 73 | 830 | | 2040 |
| 2 | P47 N | 93 | 890 | 1050 | 1430 |
| | E | 96 | 835 | 1040 | 1080 |
| | S | 85 | 1125 | 1255 | 1510 |
| | W | 62 | 1175 | 1465 | 1520 |
| | P48 N | 75 | 940 | 1125 | 1185 |
| | E | 75 | 1415 | 1410 | 1575 |
| | S | 81 | 1185 | 1330 | 1375 |
| | W | 74 | 1315 | 1595 | 1800 |
| 6 | P82-o | 90 | 1330 | | 1160 |
| | -y | 80 | 950 | | 1610 |
| | P83-o | 95 | 860 | | 1370 |
| | -y | 85 | 970 | | 1450 |
| 7 | P84-o | 115 | 690 | | 1610 |
| | -y | 90 | 780 | | 1810 |
| 8 | P85-o | 100 | 680 | | 1890 |
| | -y | 75 | 870 | | 2310 |
| 9 | P86-o | 110 | 620 | | 1360 |
| | -y | 100 | 610 | | 1470 |
| 10 | P87-o | 85 | 700 | | 1490 |
| | -y | 70 | 830 | | 1540 |
| 11 | P88-o | 80 | 760 | | 1870 |
| | -y | 75 | 1100 | | 1910 |

TABLE 2.2.2.-1 (contd.) TOTAL SULFUR LEVELS IN THE LEAVES OF *XANTHORRHOEA PREISSII* AND *KINGIA AUSTRALIS*

| SITE NO. | SAMPLE[1,5,6,7] | TOTAL MEAN LENGTH (cm) | SULFUR CONCENTRATION (ppm) | | |
|---|---|---|---|---|---|
| | | | PROXIMAL[2] | MEDIAL[3] | DISTAL[4] |
| 12 | P89-o | 80 | 780 | | 1320 |
| | -y | 75 | 740 | | 1200 |
| 13 | P90-o | 95 | 790 | | 1480 |
| | -y | 90 | 650 | | 1690 |
| 22 | P143 | 57 | 760 | | 790 |
| | P144 GT | 40 | 1810 | | 2060 |
| 23 | P146 | 64 | 960 | | 1230 |
| | P153 | 55 | 890 | | 970 |
| | P154 GT | 36 | 1190 | | 1820 |
| 24 | P155 | 51 | 820 | | 1110 |
| | P156 GT | 35 | 2780 | | 1960 |
| 25 | P157 | 59 | 590 | | 1140 |
| 26 | P170 | 79 | 670 | | 970 |
| | P171 | 85 | 730 | | 1070 |
| 27 | P188 | 71 | 770 | | 990 |
| | P189 | 71 | 610 | | 1090 |
| 29 | P200 | 68 | 540 | | 990 |
| 30 | P201 | 70 | 780 | | 1190 |
| 31 | P207 | 74 | 660 | | 1200 |
| 32 | P208 | 63 | 650 | | 1340 |
| 15-16 | P210 | 93 | 520 | | 1000 |
| 33 | P211 | 70 | 800 | | 1110 |
| 34 | P212 | 74 | 670 | | 1280 |

TABLE 2.2.2.-1 (contd.) TOTAL SULFUR LEVELS IN THE LEAVES OF *XANTHORRHOEA PREISSII* AND *KINGI AUSTRALIS*

| SITE NO. | SAMPLE[1,5,6,7] | TOTAL MEAN LENGTH (cm) | SULFUR CONCENTRATION (ppm) | | |
|---|---|---|---|---|---|
| | | | PROXIMAL[2] | MEDIAL[3] | DISTAL[4] |
| 35 | P213 | 63 | 810 | | 1100 |
| 42 | P274 | 69 | 800 | | 1150 |
| 43 | P273 | 62 | 640 | | 850 |
| 45 | P272 | 60 | 770 | | 1150 |
| 46 | P275 | 85 | 770 | | 1670 |
| 47 | P277 | 94 | 700 | | 1400 |
| 48 | P278 | 66 | 770 | | 2150 |
| 53 | P299 | 71 | 770 | | 890 |
| 54 | P302 | 89 | 710 | | 1090 |
| 56 | P306 | 77 | 680 | | 1270 |
| 56b | P309 | 64 | 860 | | 1290 |
| 60 | P337 | 66 | 810 | | 1010 |
| 61 | P341 | 74 | 730 | | 1130 |
| 101 | P558 | 71 | 750 | | 1070 |
| 104 | P559 | 56 | 680 | | 710 |
| 106 | P560 | 55 | 770 | | 1130 |

1, SAMPLE: Approximately 50 leaves cut from as near to the leaf base as possible.

2, PROXIMAL: The first 10 cm section from the cut end.

3, MEDIAL: The 10 cm section between 30 and 40 cm from the cut end.

4, DISTAL: The leaf end section cut at the point 30 cm proximal to the mean leaf length.

5, N,E,S,W: The orientation of the leaves sampled.

6, o,y: Old (lower lateral) and young (center) leaves, respectively.

7, GT: *Kingia australis*.

FIG. 2.3.2-1: LOCATION OF SELECTED LICHEN SPECIES:
*Cladonia aggregata*, ●; aff. *Cladonia aggregata*, ○.

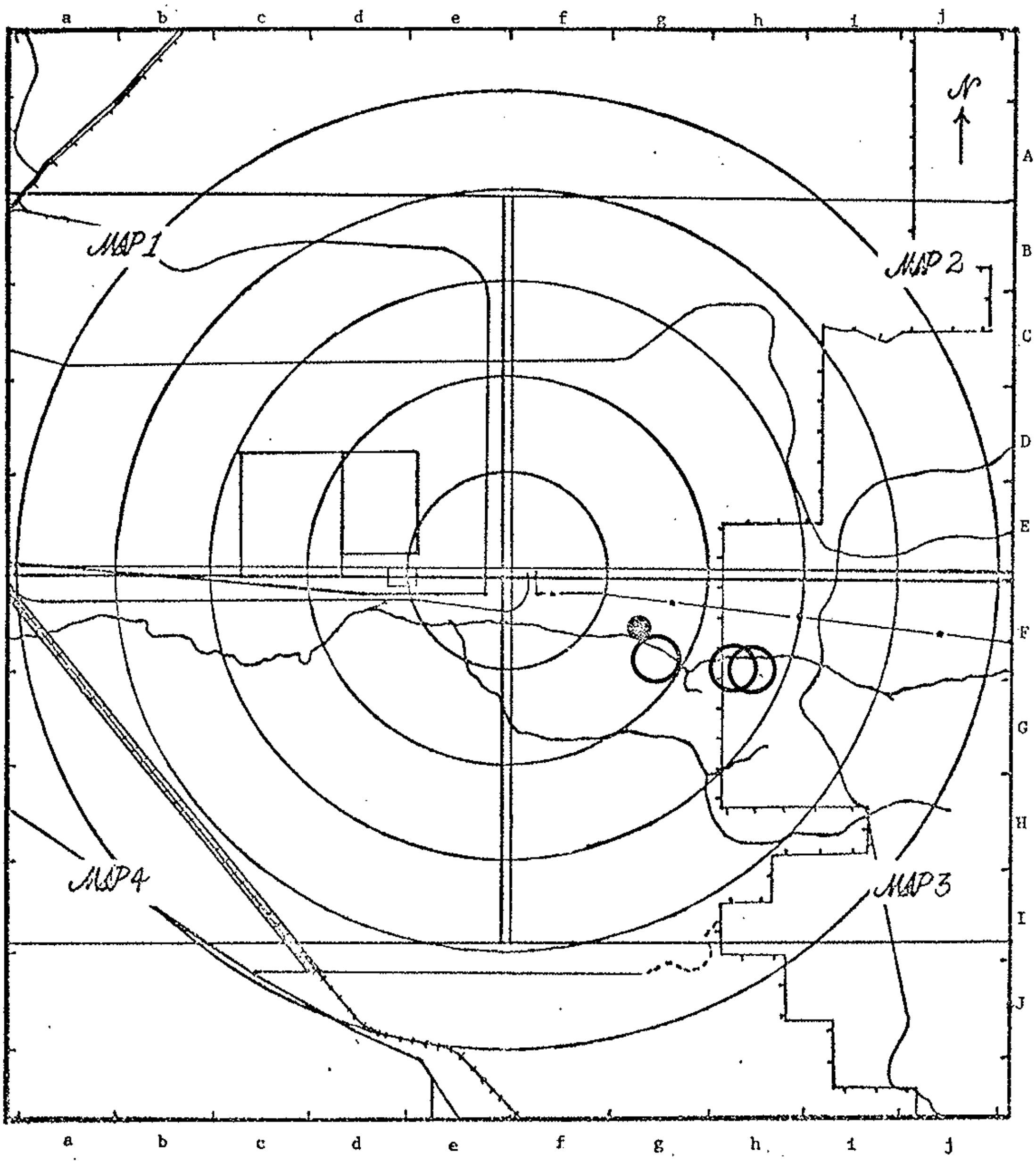


FIG. 2.3.2-2: LOCATION OF SELECTED LICHEN SPECIES: *Cladonia cariosa* ●

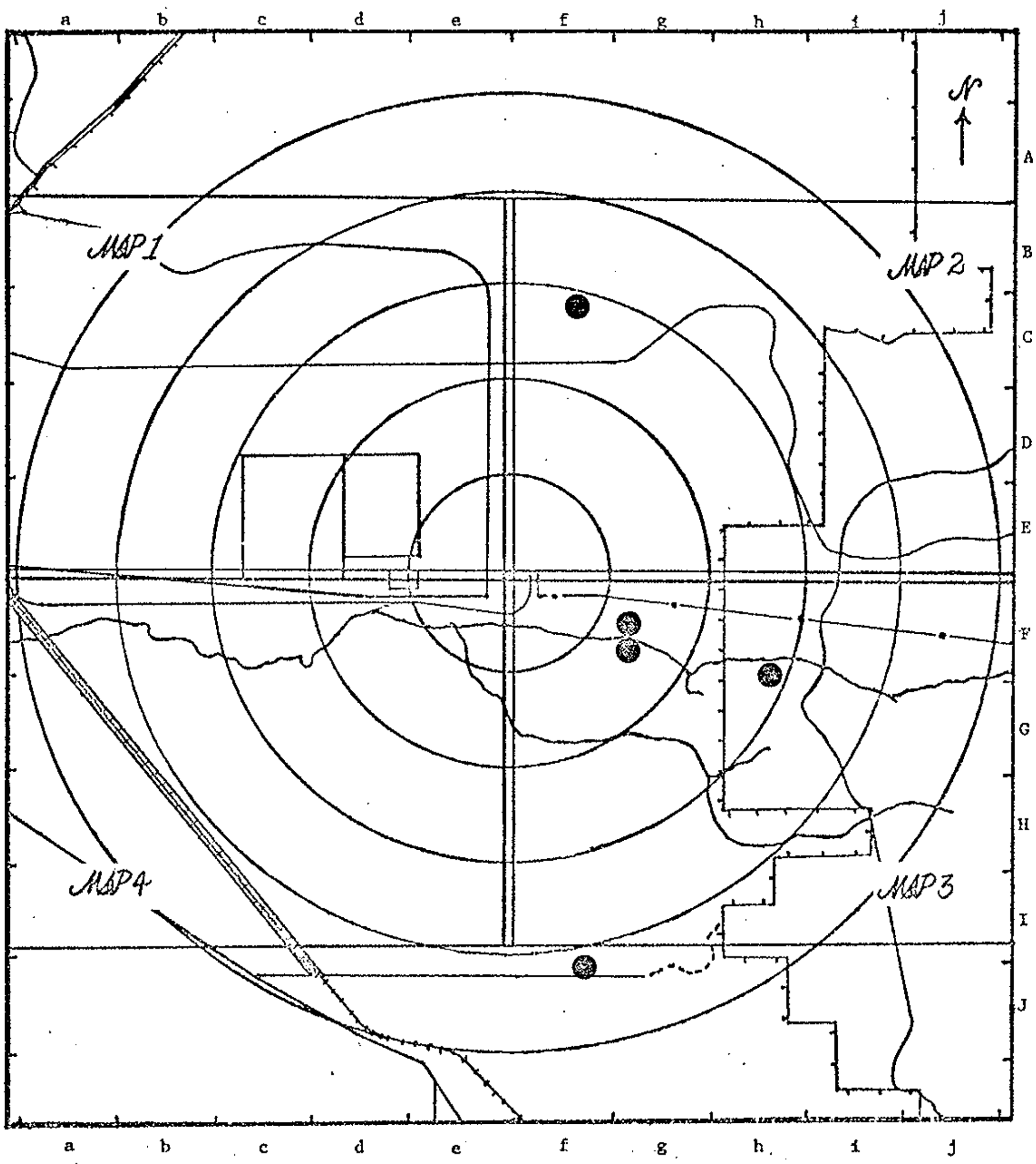


FIG. 2.3.2-3: LOCATION OF SELECTED LICHEN SPECIES: *Cladonia verticillata*, ●; aff. *Cladia verticillata*, ○.

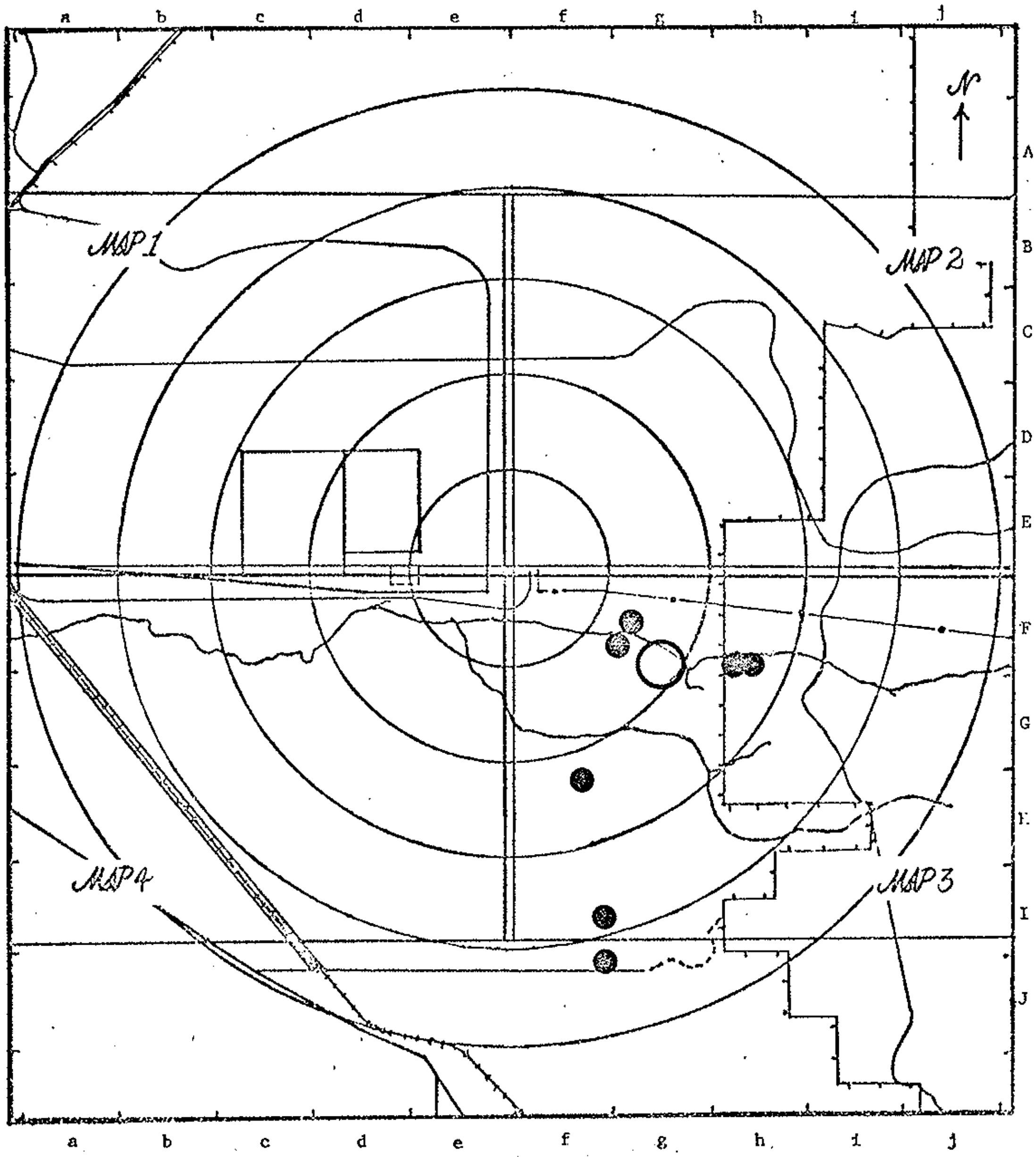


FIG. 2.3.2-4: LOCATION OF SELECTED LICHEN SPECIES: *Parmelia rutidota*, ●; *Parmelia subalbicans*, ○.

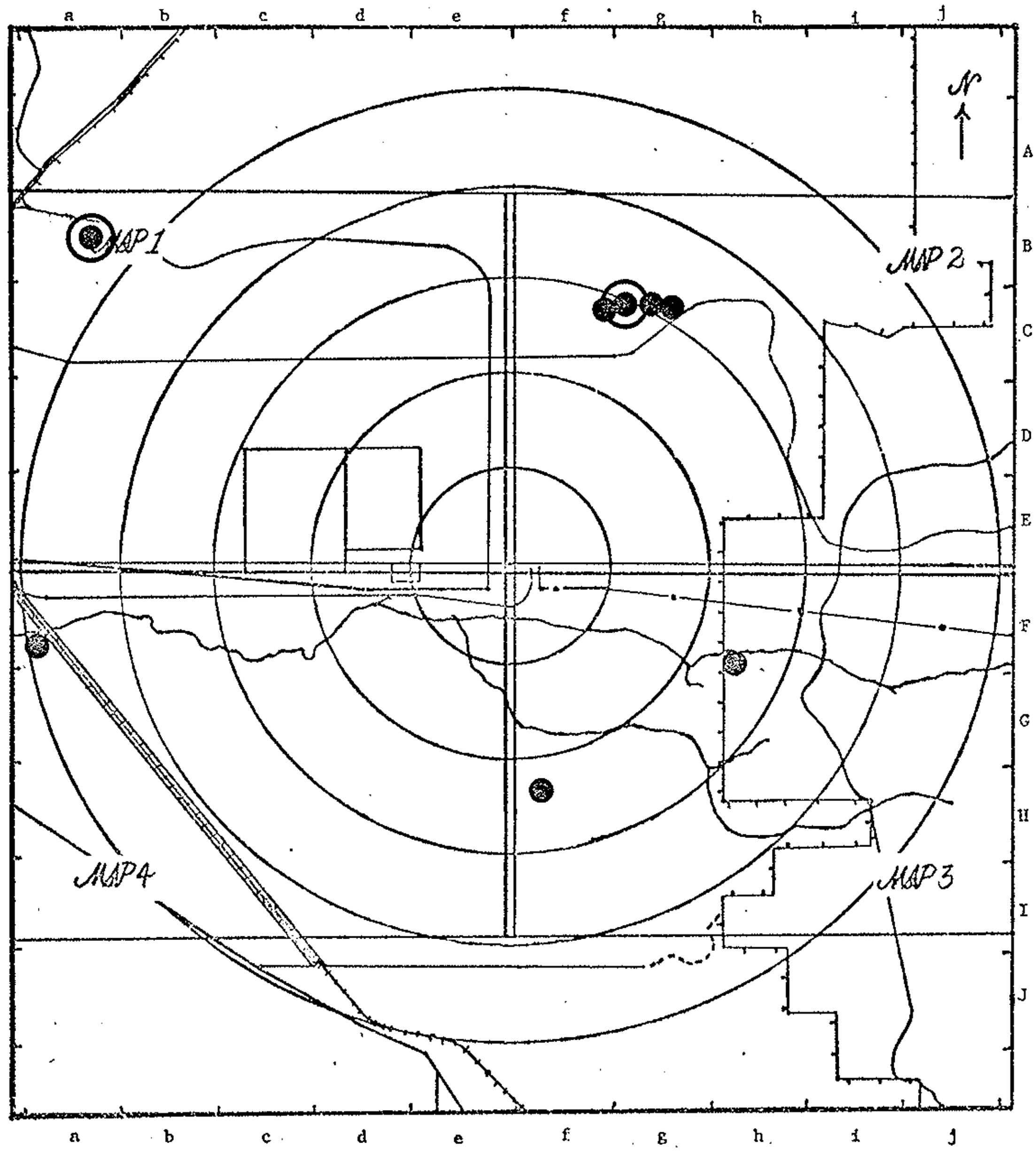


FIG. 2.3.2-5: LOCATION OF SELECTED LICHEN SPECIES:
*Thysanothecium hyalinum*, ● ;
aff. *Thysanothecium hyalinum*, ○.

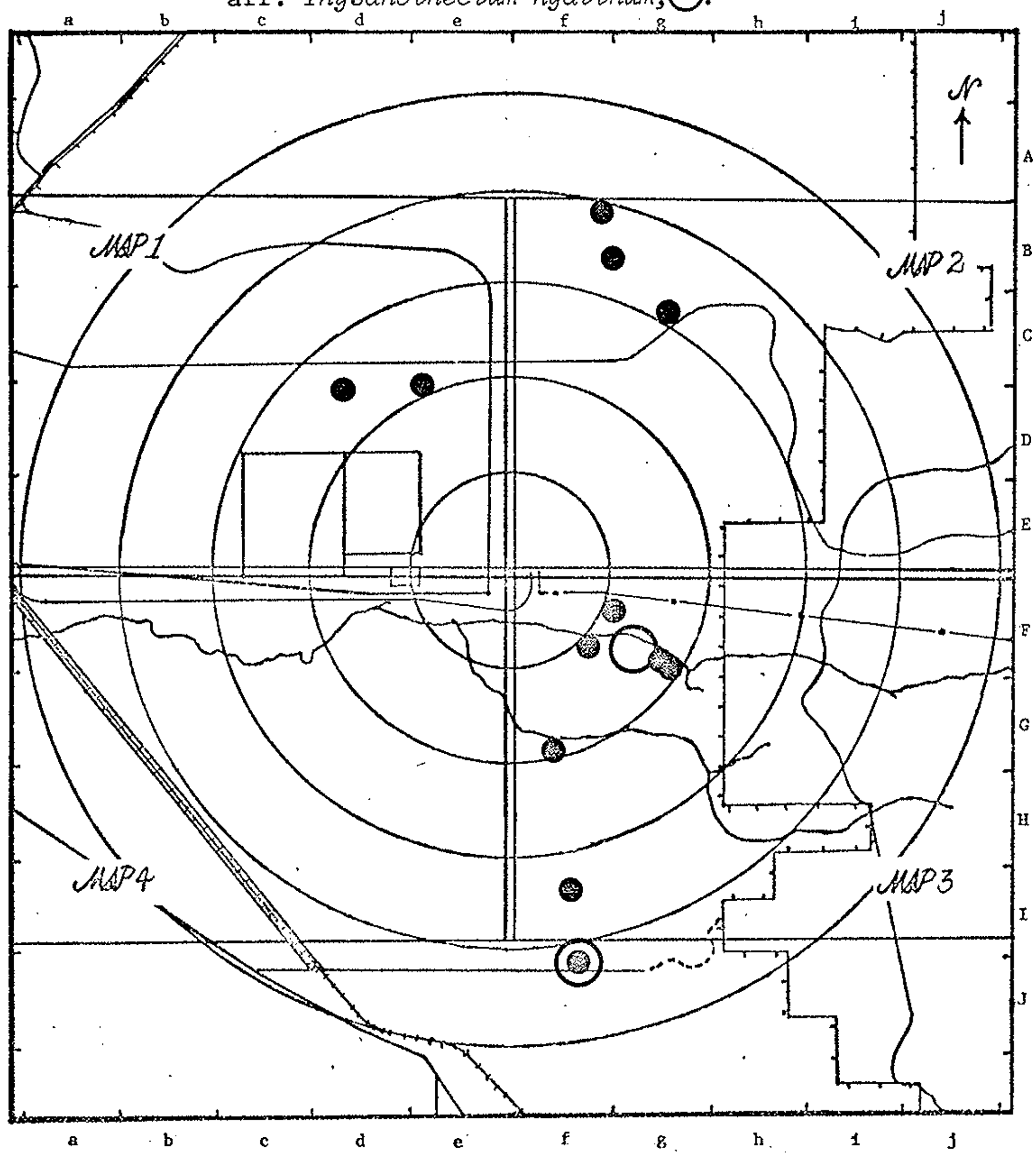


FIG. 2.3.2-6: LOCATION OF SELECTED LICHEN SPECIES:

*Usnea barbata* var. *xanthopoga*, ●.

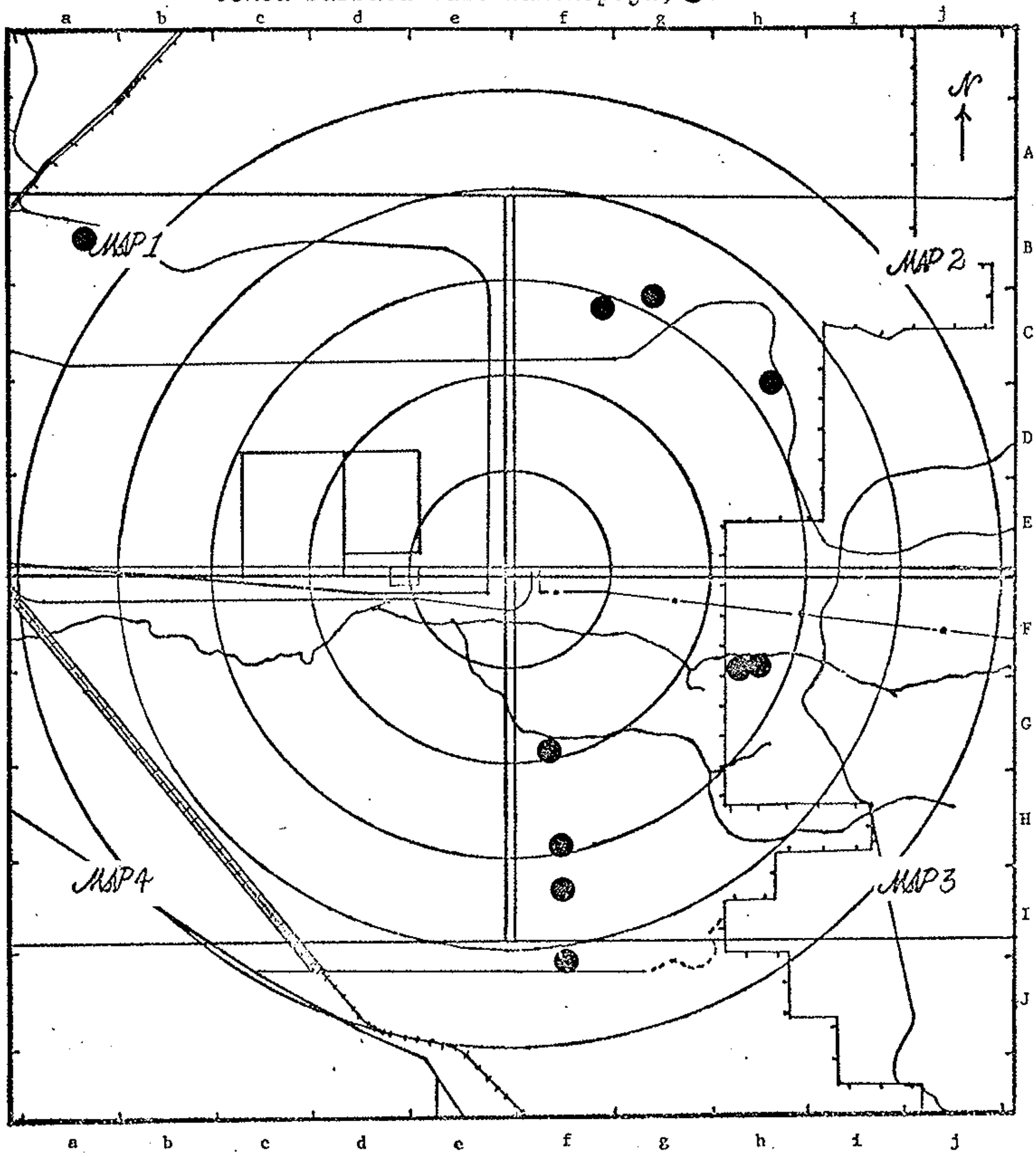
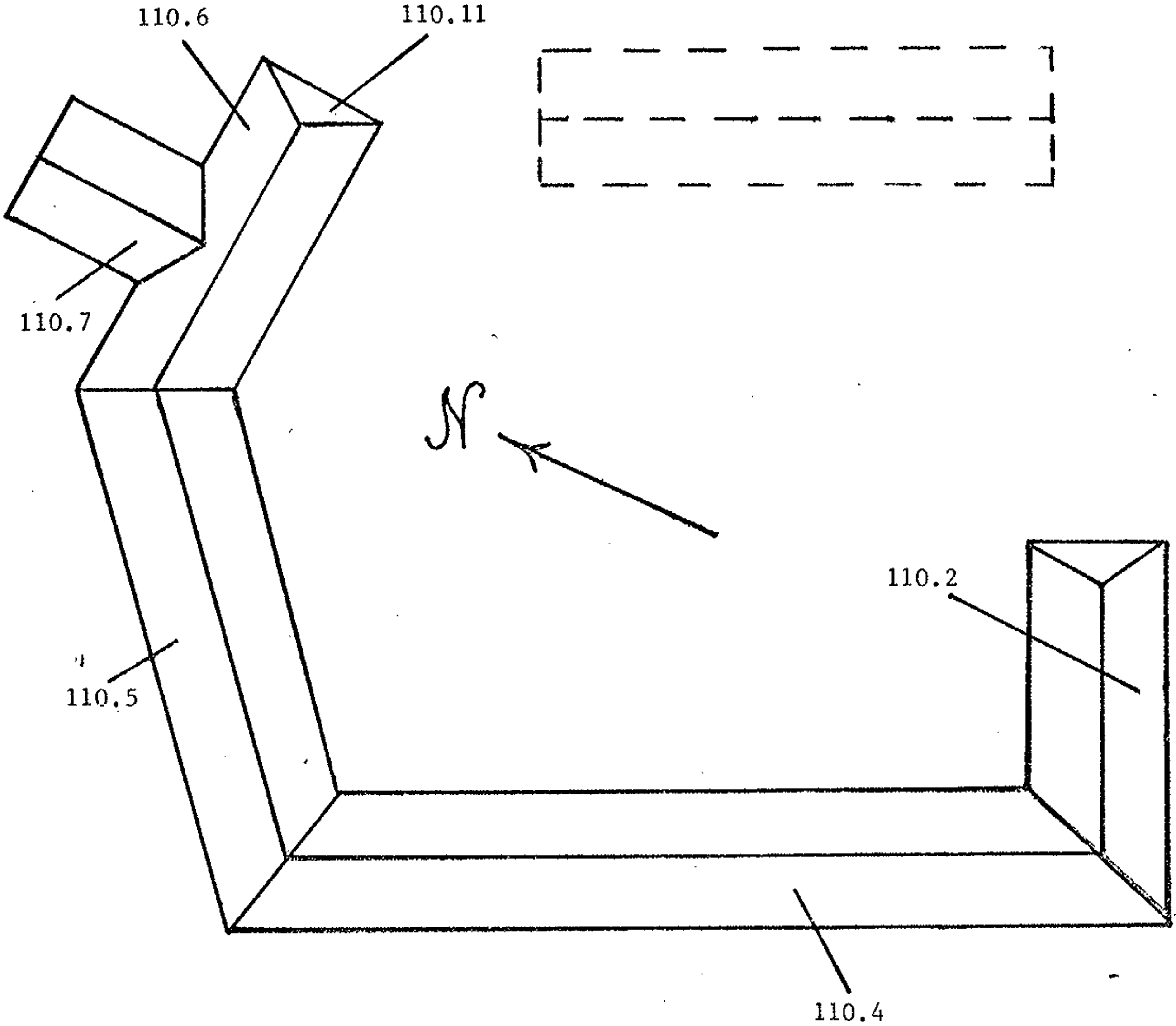


FIG. 2.3.4-1 PINJARRA HIGH SCHOOL ROOF TOP QUADRATS
(PLAN NOT TO SCALE).



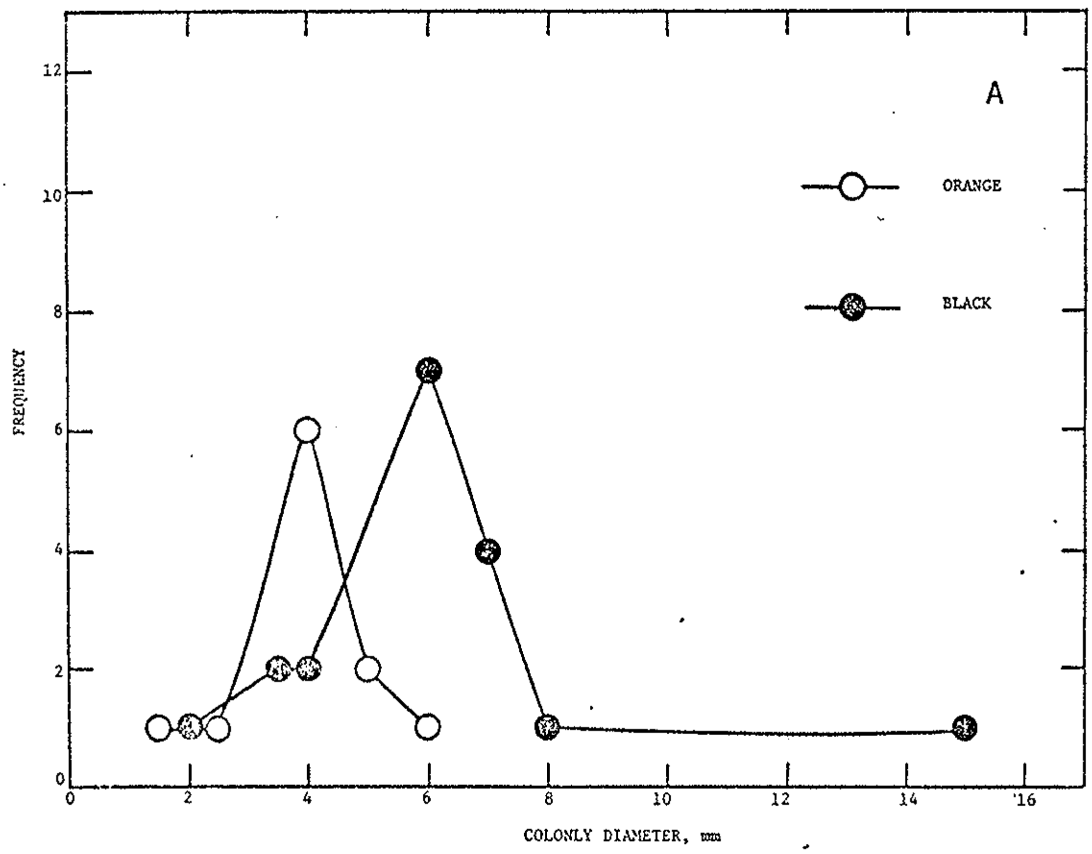
GRAVE-SITE SERIES

FIGS. 2.3.4.3-1 TO 8

PROTOCOL:

1. Figures are identified by grave-site location.
2. Colony measurements were performed using either transects or entire horizontal surfaces of grave-stones.
3. Densely colonized surfaces were not included because of the difficulty of distinguishing individual colonies.

FIG. 2.3.4.3-1A,B: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca*, ○ ; UNCLASSIFIED CRUSTOSE SPECIES WITH BLACK APOTHECIA, ● ;
A. SITE 97-37.
B. SITE 97-67.



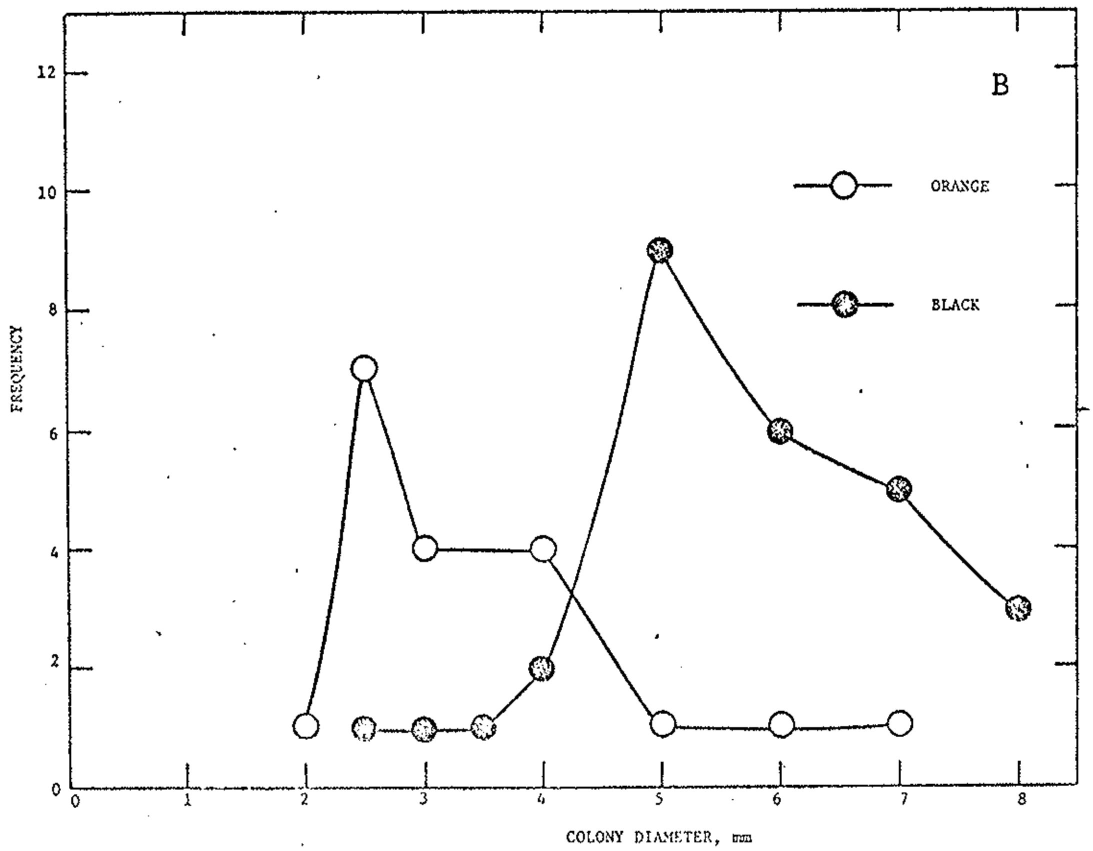
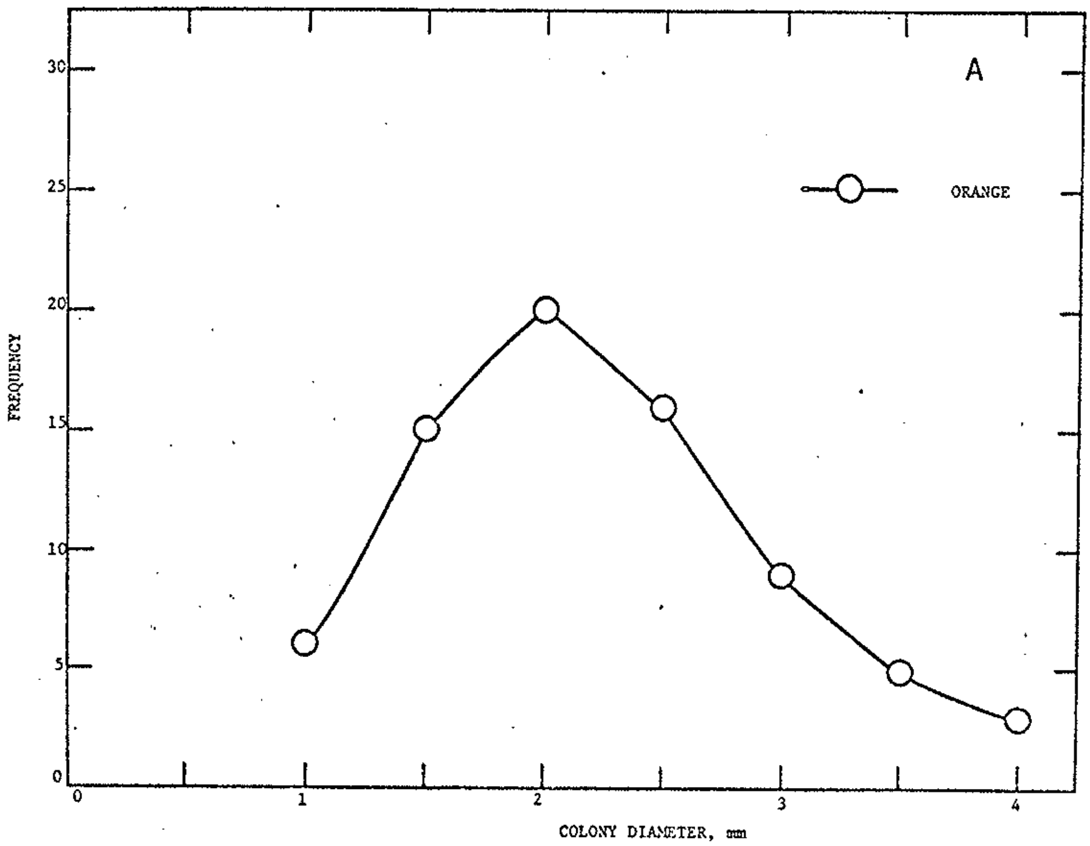
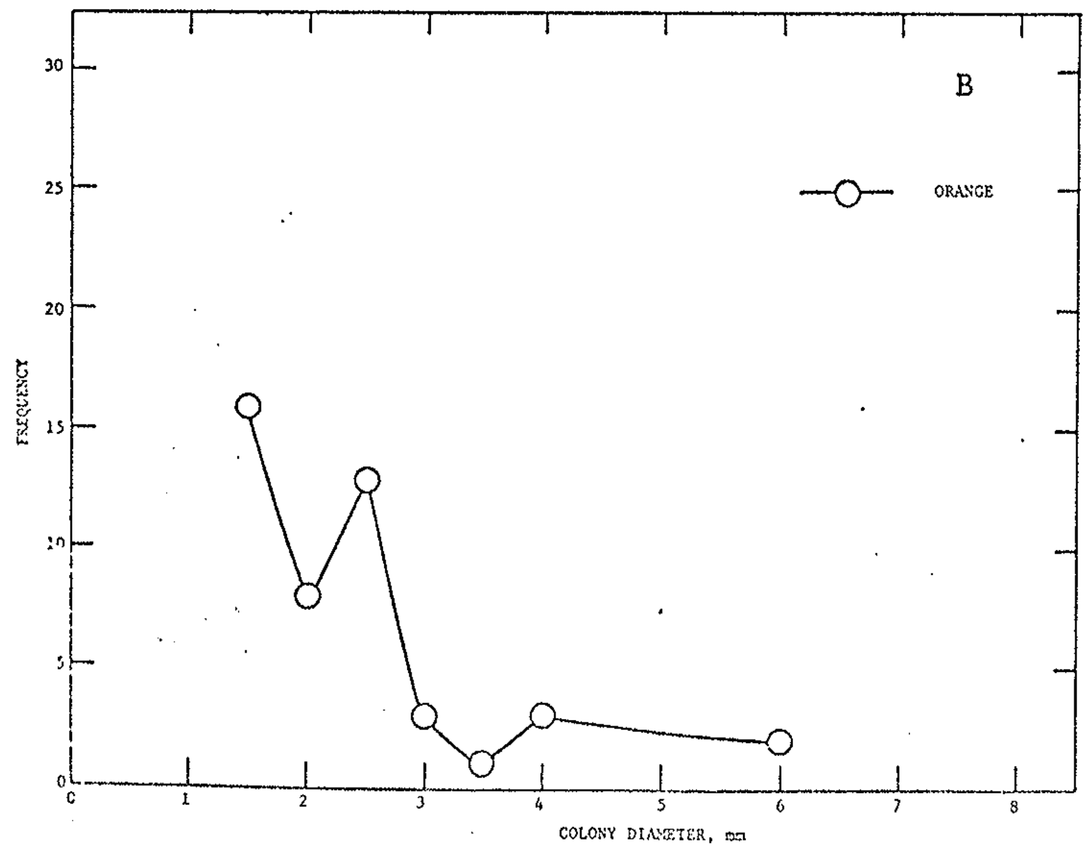



FIG. 2.3.4.3-2A,B: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca*.
A. SITE 97-8
B. SITE 97-25




SITE 97-8

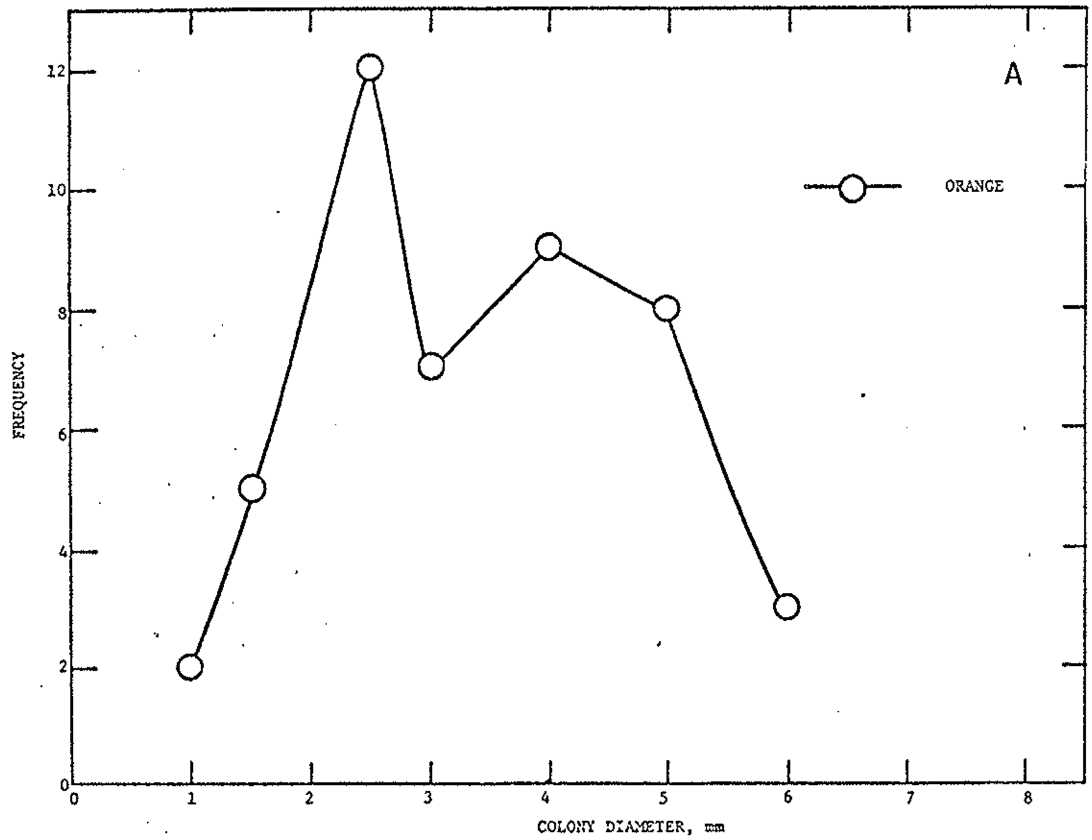



SITE 97-25

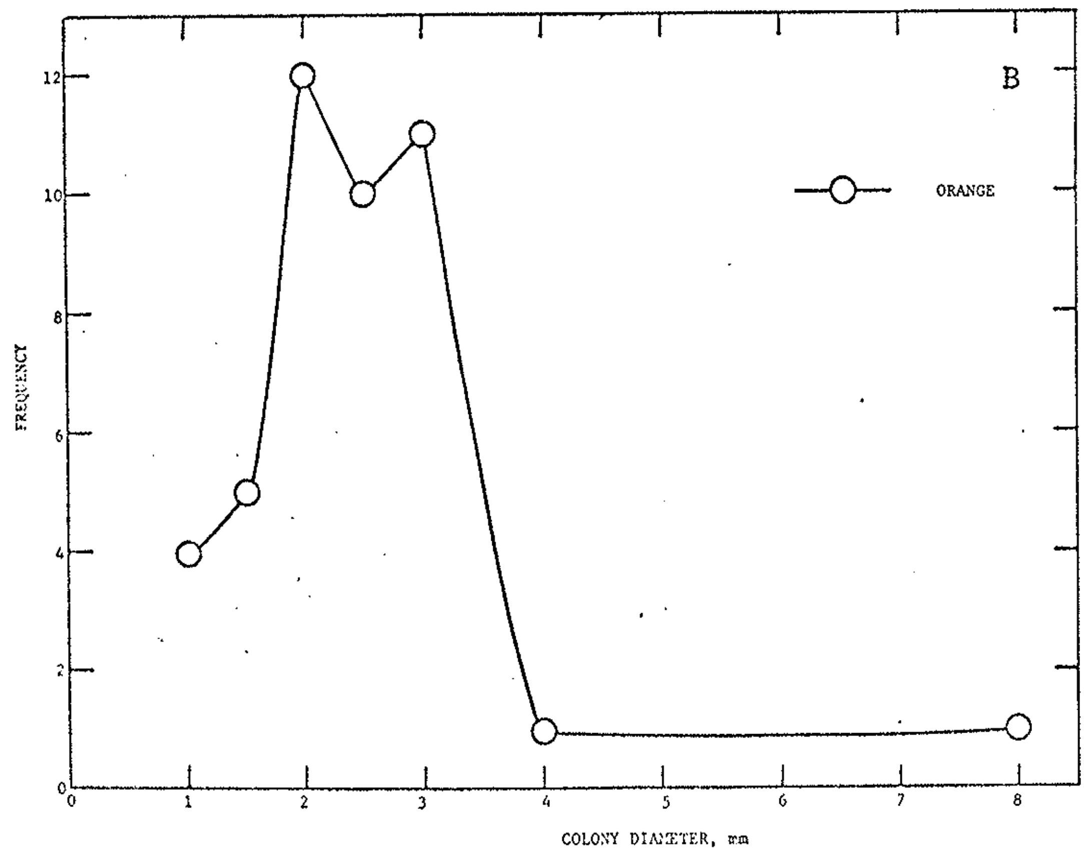
FIG. 2.3.4.3-3A,B: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca.*

A. SITE 97-27

B. SITE 97-PE



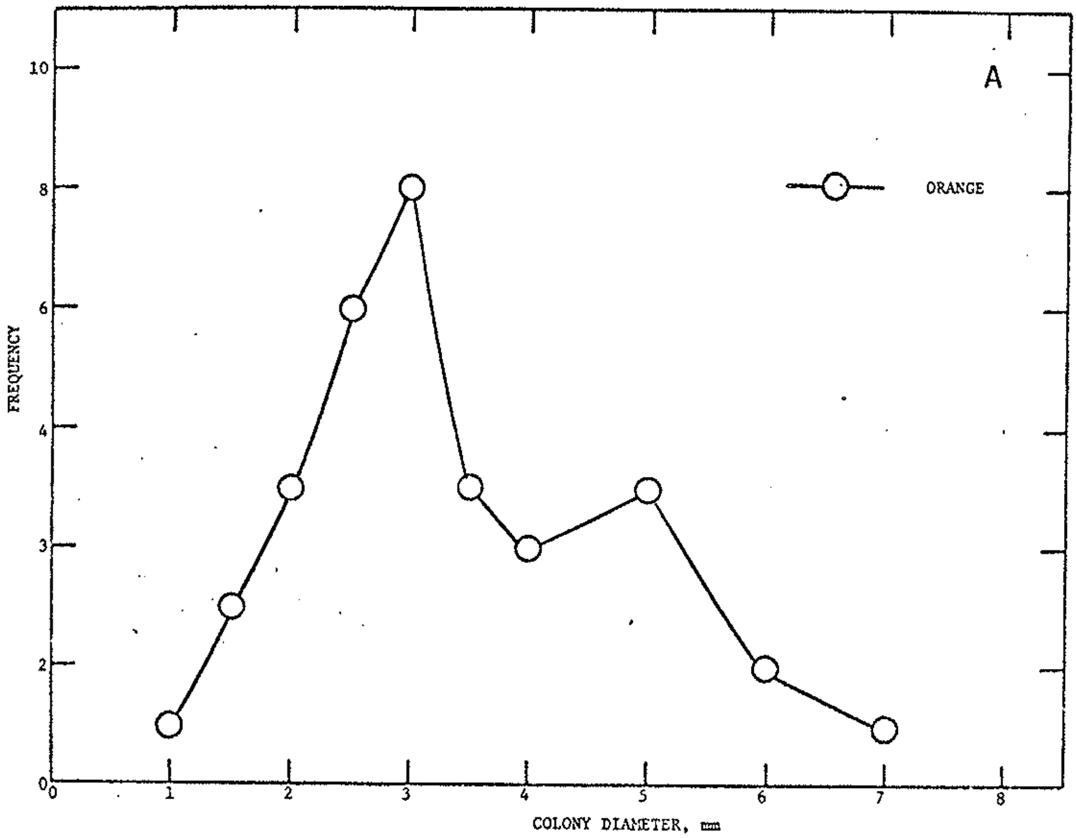

SITE 97-27



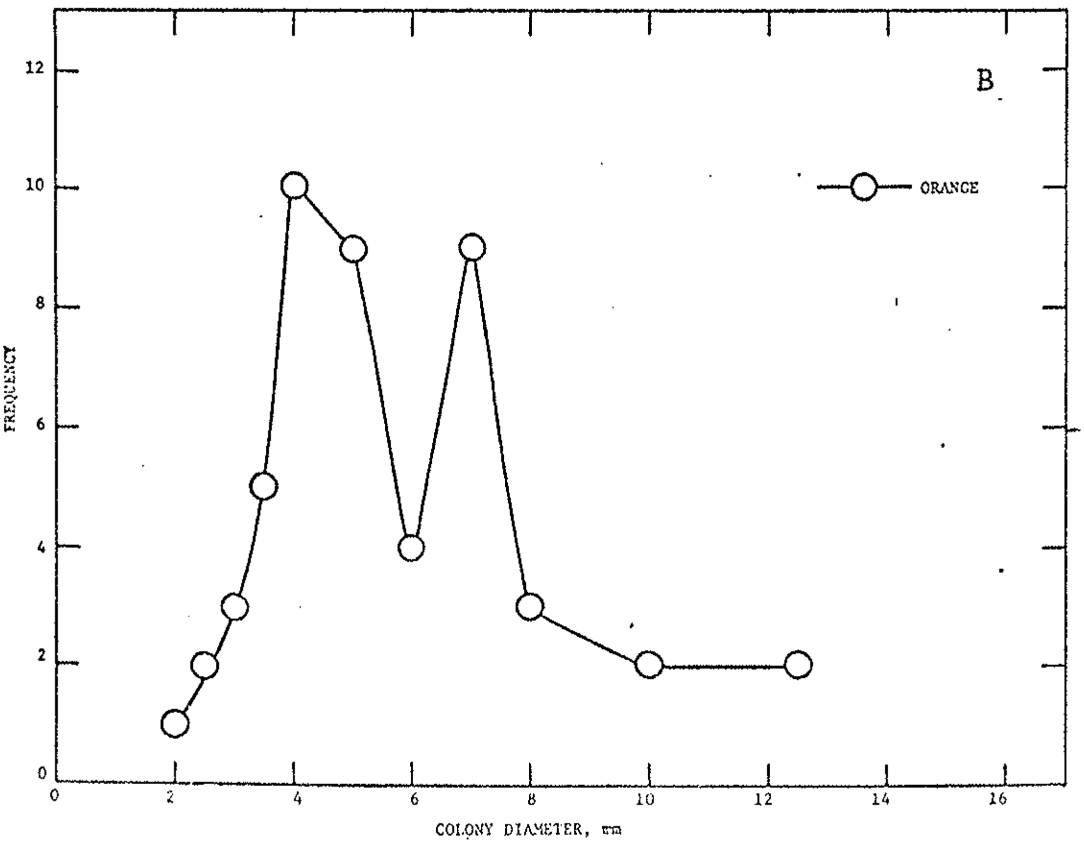

SITE 97-PE

FIG. 2.3.4.3-4A,B: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca*.

A. SITE 97-31B
B. SITE 97-82

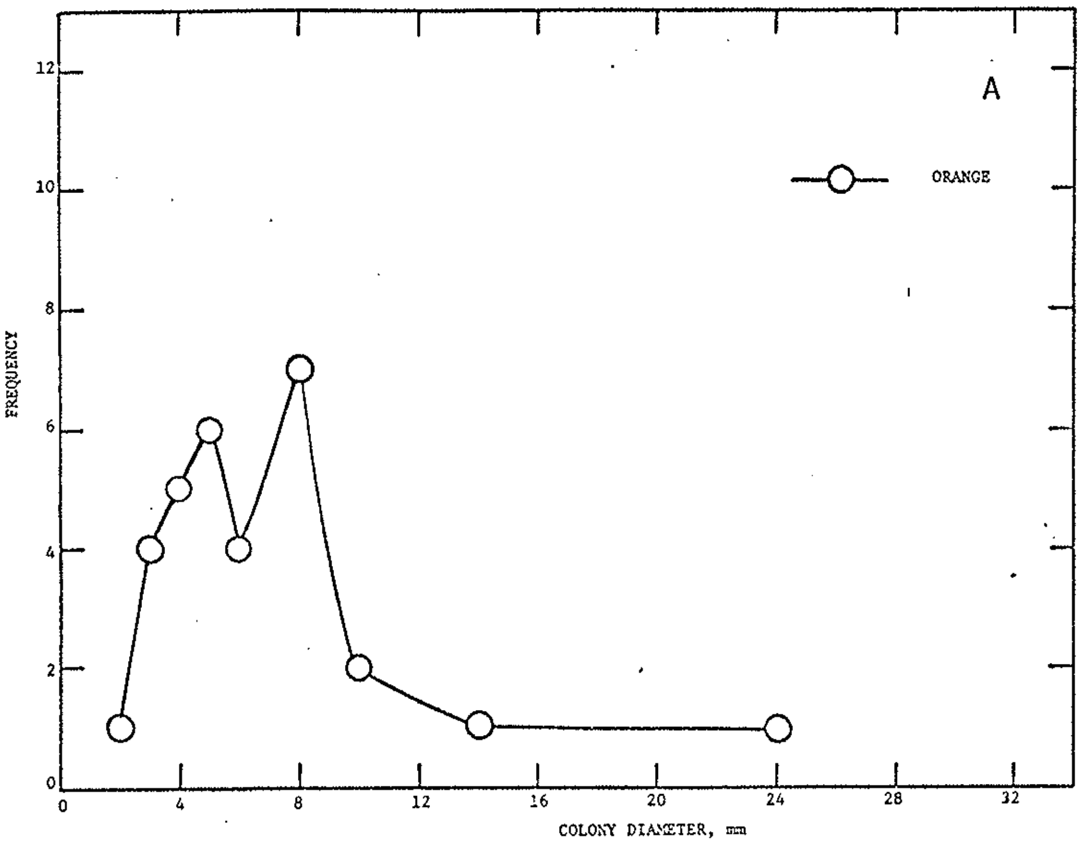



SITE 97-31B




SITE 97-82

FIG. 2.3.4.3-5A,B: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca*.
A. SITE 97-88
B. SITE 97-131



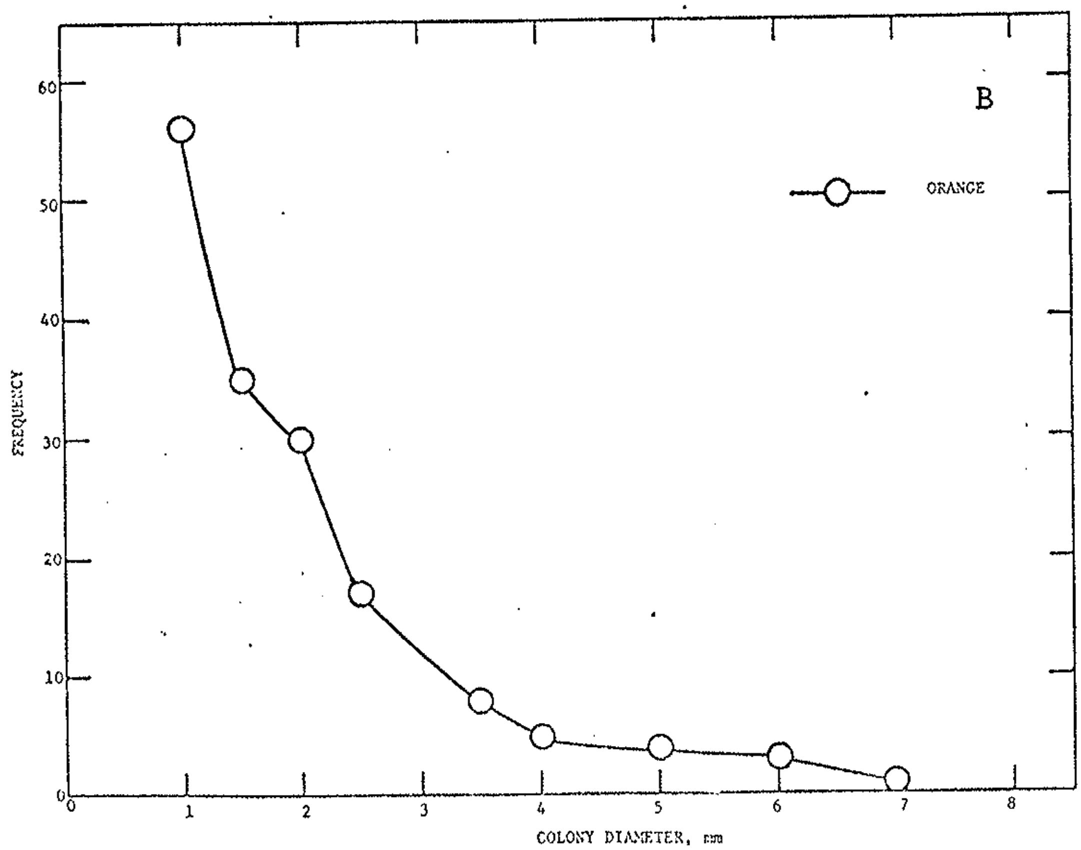



FIG. 2.3.4.3-6A,B: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca.*
A. SITE 97-138
B. SITE 97-139S

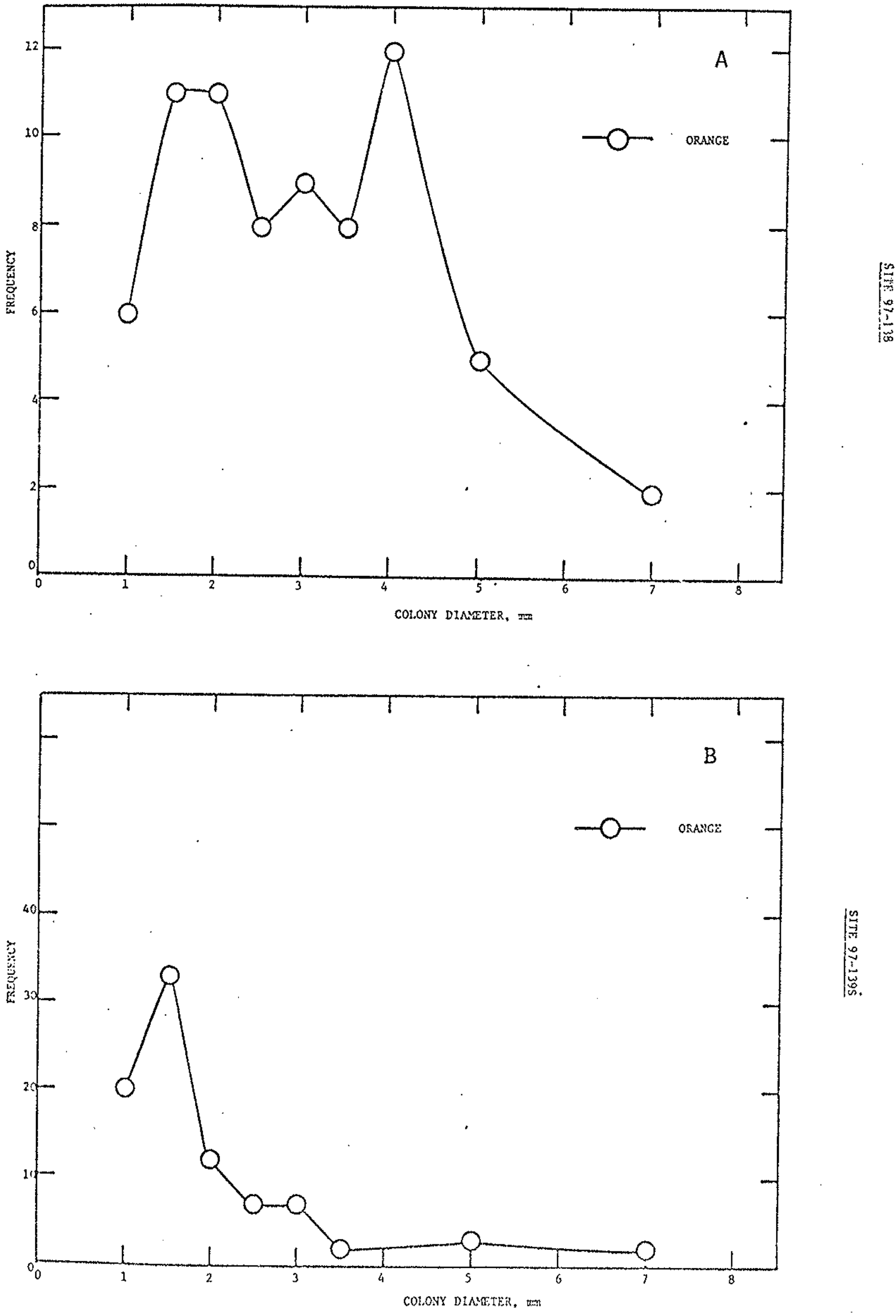
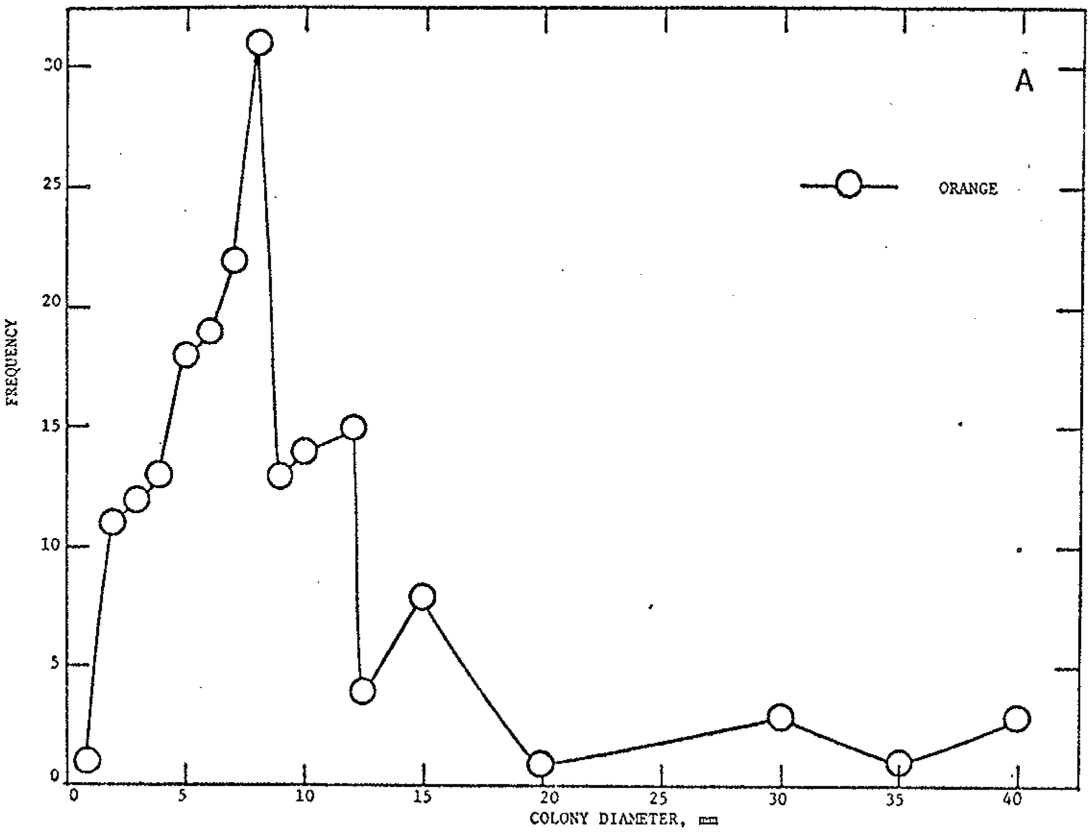


FIG. 2.3.4.3-7A,B: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca*.

A. SITE 97-204

B. SITE 97-W277



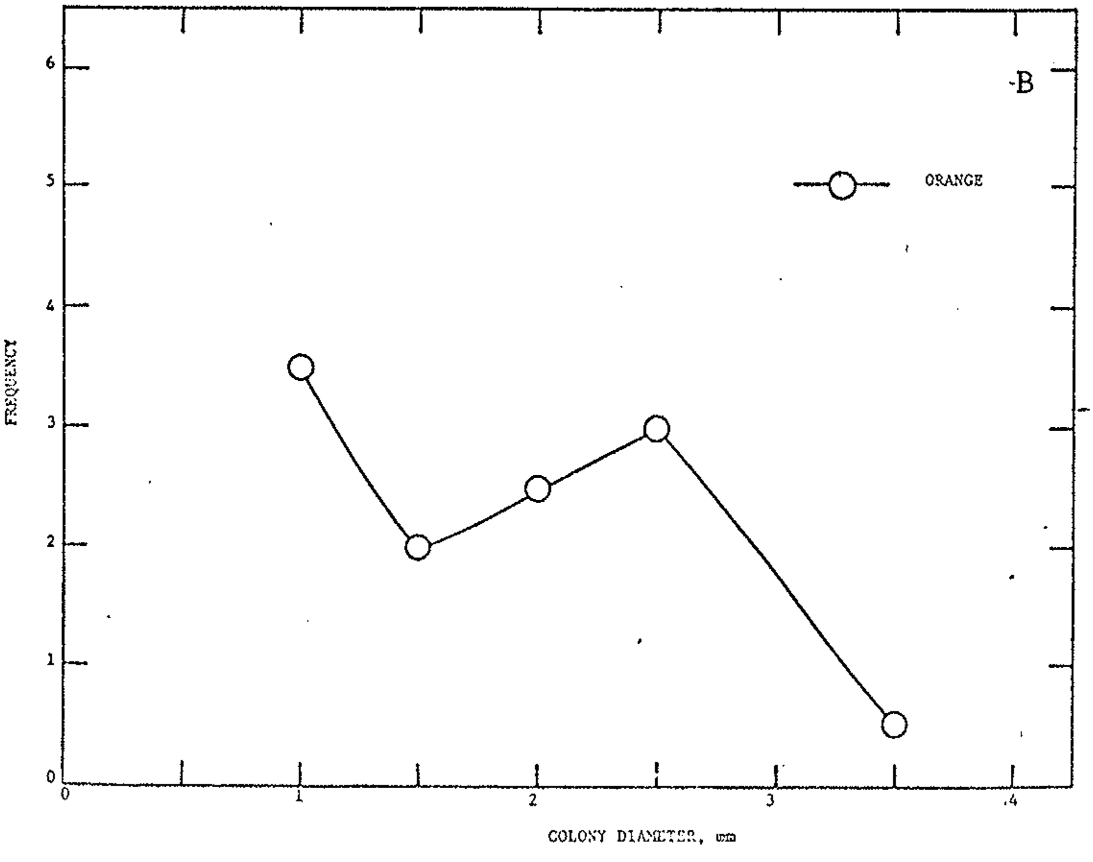



FIG. 2.3.4.3-8A: COLONY SIZE FREQUENCY DISTRIBUTION OF *Caloplaca aurantiaca*.
A. SITE 97-W279.

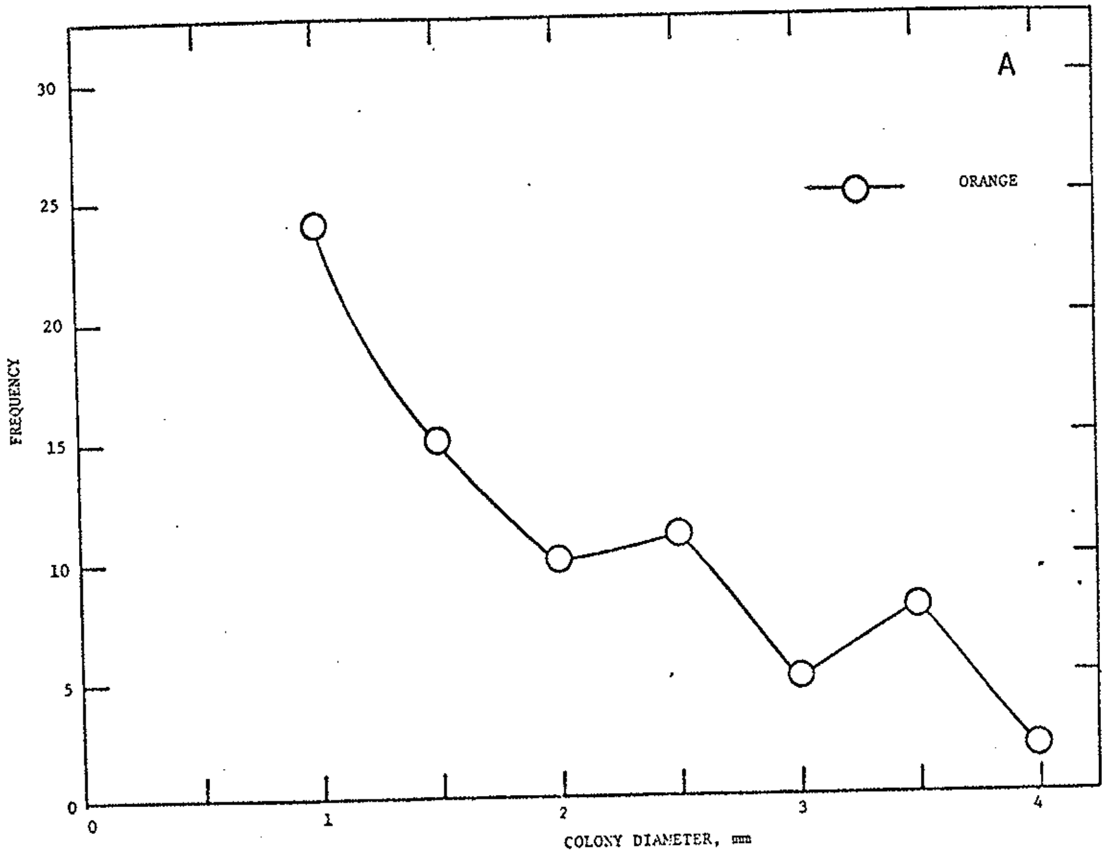


TABLE 2.3.2-1 LICHEN SPECIES LIST

Several unclassified crustose species and a few foliose species are unlisted. All fruticose species are included. These unlisted species are currently being determined. Affinity groupings are assigned where equivalence is in doubt.

| SPECIES | SITES WHERE PRESENT |
|---|---|
| *Acarospora* sp. | 15 |
| *Anaptychia obscurata* | 93 |
| *Anaptychia* sp. | 59 |
| *Buellia* sp. | 93 |
| *Caloplaca aurantiaca* | 15, 16, 91, 97, 110 |
| *Caloplaca citrina* | 0 |
| *Caloplaca fulgens* | 15, 16, 60 |
| *Candelariella vitellina* | 0, 28 |
| *Cladia aggregata* | 0, 57 |
| aff. *Cladia aggregata* | 0, 27, 59, 91, 110 |
| *Cladia fernandii* | 0 |
| aff. *Cladia fernandii* | 0 |
| *Cladionia cariosa* | 0, 18, 51, 93, 99, 101 |
| *Cladonia coniocrea* | 94 |
| *Cladonia ochrochlora* | 16, 58 |
| *Cladonia pitrea* | 41, 59, 94 |
| aff. *Cladonia pityrea* | 94 |
| *Cladonia chlorophaea* | 59 |
| aff. *Cladonia squamosa* | 0, 57 |
| *Cladonia verticillata* | 0,16,57,59,101,102,105,110 |
| aff. *Cladonia verticillata* | 28 |
| *Cladonia* sp. 425 | 91 |
| aff. *Cladonia* sp. 39 | 4, 15, 29, 56, 104 |
| aff. *Cladonia* sp. 432 | 0, 91 |

TABLE 2.3.2-1 (Contd)

LICHEN SPECIES LIST

| SPECIES | SITES WHERE PRESENT |
|---|---|
| aff. *Cladonia* sp. 290 | 15, 44 |
| aff. *Cladonia* sp. 96 | 0, 14, 15, 91, 96, 107 |
| *Dermatocarpon* sp. | 0, 59, 91 |
| *Ephebe tasmanica* | 59 |
| Graphidaceae | 0, 2, 3, 4, 5, 19, 20, 41<br>50, 53, 93, 99 |
| *Haematomma punicea* | 0, 42, 91, 96 |
| *Heterodea muelleri* | 0, 91 |
| *Hypogymnia physodes* | 41, 104 |
| *Hypogymnia subphysodes* | 43 |
| *Lecanora casiorubella* | 5, 96, 101, 104 |
| *Lecanora atra* | 41 |
| *Lecanora* sp. | 54 |
| *Lecidea contigua* | 15, 50, 51, 93, 99 |
| *Lecidea planata* | 27 |
| *Lecidea* sp. 112 | 15, 99 |
| *Lecidea* sp. 301 | 54 |
| *Lecidea* sp. 54 | 5 |
| *Lecidea* sp. 495 | 105 |
| *Parmelia caperata* | 2, 101 |
| *Parmelia conformata* | 2, 23 |
| *Parmelia cheelii* | 0 |
| *Parmelia conspersa* | 0, 2, 15, 30, 91 |
| aff. *Parmelia harrisii* | 0, 110 |
| *Parmelia perlata* | 97, 110 |
| *Parmelia rutidota* | 4, 5, 41, 42, 43, 44, 59, 97,<br>105, 108, 110 |

TABLE 2.3.2-1 (Contd)

LICHEN SPECIES LIST

| SPECIES | SITES WHERE PRESENT |
|---|---|
| *Parmelia subalbicans* | 0, 5, 42, 96, 108 |
| *Parmelia* sp. 460 | 99, |
| *Parmelia* sp. 491 | 15, 92, 93, 104 |
| *Parmelia* sp. 257 | 44 |
| *Parmelia* sp. 440A | 2, 93 |
| *Parmelia* sp. 107 | 15 |
| *Pertusaria* sp. | 0, 4, 5 |
| *Porocyphus lichenelloides* | 29, 110 |
| *Ramalea cochleata* | 51, 93 |
| aff. *Ramalea cochleata* | 92, 99, 102 |
| *Ramalina fastigiata* | 0, 5, 108 |
| *Rhizocarpon geographicum* | 0, 15, 60 |
| *Siphula caesia* | 0 |
| *Siphula coriaceae* | 0, 15, 99 |
| *Teloschistes chrysophthalmus* | 5, 97 |
| *Thysanothecium hookeri* | 16, 27, 93 |
| *Thysanothecium hyalinum* | 15, 23, 24, 44, 50, 93, 94, 98, 99, 101, 103, 106 |
| aff. *Thysanothecium hyalinum* | 18, 33, 91, 101 |
| *Umbilicaria* sp. 199 | 29 |
| *Umbilicaria* sp. 203 | 30 |
| *Usnea barbata* var. *xanthopoga* | 2, 5, 0, 41, 44, 59, 91, 101, 103, 104, 106 |
| *Usnea barbata* | 41 |
| *Usnea barbata* var. *scabrida* | 0, 108 |

TABLE 2.3.4.1-1 FREQUENCY OF OCCURRENCE OF SPECIES IN QUADRATS

| SPECIES | QUADRAT NO. / SPECIMEN PHOTO NO. | QUAD. PHOTO NO. / SPEC. NO. | 110-2 | 110-4 | 110-5 | 110-6 | 110-7 | 110-11 |
|---|---|---|---|---|---|---|---|---|
| | | | 22-2 | 22-4 | 22-7 | 23-41 | 22-13 | 23-37 |
| *Parmelia rutidota* | 21-4A | 517 | 4 | 5 | 0 | 3 | 0 | 2 |
| aff. *P. perlata* | 21-7A | 522 | 35 | 11 | 0 | 0 | 0 | 0 |
| *Parmelia harrisii* | 21-8A | 523 | 0 | 0 | 5 | 0 | 0 | 0 |
| aff. *P. harrisii* | 22-18A | 525 | 3 | 1 | 0 | 19 | 111 | 27 |
| *Cladia aggregata* | 21-12A | 527 | 15 | 2 | 0 | 0 | 0 | 0 |
| *Parmelia sp.* 528 | 22-8A | 528 | 2 | 1 | 1 | 1 | 104 | 0 |
| Reference sample 529 | 21-14A | 529 | 7 | 6 | 2 | 0 | 0 | 0 |
| Reference sample 535 | 21-19A | 535 | 0 | 0 | 0 | 0 | 0 | 3 |
| *Parmelia sp.* 538 | 21-22A | 538 | 1 | 3 | 0 | 0 | 0 | 0 |
| Reference sample 553 | 21-19A | 553 | 7 | 6 | >50 | 0 | 2 | 1* |
| " " 554 | 21-19A | 554 | 4 | >100 | >50 | 5 | 0 | >100 |
| " " 555 | 21-23A | 555 | + | + | + | + | + | + |

* Moribund

\+ Confluent areas of growth present

TABLE 2.3.4.1-2

FREQUENCY OF ISIDIA AND APOTHECIA IN TWO ROOF TOP PARMELIAS

| SPECIES | | APOTHECIA ONLY | ISIDIA ONLY | APOTHECIA AND ISIDIA | APOTHECIA AND ISIDIA ABSENT |
|---|---|---|---|---|---|
| *Parmelia* sp. 525* | QUADRAT 110-7 PHOTO NO | 5 | 5<br>22-17 | 3<br>22-16 | 98<br>22-16 |
| | QUADRAT 110-11 | 1 | 17 | 0 | 9 |
| | QUADRAT 110-6 | 3 | 2 | 5 | 9 |
| *Parmelia* sp. 528 | QUADRAT 110-7 PHOTO NO | 2<br>22-11 | 2<br>22-9 | 0 | 100** |
| | QUADRAT 110-11 | 0 | 0 | 0 | 0 |
| | QUADRAT 110-6 | 0 | 0 | 0 | 1 |

*See also PHOTO NO 22-18 showing variation in marginal lobes in this species

**Estimated

TABLE 2.3.4.3-1

GRAVESTONE DISTRIBUTION OF *Caloplaca aurantiaca*[1]

| GRAVE SITE DATE | GRAVE SITE NO. | TRANSECT NO. | MEAN COLONY DIAMETER (mm) | STANDARD ERROR | NUMBER OF OBSERVATIONS | PERCENTAGE COVER | SUBSTRATE[2] |
|---|---|---|---|---|---|---|---|
| 1936 | 97-92 | 1-2 | 3.3 | 1.6 | 91 | 9.7 | concrete |
| 1937 | -37 | - | 4.0 | 1.2 | 11 | - | G |
| 1938 | -88 | 1-3 | 6.5 | 4.1 | 33 | - | concreted conglomerate |
| 1946 | -229 | 1 | 5.9 | 2.9 | 32 | 7.7 | ref. Day & Co. |
| 1947 | -51 | 1-4 | 2.6 | 1.1 | 100 | 3.6 | concrete |
| 1948 | -257 | 1 | 5.9 | 3.2 | 23 | 5.7 | concreted conglomerate |
| 1951 | -E139 | - | 3.4 | 1.3 | 22 | - | concrete |
| 1955 | -82 | 1-4 | 5.6 | 2.4 | 51 | 3.9 | concrete |
| 1957 | -118SM | 1,3,4 | 3.5 | 1.5 | 112 | 6.6 | concrete |
| 1961 | -27 | - | 3.2 | 1.3 | 53 | - | G |
| 1961 | -135 | - | 3.3 | 1.3 | 103 | - | G |
| 1961 | -W28 | - | 3.6 | 1.3 | 21 | - | G |
| 1962 | -W277 | - | 1.8 | 0.7 | 24 | - | G |
| 1963 | -138 | - | 3.0 | 1.5 | 74 | - | G |
| 1963 | -25 | - | 2.3 | 1.1 | 51 | - | G |
| 1963 | -118GI | 1 | 2.3 | 1.2 | 40 | 4.0 | G |
| 1964 | -W279 | - | 2.0 | 1.0 | 80 | - | G |
| 1964 | -8 | - | 2.3 | 0.9 | 74 | - | concrete |
| 1964 | -BE | 1-3 | 2.0 | 1.8 | 17 | <0.007 | G |
| 1964 | -207NE | 1-4 | 2.4 | 1.1 | 66 | 2.3 | concrete |
| 1964 | -179E | 1-4 | 2.1 | 0.5 | 53 | 1.2 | concrete |
| 1965 | -131 | - | 2.0 | 1.2 | 178 | - | G |
| 1965 | -67 | - | 3.5 | 1.3 | 19 | - | G |
| 1965 | -103 | 1-4 | 2.2 | 0.7 | 36 | 2.1 | ? |
| 1966 | -PE | - | 2.4 | 1.1 | 45 | - | G |
| 1967 | -331 | - | 1.9 | 0.9 | 85 | - | G |
| 1967 | -139S | - | 2.0 | 1.2 | 87 | - | concrete |
| 1970 | -28 | - | 1.7 | 0.5 | 14 | - | G |
| 1974 | -31B | - | 3.4 | 1.5 | 48 | - | G |

[1]See also Figs. 2.3.4.3 - Grave site series

[2]G = White Terrazo

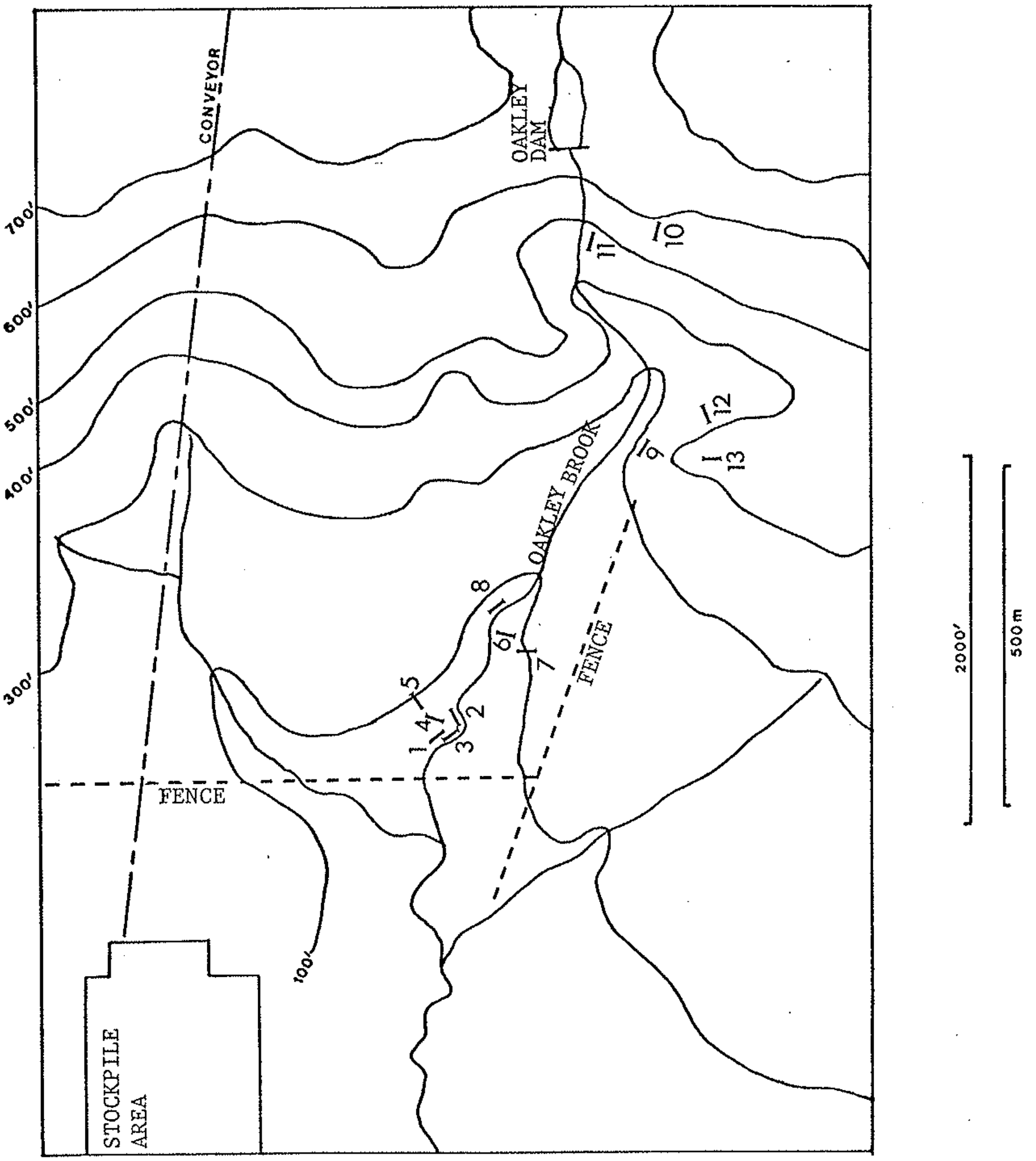



Fig. 2.4.2-1 : Oakley Brook Study Area showing locations of the 13 transects used in the vegetation survey, and the position of major man-made features.

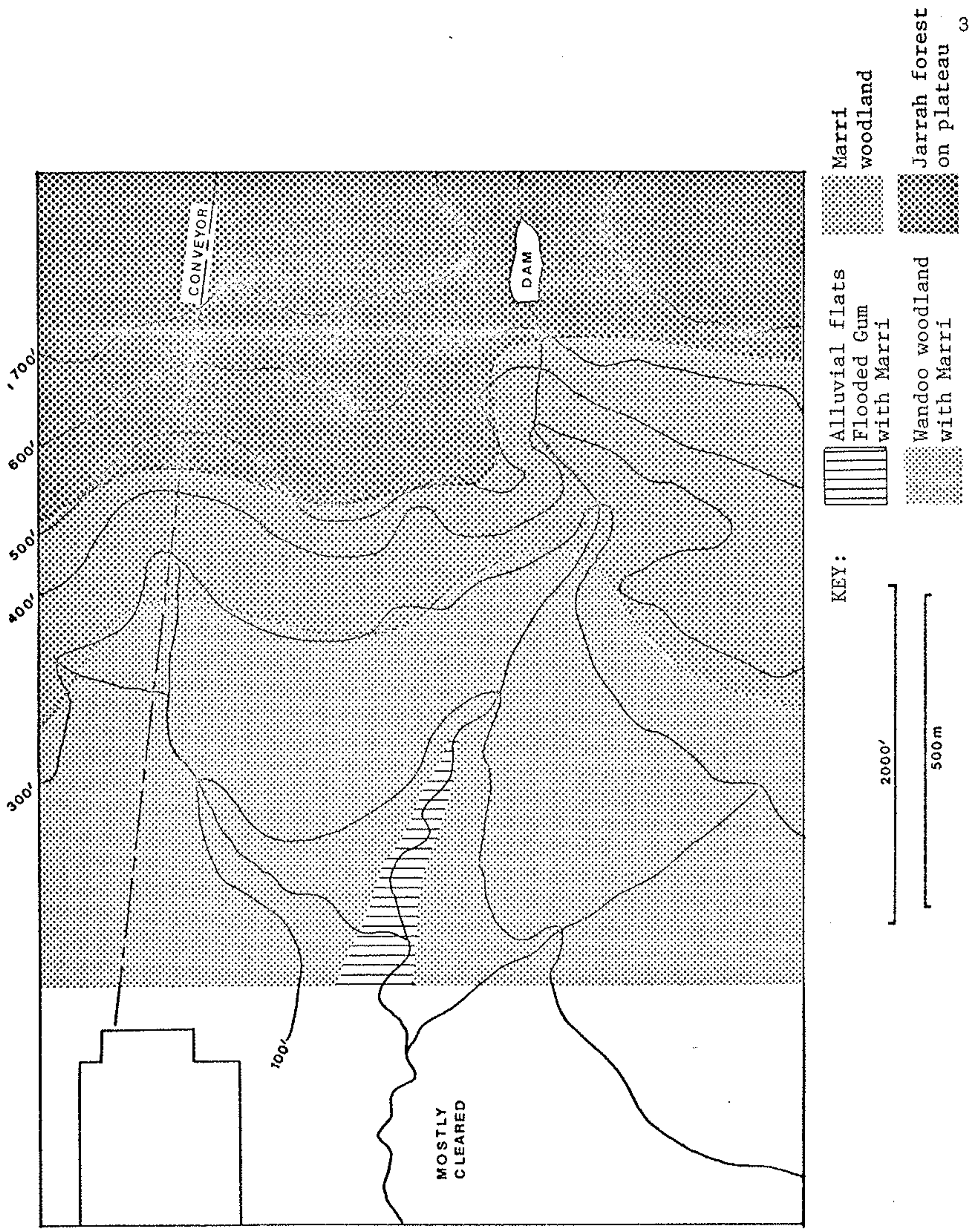



Fig. 2.4.2-2 : Distribution of plant communities in the Oakley Brook Study Area. The tall shrub community of the creek bank occurs only intermittently above the 100' contour.

# APPENDIX 4

## SPECIES RECORDED IN OAKLEY BROOK STUDY AREA AND THEIR DISTRIBUTION IN THE PLANT COMMUNITIES OF THE VALLEY

KEY: + = species recorded along 25 m transect;
† = species abundant along transect;
(+) = species observed in community but not along transect;
* = tree.

| S P E C I E S | SITE (refer to Fig. 1) | | | | | |
|---|---|---|---|---|---|---|
| | Bank of brook (Transects 3 & 8) | Alluvial flats (Transects 1 & 2) | Wandoo woodland (lower scarp face) (Transects 4,5 & 7) | Thicket on Rubble (Transect 6) | Marri woodland (upper scarp face) (Transects 10 & 11) | Granite outcrop (Transects 9,12&13) |
| *Acacia lateritia* B.R. Maslin | | | | | | + |
| *A. pulchella* R.Br. | + | + | † | + | + | + |
| *A. saligna* Wendl. | + | | | | | |
| *A. urophylla* Benth. | + | + | | | + | + |
| *A. sp.* | | | † | + | | |
| *Adiantum aethiopicum* L. | + | | | | | |
| *Agonis linearifolia* (DC.)Schau. | † | | | | | |
| *Agrostocrinum scabrum* (R.Br.)Bail. | | | | | | + |
| *Astroloma pallidum* R.Br. | + | + | + | + | | + |
| *A. ciliatum* (Lindl.)Druce | | | (+) | | (+) | |

APPENDIX 4 (Contd.)

| S P E C I E S | SITE (refer to Fig. 1) | | | | | |
|---|---|---|---|---|---|---|
| | Bank of Brook (Transects 3 & 8) | Alluvial flats (Transects 1 & 2) | Wandoo woodland (lower scarp face) (Transects 4,5 & 7) | Thicket on Rubble (Transect 6) | Marri woodland (upper scarp face) (Transects 10 & 11) | Granite outcrop (Transects 9,12&13) |
| *Baeckea camphorosmae* Endl. | | + | † | + | | + |
| *Billardiera sp.* | | | | | | + |
| *Borya nitida* Labill. | | | + | + | | |
| *Bossiaea ornata* (Lindl.)Benth. | | | + | | + | + |
| *Calothamnus quadrifidus* R.Br. | | † | † | † | | |
| *C. sp.* | | | | | † | + |
| *Calytrix sp.* | | | | | | + |
| **Casuarina huegeliana* Miq. | | | | | + | † |
| *C. humilis* Otto & Dietr. | | | + | | | |
| *Cheilanthes tenuifolia* (Burm.f.)Swartz | + | | | | | + |
| *Clematis pubescens* Hueg. | + | + | | + | + | |
| *Conostylis aculeata* R.Br. | + | + | | | + | + |
| *Cyanthochaete avenacea*(R.Br.)Benth. | | | | | + | |
| *Darwinia citriodora* (Endl.)Benth. | † | | | + | + | |
| *Daviesia horrida* Meissn. | | | | | (+) | |
| *Dioscorea hastifolia* Endl. | | + | | + | + | + |

APPENDIX 4 (Contd.)

| S P E C I E S | SITE (refer to Fig. 1) | | | | | |
|---|---|---|---|---|---|---|
| | Bank of brook (Transects 3 & 8) | Alluvial flats (Transects 1 & 2) | Wandoo woodland (lower scarp face) (Transects 4,5 & 7) | Thicket on Rubble (Transect 6) | Marri woodland (upper scarp face) (Transects 10 & 11) | Granite outcrop (Transects 9,12&13) |
| *Dodonaea aptera* Miq. | | | | | (+) | |
| *D. ceratocarpa* Endl. | | | | + | | + |
| *Dryandra armata* R.Br. | | | † | + | | |
| *D. nivea* R.Br. | | (+) | | | | + |
| *D. praemorsa* Meissn. | (+) | | | | | + |
| **Eucalyptus calophylla* R.Br. | | + | + | | † | |
| **E. laeliae* Podger & Chippendale | | | | | (+) | |
| **E. marginata* Sm. | | | | | + | |
| **E. rudis* Endl. | | † | | | | |
| **E. wandoo* Blakely | | + | † | | | |
| *Gompholobium marginatum* R.Br. | + | + | + | + | + | |
| *Grevillea bipinnatifida* R.Br. | | | + | | + | + |
| *Hakea lissocarpha* R.Br. | | | + | | + | + |
| *Haloragis sp.* | | | | + | | + |
| *Hemiandra pungens* R.Br. | | | + | | | |

APPENDIX 4 (Contd.)

| S P E C I E S | SITE (refer to Fig. 1) | | | | | |
|---|---|---|---|---|---|---|
| | Bank of brook (Transects 3 & 8) | Alluvial flats (Transects 1 & 2) | Wandoo woodland (lower scarp face) (Transects 4,5 & 7) | Thicket on Rubble (Transect 6) | Marri woodland (upper scarp face) (Transects 10 & 11) | Granite outcrop (Transects 9,12&13) |
| *Hemigenia sericea* Benth. | | | | + | | + |
| *Hibbertia hypericoides* (DC.)Benth. | | † | † | † | + | † |
| *H. montana* Steud. | | + | + | | | + |
| *H. perfoliata* Endl. | + | + | | | + | |
| *H. sp.* | | + | + | + | | + |
| *H. sp.* | | | | | + | + |
| *Hovea chorizemifolia* (Sweet)DC. | | | | | | + |
| *Hypocalymma angustifolium* Endl. | | † | + | + | | + |
| *Isopogon asper* R.Br. | | | + | | | |
| *Juncus pallidus* R.Br. | + | | | | | |
| *Kennedia coccinea* Vent. | | | | | + | |
| *Kunzea recurva* Schau. | | + | + | | + | |
| *Lepidosperma gracile* R.Br. | | † | † | + | + | + |
| *L. longitudinale* Labill. | | | | | + | + |
| *L. tetraquetrum* Nees. | + | | | | | |

APPENDIX 4 (Contd.)

| S P E C I E S | SITE (refer to Fig. 1) | | | | | |
|---|---|---|---|---|---|---|
| | Bank of brook (Transects 3 & 8) | Alluvial flats (Transects 1 & 2) | Wandoo woodland (lower scarp face) (Transects 4,5 & 7) | Thicket on Rubble (Transect 6) | Marri woodland (upper scarp face) (Transects 9,12& 13) | Granite outcrop (Transects 9,12& 13) |
| *Leucopogon capitellatus* DC. | | | | | + | + |
| *L. oxycedrus* Sond. | | | | | + | |
| *Macrozamia riedlei* (Gaud.)Gardn. | + | + | + | + | + | + |
| *Melaleuca scabra* R.Br. | | | + | | | |
| *Mesomelaena tetragona* (R.Br.)F.Muell. | | + | + | | | |
| *Olearia paucidentata* (Steetz)F.Muell. | | | (+) | | | |
| *Opercularia vaginata* Labill. | | | | + | + | |
| *Oxylobium linearifolium* (Don)Domin. | + | | | | | |
| *Patersonia occidentalis* R.Br. | + | + | | | + | |
| *P. juncea* Labill. | | | + | | | |
| *Phyllanthus calycinus* Labill. | | + | + | | | |
| *Scaevola pilosa* Benth. | | | | | | + |
| *Stylidium amoenum* R.Br. | | | | | | + |
| *S. brunonianum* Benth. | | | + | | | |
| *S. bulbiferum* Benth. | | + | + | + | + | + |

<u>APPENDIX 4 (Contd.)</u>

| S P E C I E S | SITE (refer to Fig. 1) | | | | | |
|---|---|---|---|---|---|---|
| | Bank of brook (Transects 3 & 8) | Alluvial flats (Transects 1 & 2) | Wandoo woodland (lower scarp face) (Transects 4, 5 & 7) | Thicket on Rubble (Transect 6) | Marri woodland (upper scarp face) (Transects 10 & 11) | Granite outcrop (Transects 9,12&13) |
| *Stylidium hispidum* Lindl. | | | | | | + |
| *Synaphea pinnata* Lindl. | | | + | | | |
| *Thomasia sp.* | | | | | + | |
| *Thysanotus dichotomus* (Labill.)R.Br. | | | | | + | + |
| *Trymalium ledifolium* Fenzl. | | | | + | | + |
| *T. spathulatum* (Labill.)Ostf. | + | + | | | + | + |
| *Verticordia sp.* | | | + | + | | |
| *Xanthorrhoea gracilis* Endl. | | (+) | + | | + | + |
| *X. preissii* Endl. | + | + | + | + | + | + |
| Transect totals | 19 | 26 | 34 | 23 | 34 | 40 |
| Total (excluding trees) | 19 | 23 | 32 | 23 | 31 | 39 |

## APPENDIX 5

SPECIES ENCOUNTERED IN SURVEYS IN *NE* (SITES 98,99) AND *SE* (SITES 101,102,103,106) AREAS OF REFINERY, ON YELLOW-GREY (SITES 98,101,103,106) AND LATERITIC (SITES 99,102) SANDS.

KEY: A = aestivating species or grass identifiable only in spring
* = tree
** = species important at a particular site
x = species present at site

| | | YELLOW-GREY SAND | | | | LATERITIC SAND | |
|---|---|---|---|---|---|---|---|
| | Site no. | 98 | 101 | 103 | 106 | 99 | 102 |
| | *Acacia acuaria* W.V.Fitzg. | ** | | x | | | |
| | *A. diptera* Lindl. | x | x | x | | x | |
| | *A. lateritia* B.R.Maslin | | | | | x | |
| | *A. pulchella* R.Br. | x | x | | | x | |
| | *A. saligna* Wendl. | | | | | | x |
| | *A. stenoptera* Benth. | | x | | | | |
| | *A. sp.* | x | | | | | |
| | *Adenanthos meisneri* Lehm. | x | | | | | |
| A | *Anigozanthos manglesii* D.Don. | x | | x | | | |
| | *Astroloma ciliatum* (Lindl.)Druce | | | | | | x |
| | *A. pallidum* R.Br. | x | | | | | |
| | *Baeckea camphorosmae* Endl. | x | x | x | x | ** | |
| | *Boronia tenuis* Benth. | | | | | x | |
| | *Borya nitida* Labill. | | | | | x | |

APPENDIX 5 (Contd.)

| | | YELLOW-GREY SAND | | | | LATERITIC SAND | |
|---|---|---|---|---|---|---|---|
| | Site no. | 98 | 101 | 103 | 106 | 99 | 102 |
| | *Bossiaea eriocarpa* Benth. | ** | | x | | x | |
| | *B. ornata* (Lindl.)Benth. | | x | | x | ** | x |
| A | *Burchardia umbellata* R.Br. | x | x | x | | x | x |
| A | *Caesia parviflora* R.Br. | | | | | x | |
| A | *Caladenia flava* R.Br. | x | x | x | x | | |
| A | *C. sericea* Lindl. | x | | | | | |
| | *Calectasia cyanea* R.Br. | | | x | | | |
| | *Casuarina humilis* Otto & Dietr. | ** | | | | | |
| A | *Chamaescilla corymbosa* (R.Br.)F.Muell. | x | x | x | | | x |
| | *Conospermum stoechadis* Endl. | x | x | x | | | |
| | *Conostylis juncea* Endl. | ** | x | x | | | |
| | *C. setigera* R.Br. | ** | | x | x | x | |
| | *C. sp.* | | | | x | x | |
| | *Cyathochaete avenacea* (R.Br.)Benth. | ** | x | | | x | |
| | *Dampiera linearis* R.Br. | x | | | x | x | |
| | *Dasypogon bromeliifolius* R.Br. | ** | | x | | x | |
| | *Daviesia aphylla* (F.Muell.)Benth. | x | | | | | |
| | *D. incrassata* Sm. | x | | | | | |
| | *D. pectinata* Lindl. | x | | | | | |
| | *D. preissii* Meissn. | | | | | x | |
| | *D. sp.* | | | | | x | |

APPENDIX 5 (Contd.)

| | | YELLOW-GREY SAND | | | | LATERITIC SAND | |
|---|---|---|---|---|---|---|---|
| | Site no. | 98 | 101 | 103 | 106 | 99 | 102 |
| A | *Drosera erythrorhiza* Lindl. | x | | | x | x | x |
| A | *D. gigantea* Lindl. | | | | | x | |
| A | *D. glanduligera* Lehm. | | | | | x | |
| A | *D. macrantha* Endl. | x | | x | x | x | |
| A | *D. stolonifera* Endl. | x | x | x | | | |
| A | *D. sp.* | | | | | x | |
| A | *D. sp.* | | | | | x | |
| | *Dryandra armata* R.Br. | | x | | x | | |
| | *D. bipinnatifida* R.Br. | | x | | x | | |
| | *D. praemorsa* Meissn. | | | x | | | |
| | *D. nivea* R.Br. | x | x | x | | x | x |
| | *Eriostemon spicatus* A.Rich. | x | | x | | x | |
| * | *Eucalyptus calophylla* R.Br. | ** | ** | ** | ** | ** | ** |
| * | *E. marginata* Sm. | ** | ** | ** | ** | ** | ** |
| | *Gompholobium knightianum* Lindl. | x | | x | | | |
| | *G. marginatum* R.Br. | | | | | x | x |
| | *Grevillea pilulifera* (Lindl.)C.A.Gardn. | x | x | | x | x | |
| | *G. wilsoni* A.Cunn. | x | | | | ** | |
| A | *Haemodorum paniculatum* Lindl. | x | | x | | x | |
| A | *H. spicatum* R.Br. | x | | | | | x |
| | *Hakea amplexicaulis* R.Br. | | x | | x | | x |

APPENDIX 5 (Contd.)

| | | YELLOW-GREY SAND | | | | LATERITIC SAND | |
|---|---|---|---|---|---|---|---|
| | Site no. | 98 | 101 | 103 | 106 | 99 | 102 |
| | *Hakea linearis* R.Br. | | | | | x | |
| | *H. lissocarpha* R.Br. | | x | | | x | x |
| | *H. ruscifolia* Labill. | x | x | x | | | |
| | *H. stenocarpa* R.Br. | x | | | x | | |
| | *H. sp.* | | | | x | | |
| | *Haloragis sp.* | | | | | x | x |
| | *Hibbertia hypericoides* (DC.)Benth. | x | x | x | x | ** | ** |
| | *H. montana* Steud. | | x | | x | | |
| | *H. vaginata* (Benth.)F.Muell. | x | | x | | | |
| | *Hovea trisperma* Benth. | x | | | x | | |
| | *Hypocalymma angustifolium* Endl. | x | | | | x | x |
| | *H. robustum* Endl. | | x | x | | | |
| A | *Hypolaena exsulca* R.Br. | x | | x | | x | |
| | *Isopogon asper* R.Br. | | | | | x | |
| | *I. sphaerocephalus* Lindl. | | x | | x | | |
| | *Jacksonia furcellata* (Bonpl.)DC. | | x | | | | |
| | *Kennedia coccinea* Vent. | x | | | | | |
| | *Kingia australis* R.Br. | ** | | | x | ** | |
| | *Kunzea recurva* Schau. | | | | x | x | |
| A | *Lagenifera stipitata* (Labill.)Druce | | | x | | | |
| | *Lambertia multiflora* Lindl. | | | | x | | |

APPENDIX 5 (Contd.)

| | | YELLOW-GREY SAND | | | | LATERITIC SAND | |
|---|---|---|---|---|---|---|---|
| | Site no. | 98 | 101 | 103 | 106 | 99 | 102 |
| | *Patersonia occidentalis* R.Br. | | x | | x | | |
| | *Petrophile linearis* R.Br. | x | | | x | | |
| | *P. striata* R.Br. | | | | x | x | |
| | *Phlebocarya ciliata* R.Br. | ** | | | | | |
| | *Phyllanthus calycinus* Labill. | | x | x | | x | |
| | *Pimelea imbricata* R.Br. | | | | | | x |
| | *P. suaveolens* (Endl.)Meissn. | x | | x | | ** | |
| A | *Prasophyllum sp.* | | | | | x | |
| | *Stirlingia latifolia* (R.Br.)Steud. | x | x | | | | |
| A | *Schoenus curvifolius* (R.Br.)Benth. | x | | | | | |
| A | *Sowerbaea laxiflora* Lindl. | | x | x | | | |
| | *Stylidium amoenum* R.Br. | | | x | | x | |
| | *S. brunonianum* Benth. | x | | x | | | |
| | *S. bulbiferum* Benth. | | | x | | x | x |
| | *S. schoenoides* DC. | x | | | | | |
| | *Synaphea pinnata* Lindl. | | | x | | x | |
| A | *Thysanotus patersonii* R.Br. | | | | | x | |
| | *Xanthorrhoea gracilis* Endl. | x | x | | x | | |
| | *X. preissii* Endl. | ** | x | | x | x | x |
| | *Xylomelum occidentale* R.Br. | | | x | x | | |

APPENDIX 5 (Contd.)

| | | YELLOW-GREY SAND | | | | LATERITIC SAND | |
|---|---|---|---|---|---|---|---|
| | Site no. | 98 | 101 | 103 | 106 | 99 | 102 |
| A | *Laxmannia sessiliflora* Dcne. | | | x | | | |
| | *Lechenaultia biloba* Lindl. | ** | x | x | | ** | x |
| | *Lepidosperma angustatum* R.Br. | x | | x | | | |
| | *L. gracile* R.Br. | | x | | | | x |
| A | *Leporella fimbriata* (Lindl.)A.S.George | x | | | | | |
| | *Lomandra endlicheri* (F.Muell.)Ewart | x | x | x | | x | |
| | *L. preissii* (Endl.)Ewart | x | | | | x | |
| | *L. sp.* | | x | | | x | |
| | *Loxocarya fasciculata* (R.Br.)Benth. | x | | x | | x | |
| | *Lyginia barbata* R.Br. | x | | | | | |
| A | *Lyperanthus nigricans* R.Br. | | | x | | | |
| | *Lysinema ciliatum* R.Br. | x | | | | | |
| | *Macrozamia riedlei* (Gaud.)C.A.Gardn. | | x | x | | | x |
| | *Melaleuca scabra* R.Br. | x | x | | | | |
| | *Mesomelaena tetragona* (R.Br.)F.Muell. | ** | | x | x | x | |
| A | *Neurachne alopecuroides* R.Br. | x | x | | | x | x |
| * | *Nuytsia floribunda* (Labill.)R.Br. | x | | x | | | |
| | *Olearia paucidentata* (Steetz.)F.Muell. | x | | | | x | |
| | *Oxylobium capitatum* Benth. | x | | | | x | |
| | *O. cuneatum* Benth. | | | | | ** | |
| | *Patersonia juncea* Lindl. | x | | | | | |

APPENDIX 5 (Contd.)

| | | YELLOW-GREY SAND | | | | LATERITIC SAND | |
|---|---|---|---|---|---|---|---|
| | Site no. | 98 | 101 | 103 | 106 | 99 | 102 |
| WEEDS | | | | | | | |
| *Arctotheca calendula* (L.) Levyns | | x | | | | | |
| *Briza maxima* L. | | x | x | | | | |
| *Ehrharta longiflora* Sm. | | x | x | | | | |
| *Hordeum murinum* L. | | x | | | | | |
| *Hypochoeris radicata* L. | | x | x | | | | |
| *Lupinus sp.* | | | x | | | | |
| *Medicago sp.* | | x | | | | | |
| *Romulea rosea* (L.)Eckl. | | x | x | | | | |
| *Serradella sp.* | | | x | | | | |
| *Trifolium sp.* | | | x | | | | |
| *Ursinia anthemoides* (R.Br.)Gaertn. | | x | x | | | | |
| TOTAL | 118 | 76 | 47 | 45 | 30 | 59 | 23 |
| TREES | 3 | 3 | 2 | 3 | 2 | 2 | 2 |
| SHRUBS & PERENNIAL HERBS - no. | 79 | 50 | 32 | 30 | 25 | 44 | 16 |
| - % | 67 | 66 | 68 | 67 | 83 | 75 | 70 |
| AESTIVATING SPECIES & GRASSES IDENTIFIABLE ONLY IN SPRING | 25 | 15 | 5 | 12 | 3 | 13 | 5 |
| WEEDS | 11 | 8 | 8 | - | - | - | - |

FIG. 3.2.2.2-1: RECOMMENDED SITES FOR PERMANENT QUADRATS.

KEY: , APPROXIMATE QUADRAT LOCATION, ○.

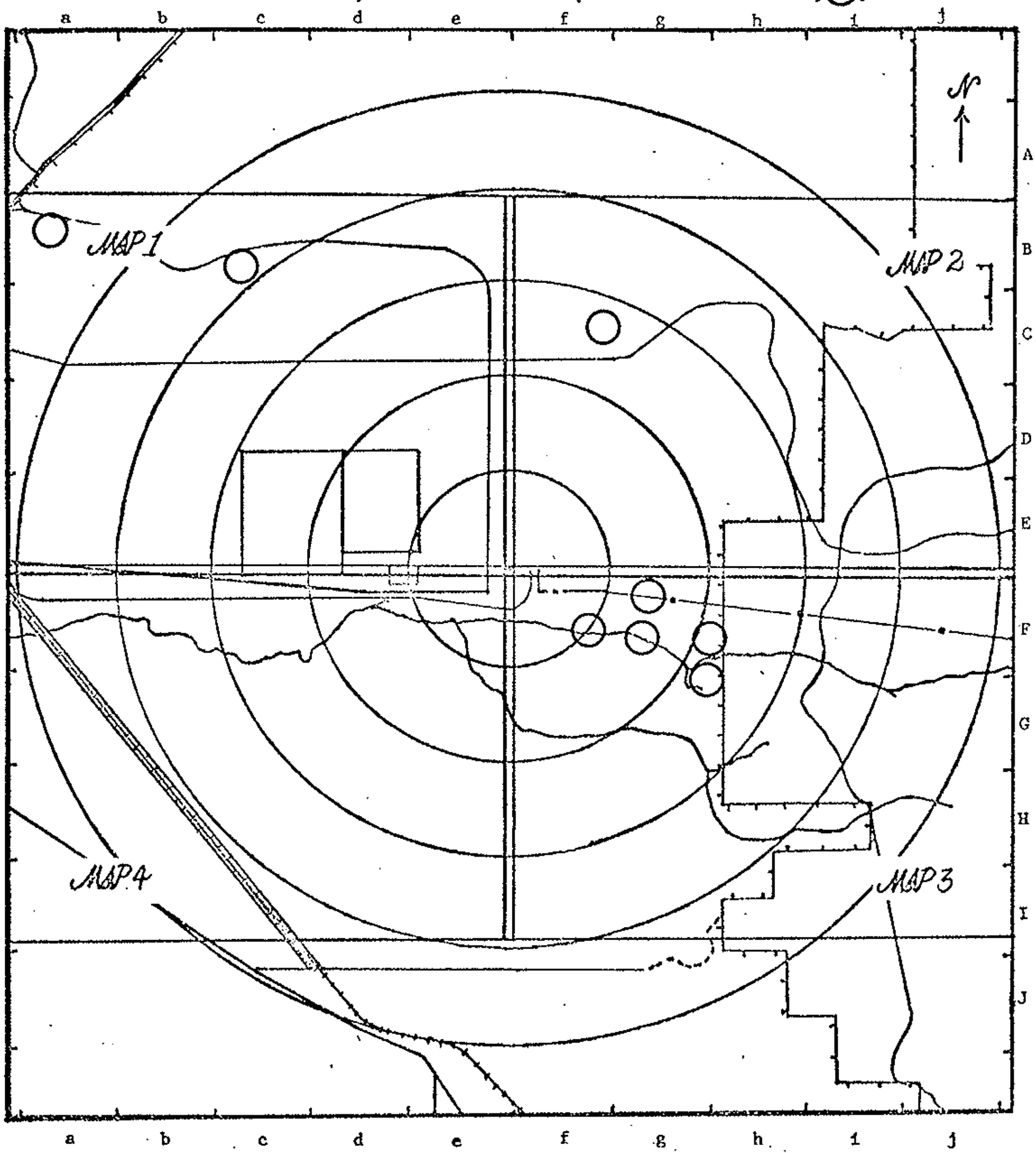


FIG. 3.2.2.2-2: RECOMMENDED SITES FOR MONITORING WITH LICHEN TRANSPLANTS. KEY: , APPROXIMATE SITE LOCATION,○.

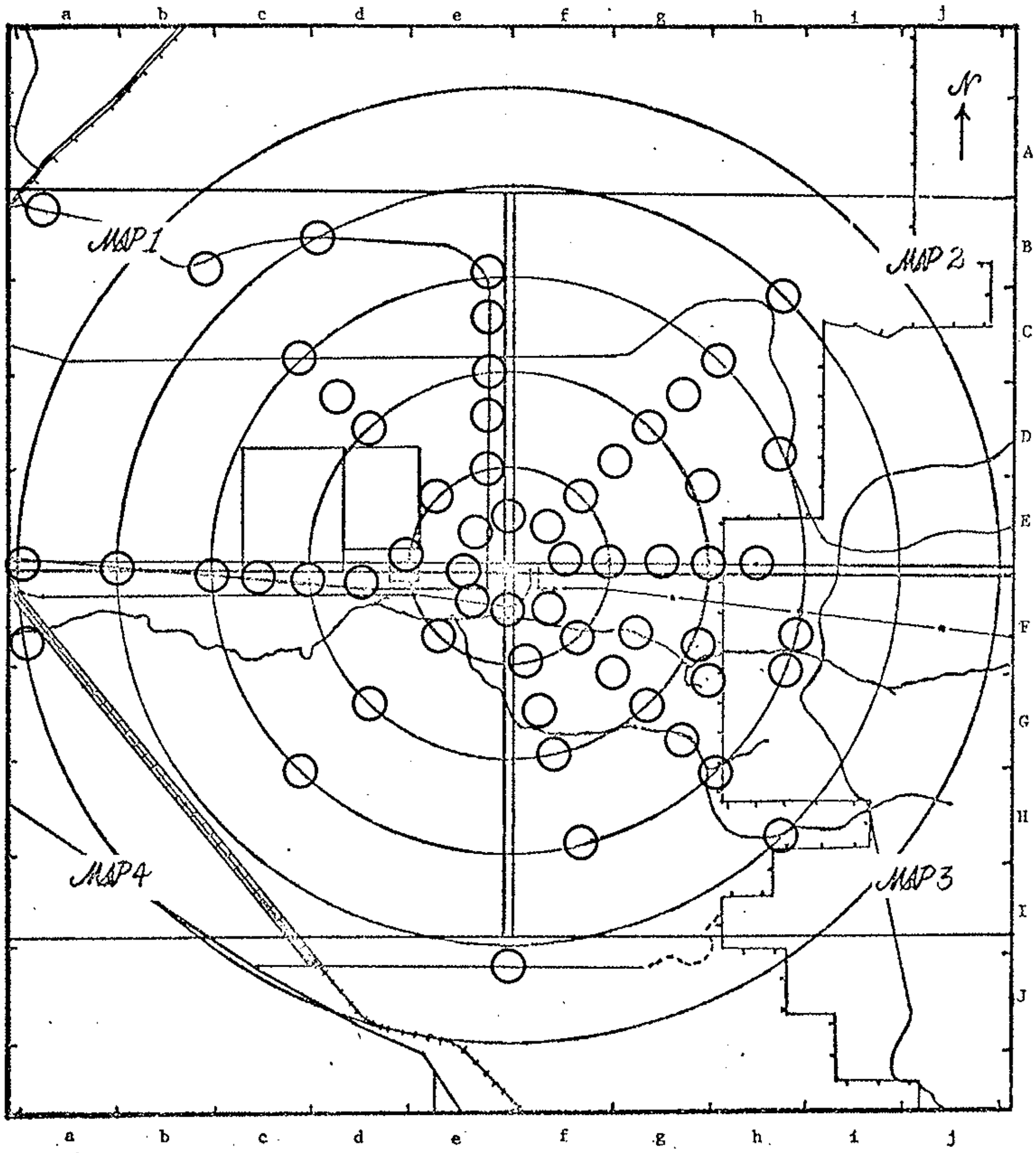


TABLE 3.2.2.6-1

PROPOSED LICHEN INDICATOR SPECIES

| SPECIES | SPECIMEN REFERENCE | |
|---|---|---|
| | SPECIMEN NUMBER | PRINT NUMBER |
| *Usnea barbata* var. *xanthopoga* | 240-41 | 10-36 |
| *Usnea barbata* var. *scabrida* | 508-108 | -- |
| *Cladia fernandii* | 1-0 | 1-23 |
| *Siphula coriaceae* | 317-15 | 10-20 |
| *Caloplaca aurantiaca* | 556-110.4 | 21-24A |
| *Hypogymnia physodes* | 244-41 | 10-39 |
| *Parmelia conspersa* | 6-0 | -- |

PIND Ø2

Pind Ø2 Pinjarra 1 Threatened & poorly reserved plant community type. 17-11-95

BASELINE SURVEY

OF

LICHENS AND HIGHER PLANTS

PINJARRA, W.A.

A REPORT PREPARED FOR

ALCOA OF AUSTRALIA (W.A.) LTD.

SEPTEMBER, 1979

FERMCO PTY. LTD.

VOLUME 1 : TEXT

# FERMCO PTY. LTD.

INDUSTRIAL & ENVIRONMENTAL CONSULTING DIVISION

REGISTERED OFFICE:
MIDDLETON, STEVENS & CO.
44 OUTRAM STREET,
WEST PERTH, W.A. 6005
TELEPHONE 09 321 7078

7 JUNIPER WAY,
DUNCRAIG, W.A. 6023
TELEPHONE 09 447 8347

October 8th, 1979.

Alcoa of Australia (W.A.) Limited,
FREMANTLE, Western Australia.

Attention: Mr. John Quilty

Dear Sir:

We are pleased to present our report on the lichen and higher plant species in the vicinity of the Pinjarra Refinery. Their use as indicator species for environmental management is discussed and recommendations are made.

Please note that the report consists of:

(i) Volume 1: Text without tables or figures. (20 copies)

(ii) Volume 2: Appendices containing all tables and figures. (20 copies)

(iii) Volume 3: Appendices containing all photographic plates. (1 copy).

(iv) Herbarium Specimens: Higher plants (3 boxes)

(v) Herbarium Specimens: Lichens and mosses. (3 boxes)

Yours sincerely,

D.K. Kidby
(Governing Director)

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TABLE OF CONTENTS

## SUMMARY OF REPORT

1. The suitability of lichens and higher plants for air pollutant monitoring is discussed and specific recommendations are made.

2. Observations on the directional frequency and observed ground contacts of the stack plume, together with leaf analyses for total sulfur in *Xanthorrhoea preissii*, indicate that the area currently influenced by emissions is limited to about 3 km from the emission source. However, there are regions such as the Oakley Brook area which are well within this 3 km zone and show no apparent effects of air pollutants. This observation is confirmed by the survey of lichens and higher plants in this area.

3. The region surrounding the Refinery, within the buffer zone, harbours an extensive flora of between 50 and 100 lichen species and a similar number of higher plants. A previously unknown species of *Calothamnus* has been discovered.

4. Lichens at selected sites within the Pinjarra Townsite have been surveyed. An extensive study was made of *Caloplaca aurantiaca* colonization of gravestones in the Pinjarra Cemetery. The previous history of this species, and others in the Townsite, is now well established.

5. Recommendations are made for the use of indigenous and transplanted lichens as indicator species for atmospheric pollutants. Potentially suitable indicator species of lichens and higher plants are suggested. Procedures and monitor sites are also discussed.

## ACKNOWLEDGEMENTS

The Consultants wish to express their appreciation of helpful discussions with members of the W.A. Department of Agriculture, Department of Conservation and Environment, Forests Department, Lands and Surveys Department, Public Health Department, and the Government Chemical Laboratories. Helpful advice was also obtained from members of the University of W.A., the Commonwealth Industrial and Scientific Research Organization, and ANALABS Pty. Ltd. The assistance of Professor Douglas Ormrod of the University of Guelph, Ontario is gratefully acknowledged.

The assistance of members of the Clergy at Pinjarra was especially helpful and is very much appreciated.

The help and advice of numerous members of ALCOA OF AUSTRALIA (W.A.) LTD is also gratefully acknowledged. In particular we would like to express our thanks to the invaluable help given by Mr. John Garner and Mr. John Quilty.

# 1. INTRODUCTION

## 1.1 AIMS OF THE STUDY

The Consultant was required to assist in the assessment of possible influences of stack emissions on indigenous and introduced plant species in the vicinity of the Pinjarra Refinery. The primary concern was the influence of sulfur dioxide. Specifically, the Consultant was required to conduct an initial lichen survey of the area, advise on establishment of monitor sites for further observations upon lichens and higher plants, and also advise on the use and introduction of monitor species.

These objectives were pursued in accordance with stack emission data and plume observations made available to the Consultant. A preliminary survey was conducted to define areas for more detailed examination. To a certain extent the approach used by other workers was applied to the present study. However, the study area is characterised by a number of special features, such as habitat distribution, topography and emission distribution, which specifically influenced the course of the study. These special considerations are discussed in the following section.

## 1.2 SPECIAL CONSIDERATIONS AFFECTING THE COURSE OF THE STUDY

### 1.2.1 The use of lichens as air pollutant monitors.

The sensitivity of lichens to air pollutants is well established and was noted as early as 1859 by Grindon (Richardson, 1975). Studies relating sulfur dioxide levels to the growth and persistence of lichens are numerous and have been extensively reviewed by various authors (see, for example, Nieboer *et al.*, 1976; Hawksworth, 1974; Guderian, 1977; Ferry *et al.*, 1973; Seaward, 1977). The attempts to correlate presence or absence of particular lichen species with the levels of sulfur dioxide have ranged from highly localized studies involving sites such as asbestos roof tiles and tombstones (Gilbert, 1973), to extensive studies such as the mapping of entire countries (Mabey, 1974; de Wit, 1977).

The number of species mapped and the intensity of sampling in any given area is perhaps not as important as the recognition of species which will provide the best indication of pollutant levels. It may not be necessary to exhaustively map the lichens of a region influenced by a pollutant in order to demonstrate the effect and level of the pollutant. Thus the extensive but more or less cursory survey of British lichens (Mabey, 1974) has produced entirely satisfactory data for the correlation of certain key species with known levels of sulfur dioxide (see Hawksworth and Rose, 1970). However, there are certain pre-conditions to be met for such a survey to be useful. Firstly, a large number of accurate determinations of both the lichen species involved and their sensitivities to the pollutant must have been made. Controlled fumigation trials, while useful, cannot be relied upon to produce this data. Thus, determinations of pollutants in the field are necessary. Even with this background of information, difficulties do arise. Some of the problems encountered are pointed out by de Wit (1977) in perhaps the most extensive and intensive study of lichen distribution in relation to sulfur dioxide levels yet undertaken.

In deciding how to deal with the present study the experience gained in the Dutch survey by de Wit (1977) was carefully considered. Some of the relevant features of this survey are discussed below.

1.2.1.1 Lichens and air pollution in the Dutch study

The significant influences on epiphyte distribution were found to be:

(i) phorophyte species; (ii) micro-climate; (iii) eutrophiation; (iv) bark wounds; (v) rain water tracks; (vi) dust accumulation; (vii) structure of bark.

The most appropriate parameters for the mapping of lichens were found to be:

(i) species diversity; (ii) frequency of occurrence; (iii) percentage of cover; (iv) vitality; (v) fertility; (vi) species number per unit (where, unit = sample of epiphytes of a group of trees standing fairly close together, and sample = species list recording number and names of species present). The last parameter, species number per unit, was considered to be the most important.

Only lichens on free-standing vertical trees of a particular species, on all sides of the trunk up to 2 m above ground were included in the sample. This provided for comparable micro-climates and removed the phorophyte abundance variable. Supplementary data were collected where possible, for example, vitality, fertility, abundance, frequency.

Lichen zones were found to correlate best with winter sulfur dioxide levels, which is in accord with other reports of enhanced sensitivity of wet lichens. An important observation was that substrate differences, for example, as between *Quercus* and *Ulmus*, can not only change the rate of response of a lichen species to sulfur dioxide, but can even reverse species sensitivity rankings. Lichens seemed least sensitive on the tree species on which they occur most frequently.

Despite all of these inherent difficulties, fair correlations between zone C lichens and 50-70μg $m^{-3}$ $SO_2$ were obtained (where zone C = zone in which foliose lichens first appear). Of particular interest is the comparison of the results of the Dutch study with those of other workers. The peak values (98th percentile) of sulfur dioxide were found to be the most significant influence upon epiphytes. We suggest that this dependence on peak values is very important because of the implications for the management of stack emissions in relation to their effects on the surrounding vegetation. We would also suggest that some scope for management is offered by the now well supported conclusion that lichens, and other plants, are far more sensitive during moist conditions. Management options could be particularly effective in the climatic conditions of the South West of Western Australia, where a relatively long dry summer is experienced. The use of alternative fuels of lower sulfur content during the relatively short period of high susceptibility would be especially effective. The significance of peak values is not clearly revealed in other less painstaking studies even though the concept of maxima is referred to elsewhere, for example, by Hawksworth (1974).

The strongest correlations which emerged from the Dutch study were the following.

(i) For very low sulfur dioxide: the distribution of sensitive species.

(ii) For low sulfur dioxide: the number of species per square (where, square = 25 $km^2$).

(iii) For high sulfur dioxide: the number of species per sampling site.

In the Pinjarra study there is no doubt that it is the very low sulfur dioxide category which is of concern. This is indicated by the results of the current sulfur dioxide monitoring program. Therefore, it is the distribution of sensitive species which should be emphasised in the approach to the present study.

#### 1.2.1.2 Lichens as air pollutant indicators in the present study

The area immediately surrounding the Refinery is, with the exception of the region to the South East, naturally poor in lichens due to past and present agricultural activities. The main influence of agriculture is loss of phorophytes due to clearing, shading of the soil surface by dense pasture swards, disturbance by cultivation, and use of fertilizers. The effects of fertilizer are obscure and although adverse effects have been claimed, there is also evidence to the contrary.

The farmed areas have a few remaining trees (such as *Nuytsia, Banksia, Kingia, Xanthorrhoea, Eucalyptus,* and *Melaleuca*) which do harbour some lichen species. However, apart from some of the lower lying areas to the North West of the Refinery, these are not as useful as the more heavily vegetated areas because of the difficulty in finding comparable sites with comparable phorophytes. However, it should be pointed out that many of the older farm fence-posts harbour considerable lichen populations which are of potential use as indicators of sulfur dioxide levels as a function of distance from the emission source.

The study area, in general, is composed of many distinct habitats, distinguishable by topography, geology, soil type, and vegetation. All of these features with the exception of vegetation have already been characterized in sufficient detail for the present purposes. The soils and superficial geology of the area are the most significant characteristics, at least in the present case, for the study of lichens and higher plants and the soil survey of McArthur, Bettenay and Hingston (1959) should be consulted.

It is of significance to the present study that many of these areas are small, a few hectares or less, and therefore do not lend themselves to the distinguishing of zones of emission affects. This problem can be most easily understood by comparing the size of the present study area with the unit sample area sizes used in the mapping of lichens by other workers. The most thorough of such studies is that of de Wit (1977), in which the unit sample size was 25 $km^2$, or about one third of the total area of the present study. If a 25 $km^2$ unit sample area was adopted for the present survey, the minimum total area would need to be expanded to about 700 $km^2$ to enable the identification of any zone affects. Such an area would be feasible where a restricted number of species can be selected for monitoring purposes, but it is not appropriate for a baseline study of the present type which cannot be very selective.

The present study also differs from any other recorded in the literature in that it deals with a very low level single emission. The very low levels of sulfur dioxide encountered would not be expected to exert an immediately obvious influence, even in the regions of highest ground level concentrations. Application of the general rule that a single stack will yield, under neutral or unstable atmospheric conditions, highest ground level concentrations at about 20 stack heights (see Strom, 1968), suggests that the present stack would be expected to produce the highest concentration at about 600 m. This is in reasonable accord with stack plume observations, and this is discussed further in the report.

In previous studies on the effects of sulfur dioxide on the distribution of lichens, it is largely the epiphytes which have been employed. This is probably due to a number of reasons. Firstly, epiphytes have been relatively abundant in the areas studied. Secondly, epiphytes embrace a greater range of lichen types than do more restricted substrates such as roof tops or tombstones. Trees are particularly favourable substrates for fruticose lichens, many of which display high sensitivity to sulfur dioxide. Thirdly, the specificity of phorophyte-epiphyte relationships permit comparisons between more widely separated areas than could be otherwise achieved. While epiphytes are present in the present study area, their restricted habitat has made necessary the consideration of lichens in less restricted situations, such as soil and rocks, for use as indicator species for sulfur dioxide affects.

The use of lichen transplants for monitoring purposes is almost certainly the most economical and reliable procedure for indicating the biologically effective level of pollutants such as sulfur dioxide. The use of indigenous species *in situ* would also require the use of transplants to perform the function of a monitor control in an area free from atmospheric pollutants.

A sufficient body of data has been amassed in some areas of the world, for example, in England and the Netherlands, to enable appropriate choices of lichen species for monitoring of sulfur dioxide by transplants. However, there is no doubt that any choices made for the local situations will require at least empirical confirmation.

The examination of potential indicator species by either fumigation, or sulfur dioxide in solution, may or may not be a valid means of ranking sensitivities for field use. A more appropriate procedure may be the transplantation of a range of potential indicators for a direct field assessment. The abundance of fruticose and foliose species available for the purpose suggest that: (i) this empirical procedure could hardly be unsuccessful in obtaining appropriate indicator species; (ii) a field assessment of this type would generate useful basic information on sensitivities and save both time and expense in the selection and application of indicator species. In making a choice between the available procedures it is evident that no matter what approach is taken, field assessment of selected indicators is unavoidable. However, there is also no doubt that fumigation trials are desirable and would assist in correctly assigning symptoms as well as ranking of indicator sensitivities.

A further approach to the question of choosing indicator species is to assess the sensitivity ranking of species in an area known to be affected by the pollutant of interest. This approach is of obvious value and has been utilised in the present study.

### 1.2.2 Higher plants as air pollution indicators in the present study

A number of higher plants have been recommended as useful for field-monitoring of sulfur dioxide (see for example, Guderian, 1977). The response of lichens to sulfur dioxide does not directly reveal the risk to higher plants. Thus there may be a requirement for the use of higher plants if accurate risk assessments are to be made. In considering the use of higher plants for monitoring purposes the following factors should be considered. Higher plants are: (i) less sensitive than lichens to sulfur dioxide, and many other pollutants; (ii) less suitable for long-term monitoring than are lichens but more suitable for short term (weeks rather than months) affects; (iii) relatively expensive to use as monitors; (iv) perhaps unlikely to be very sensitive to sulfur dioxide in the case of most local native species which tend to have low growth rates, relatively impervious leaf surfaces, low moisture content, and low gaseous exchange rates (some of the faster growing Papilionaceae might, however, be expected to be quite sensitive); (v) more susceptible to disturbance by animals and other hazards; (vi) however, particularly relevant where they form an agricultural or horticultural speciesof local importance.

In contrast to the assessment of potential lichen indicator species, it would be necessary to first perform fumigation trials for native species of higher plants if these are to be ranked for sensitivity. This would not be so necessary for the use of introduced pasture species such as sub-clover (*Trifolium subterraneum*). However, fumigation trials would be of obvious use for confirmation of symptoms.

### 1.2.3 Plant sulfur analyses.

It has been demonstrated that plants exposed to high levels of sulfur dioxide may have significantly increased tissue sulfur levels. Therefore the use of plant sulfur analyses for the monitoring of sulfur dioxide should not be overlooked. The present study was aided by the experience gained in CAPS (EPA Coogee Air Pollution Study Report, 1974) in which it was determined that *Xanthorrhoea preissii* was the most suitable indigenous species for correlation of tissue sulfur concentrations and atmospheric sulfur dioxide levels. In the present study area this species is sufficiently well distributed for use as a biological indicator. However, the assessment of this species is viewed more as a component of the base-line study and an indicator of the limits of significant sulfur fall-out.

Considerations affecting the extensive use of plant tissue sulfur analyses are that: (i) plant tissue analyses are not indicated to be as sensitive as alternative procedures such as lichen monitoring; (ii) the procedure is relatively expensive; (iii) it would be extremely difficult to establish a useful relationship between atmospheric sulfur dioxide levels in even a relatively suitable species such as *X. preissii*.

### 1.2.4 Mapping of lichen species.

A large number of mapping procedures have been used for lichens. The technique used for a nation-wide survey of epiphytes has already been briefly discussed in Section 1.2.1.1. In the case of roof-top or tombstone studies (Gilbert, 1973), procedures have ranged from recording relative numbers of one or more species to transect mapping in the same manner as field studies of higher plants. The percent coverage on a defined substrate may be used to define the extent of colonization. In the case of fruticose species, the length of the fruticose component has been used as an index of growth.

While there are both obvious merits and problems inherent in the various mapping procedures employed, the important considerations in the present study are as follows:

(i) Because of large differences in habitats, no single mapping procedure is appropriate;

(ii) It cannot yet be known with certainty which of the species encountered will prove to be of most use in the evaluation of environmental affects.

(iii) The absence of previous studies of this kind in this or similar areas (the observations at the Wagerup site appear to be of a cursory nature only) precludes any assumptions about the incidence of other than some common species.

(iv) Much of the study area is cleared and under pasture and is such a restricted habitat that apart from general observations cannot be usefully mapped.

(v) A number of sites within the study area possess a rich and varied flora and detailed observations appear warranted.

(vi) Because of the importance of the study as a base-line survey, extensive macro-photographic records of individual species encountered and their associated habitats are necessary so that any future questions concerning determination or morphology may be resolved. A frequently encountered criticism of past studies is that, even the most experienced workers, either fail to anticipate the future usefulness of some specific aspect of morphology or, having neither the means nor time to devote to such details, omit important data completely. Appropriate photographic procedures can largely overcome such difficulties and, in conjunction with collection and preservation of specimens, provide adequately for the needs of future workers.

(vii) The establishment of a reference herbarium for the area under study.

(viii) The desirability of extending the study to a similar area which is beyond any possible influence of atmospheric pollutants. Such an area may serve two important purposes. Firstly the absence of any species, in either area, is more likely to be rapidly revealed. Secondly the reference area can serve as a source of transplants and as a control area for transplants.

### 1.2.5 Mapping of higher plant species

The procedures appropriate to the present study vary according to the purpose. In some cases, the major concern is to identify potential or actual phorophytes, for example, in the farmed areas. For other regions, for example, Oakley Brook, the plant species are themselves of intrinsic importance to the establishment of the base-line. In such cases the observation of prominent species together with selected transects should provide a good indication of the major communities present. The setting up of permanent quadrats was not undertaken because of the preliminary nature of the survey. However, there seems no doubt that these should be employed when the results of the present study have been evaluated.

### 1.2.6 Summary of introduction

The approaches to the study have been briefly reviewed in terms of the principle objectives. The use of lichens and higher plants as indicators for monitoring sulfur dioxide in the study area has been accorded a preliminary evaluation. The relevant experience of other workers has been briefly reviewed. The features of this present study which present unusual or peculiar difficulties have been considered. It has been the intention to acquaint readers of the report, who are not lichenologists, with the reasons for the particular approaches taken.

# 2. RESULTS

## 2.1 STACK PLUME OBSERVATIONS

There are a number of ways of reducing the estimates of maximum ground level sulfur dioxide concentrations in the present study. The use of stack plume tracers and direct sulfur dioxide measurement, while useful, is not a practical means of supplying information on long term affects except for a restricted number of sites.

Theoretical treatment of wind data, insolation, and other ambient parameters, together with stack characteristics and local topographical features is a further approach and has been performed for the area under study (Dames and Moore, 1977). While this may suffer certain deficiencies, for example in the data base used for calculations, it is nevertheless instructive to consider the theoretical maxima obtained for the various Pasquill stability classes (which are essentially determined by wind speed, cloud cover, and insolation). For the present stack, the distance at which the maximum sulfur dioxide level would be expected ranges from about 200 m to 700 m for stability classes A through D. The greatest stack height considered was 91 m and the corresponding range for sulfur dioxide maxima is 500 m to 2,300 m. The maxima in the E to F class (wind speed > 6 m $sec^{-1}$) is, for the present purposes, not considered because of the very low maximum concentrations reached. It can be seen from the foregoing estimates that the region of mean maximum sulfur dioxide concentration should fall well within the projected study area of radius 5 km.

The most useful approach to the reduction of these estimates would seem to be an analysis of the existing stack plume observations carried out at the Refinery over the past 3 years.

In terms of potential biological effects, it is the observations over the winter months which are considered to be most significant because it is during this period that lichens, and other higher plant species, will be most sensitive.

The approach taken in this study was to examine: (i) the frequency with which the plume moved in each of 8 horizontal directions during the period April to September (data for morning and afternoon observations are aggregated) and, (ii) the frequency with which the plume made ground level contact in each of these 8 directions at intervals of 100 m. Figure 2.1-1 summarizes this data. The radial distances indicated should be regarded as minimum distances for purposes of estimating maximum gas concentrations since the region of highest concentration will extend beyond the observed contact point of the plume. How much greater this distance will be, will depend upon plume particle size distribution and wind speed, but it is certainly not less than the observed distance.

If the concentration distributions of sulfur dioxide estimated by Dames and Moore (1977) are related to the distances at which initial ground contact is observed (see Figure 2.1-1) it is apparent that the maximum concentration of sulfur dioxide may be at least 300 to 500 m beyond the observed distance for plume contact. If the distance at which maximum concentration occurs is estimated in this way, it can be seen from Figure 2.1-1 that the mean maximum levels may occur at about 1,000 m, or even greater distances, for the present stack. This would suggest the possibility that the maximum concentration may occur at distances greater than those calculated by Dames and Moore. Bearing in mind that this re-estimation depends upon unsupported assumptions about the possible relationship of plume observations to gas concentration, this difference in the distance estimates should not be regarded as significant. However, the re-estimated distance should be taken into account in defining the most probable fall-out distances in the study region. It is therefore concluded that it would be worth considering the possibility that the region of maximum outfall might be in the vicinity of 1,000 m.

A further consideration of importance is the incidence of fumigation from the stack plume. For short term effects on the vegetation in the immediate vicinity of the emission source, this situation is of far greater importance than the mean distance of maximum sulfur dioxide concentration. The latter is, of course, of ultimate importance in terms of long term effects. The observations of the Consultant which bear directly upon this question relate to a presumed episode of fumigation resulting in the appearance of symptoms in *Eucalyptus* and *Acacia* species consistent with sulfur dioxide affects. These symptoms are discussed in the section dealing with higher plants.

## 2.2 SULFUR ANALYSES

### 2.2.1 Procedures adopted

The rationale for examining *Xanthorrhoea preissii* has already been advanced in Section 1.2.3. However, while the report cited provided sufficient evidence to suggest the advantages of using this species as an indicator, the sampling procedure seemed not to have been extensively examined. Specifically, no information was available on the influence upon total sulfur levels in leaves of:

(i) leaf age;

(ii) orientation of sample with respect to direction;

(iii) differences between proximal, medial, and distal leaf sections.

These factors were therefore investigated. The possible suitability of *Kingia australis* was also considered and leaves of this species were examined.

Total elemental sulfur was determined by X-ray fluorescence on leaves which had been dried overnight (ca. 16 hours) at 80°C in a forced-draught oven and milled to about 300 mesh.

Reference samples were obtained from Site zero and adjacent areas. However, it should be clearly understood that such reference material can be of only marginal value since the sulfur uptake response curves for this species on different soil types is not known. Nevertheless, it was felt that the comparisons might prove to be of some use.

### 2.2.2 Results of sulfur analyses

A comparison of samples from North, South, East and West orientations of older leaves from *X. preissii* at Site 3 revealed no obvious effect of orientation. For total sulfur concentrations in leaves see Figs. 2.2.2-0, 1, 2, 3, and 4 (Volume 2). Table 2.2.2-0 may be consulted for a listing of site locations. Table 2.2.2-1 should be consulted for the complete listing of sulfur analysis data.

In the same plants an examination was made of the differences between proximal, medial and distal leaf sections. This revealed apparently significant differences and this question was examined more extensively in a second set of samples which included both old and young leaves.

The results of this second survey can be summarised as follows. There appeared to be only slight differences between sulfur levels between the oldest and youngest leaves. However, there was a two-fold difference in total sulfur concentration between the distal and proximal ends of leaves. Because of this large difference it was decided to routinely analyse both proximal and distal leaf sections to determine if the response of the older plant tissues could be measured in relation to the younger (proximal) tissues. It should also be pointed out that plots of sulfur concentration versus distance along leaf, revealed an essentially linear rise in sulfur towards the leaf tip with no evidence of abrupt changes. To the writer's knowledge this is the first time that an examination of these factors has been undertaken. Since no significant orientation or age differences were observed, the practice of sampling the younger, central crown leaves was adopted. Sulfur levels plotted against the distance from the proximal leaf end are shown in Fig. 2.2.2-5.

The results of these and further samplings (Figs. 2.2.2-1, 2,3,4 and Table 2.2.2-1) are of some interest since a number of points emerge.

(i) *Kingia australis* leaves contained approximately twice the sulfur concentration of *Xanthorrhoea preissii* leaves.

(ii) Sites closest to, and to the West of, the emission source tend to have higher sulfur levels (high levels were also observed at site 2).

(iii) *X. preissii* sulfur levels at and near (site 26) site zero (emission-free control sites) are comparable to those in the vicinity of the Refinery, except for those sites referred to in (ii) above.

(iv) Where high leaf sulfur levels do occur, the ratio of distal to proximal leaf levels are also high (this is an extremely interesting observation which deserves further investigation).

(v) There is some indication of a relationship between the distribution of high sulfur levels and the directional frequency of plume ground contacts (Fig. 2.1-1).

It may be concluded that there is some evidence of raised sulfur levels in the immediate vicinity of the emission source. However, it is also true that sites close to the Refinery, for example in the Oakley Brook area, have levels even lower than those in the emission-free control area (site zero). There seems little doubt that, at the low emission levels involved in the present study, plant sulfur levels are not likely to be greatly raised, except in the regions of highest ground level plume gas concentrations. In terms of the requirements of the study, it is considered that the investigation of plant sulfur levels has been useful.

## 2.3 LICHENS

### 2.3.1 Areas studied

The survey was divided in the following way.

i) Habitats surrounding the Refinery were selected on the basis of: direction and distance from the emission source; presumed suitability for lichens (without making allowance for any influence of stack emissions).

ii) Habitats beyond the buffer zone (Alcoa property) were selected on the basis of: their potential importance for future monitoring (for example township sites); suitability for lichens.

iii) Habitats remote from the Refinery, or any other man made influence, were selected for use as control sites.

On the basis of the above considerations the study areas included:

i) The buffer zone surrounding the Refinery and some sites slightly beyond this.

ii) Pinjarra Townsite, including St John's Churchyard and the more recent Interdenominational Cemetery.

iii) Fairbridge Farm adjacent to the buffer zone (including the Fairbridge Cemetery)

iv) A Control area at Manna Flat Farm, York, W.A.

v) A Control area at the York (W.A.) Cemetery.

### 2.3.2 Sites immediately surrounding the Refinery

The Refinery site itself may be considered a lichen desert, as would be expected for any similar industrial site. Other than transplanted lichens such as *Parmelia* and *Caloplaca* species at Site 38 (see

Plate 2.3.2-3), and those transplanted to Site 21 (see Plate 2.5.2-6), lichens were not observed.

The nearest site at which indigenous (not transplanted) lichens can be observed is Site 1, which is the Car Park area. However, the population is sparse and confined to occasional *Graphis* species, either corticolous or lignicolous on *Banksia.*

Significant foliose and fructicose species do not occur to the North of the Refinery until Adelaide Rd (Sites 22 to 25) is reached. These include *Parmelia rutidota* and *Cladonia* species but often without fruiting structures. *Cladonia* is frequently only present as a farinaceous vegetative thallus. Both genera are epiphytic on *Kingia* and *Xanthorrhoea*, usually at or near the base on the Southern side, and also lignicolous on *Eucalyptus* stumps. Charcoal, for example charred tree stumps, seems to be a preferred substrate for some *Cladonia* species. *Graphis* species are abundant in all areas and will not be further commented upon except where an unusual species has been observed. The restricted population in this area may be attributed to the lack of a suitable habitat rather than any directly observable influence of the Refinery.

In the area to the West in the 2 to 4 km range (Sites 6 to 13) there are rather more suitable habitats, possibly due to trees providing more shelter. Here, the fence-posts, in particular, are generally well populated with *Parmelia* species, and *Usnea* is also frequently present. Also present is *Caloplaca*, which while described in some keys as having a distinctly lobed thallus, tends here to adopt a submerged growth habit. Other crustose species are occasionally present but the dominant and potentially most useful fence-post flora are the *Parmelia* and *Usnea* species, particularly the latter.

It should be pointed out that most species encountered in the surveyed areas, other than a few on the scarp to the East of the Refinery, are xeric in character. *Cladonia* species observed in this study may also be considered xeric though skiophilous. It is nonetheless evident that most, if not all, of the lichens encountered were substantially assisted by higher moisture. A few lichens such as *Heterodea* and *Dermatocarpon* were observed only in moist, shaded locations.

The area immediately to the South East of the Refinery, 1 to 2 km from the emission source, was totally different to any other studied in that it possessed most of the characteristics, such as shade, moisture, clay soil, rock surfaces, and fallen timber, that would be expected to favour a diverse population of lichens. One obvious lack was suitable phorophytes for corticolous species. Generally speaking, *Eucalyptus* is a rather poor host, *Xanthorrhoea, Kingia* and *Banksia* are somewhat better (*Usnea* are occasionally observed on these latter), while *Casuarina*, some *Acacia* and most *Melaleuca* are frequently very well colonised. Thus, in the Oakley Brook area, most lichens were present as either saxicolous or terricolous species. Rabbit holes, creek banks, and ant hills are particularly well colonized in the area. These, together with termite mounds, dead trees and virtually all exposed rock surfaces are particularly rich in lichens. Mosses, where present, tend to be well colonized by muscicolous species. Other particularly suitable habitats are at the base of dead trees and on the dead limbs of these.

The area to the South of the Refinery is a fairly uniform woodland with *Eucalyptus* predominating the tree species. However in some of the sandier areas, *Banksia* provides a suitable phorophyte for some corticolous lichens such as *Parmelia, Hypogymnia* and *Usnea*. Otherwise, most lichens tend to be confined to microhabitats such as burned out stumps. *Cladonia* species are frequently terricolous here, in protected microhabitats. Interestingly, soil type seems to have little influence on the distribution of *Cladonia verticillata* which is the most common terricolous species. Also of considerable interest was the abundance of *Parmelia* and *Usnea* on North-South fence posts in this region. These might be expected to be of some potential use in the monitoring of emissions.

The significant lichens encountered are indicated in the series of maps contained in Appendix 3 (Volume 2 of Report). For a complete list of lichens encountered, the LICHEN SPECIES LIST (Table 2.3.2-1) should be consulted. In the case of relatively rare lichens, such as *Haematomma puniceа, Teloschistes chrysopthalmus, Dermatocarpon hepaticum, Heterodea* sp., these are not mapped but are given a site reference in the list itself.

2.3.3 Control area

The control area (Site Zero) comprises a typical Wandoo Forest but with areas of Jarrah and Marri which resemble the Pinjarra study area in many respects. However, *Banksia* is absent from Site Zero. Except for an absence of sandy areas, the soil types are also similar, as are the surface rocks. The area covers about 300 ha and is situated on the Helena Rd, York, W.A. As would be expected, the lichens present are also similar. A site photograph is included (2.3.3-1). The area photographed is similar in all essential respects to Site 92. The only significant and unexplained difference between the two areas is the absence of *Cladia fernandii* from the Pinjarra area (this species has been found in the Wagerup area).

2.3.4 Pinjarra townsite

This area includes sites which are representative of all the significant lichen habitats. Each is fairly distinct and will be dealt with separately.

2.3.4.1 High School roof top

This provided a particularly valuable site (110) since the roof of the older section of the school is relatively exposed and has a number of orientations. The identification of roof sections and quadrats appears in Figure 2.3.4.1-1.

The list of significant species in quadrat surveys appear in Table 2.3.4.1-1 (Volume 2). The distribution of isidia and apothecia in two *Parmelia* species is recorded in Table 2.3.4.1-2 (Volume 2). The latter observation is considered significant because of the probability that the very low levels of emissions in the present study may cause subtle effects such as changes in the proportions of reproductive structures.

The photographs cover the roof-top species fairly comprehensively and these may be consulted in Section 2.3.4 (Volume 3).

The occurrence of *Cladonia verticillata* on this roof top seemed surprising since its distribution at other sites studied, suggested a requirement for some degree of protection.

This site is, potentially, the most useful in the Township for emission monitoring using lichen indicator species.

#### 2.3.4.2 St. John's Churchyard

The utility of this site (109) is in the known age of substrates (gravestones and the Church wall) and its position at the Eastern edge of the town. The procedure employed was to photograph the typical and significant lichens present. The measurements of surface coverage and colony size, which were performed on gravestones in the Cemetery at the South end of the town, were not repeated at St. John's because of the insufficient numbers of comparable gravestones. However, criteria for changes in species abundance may still be applied since the photographic record of specified sites provides a clear basis for comparison (see Section 2.3.5, Volume 3). What cannot be obtained from the St. John's site is any clear evidence of colonization rate during past years.

The distribution of lichens at this site is consistent with the species obtained in the other Cemetery (see following section), the most significant being *Parmelia* sp. and *Caloplaca aurantiaca*.

### 2.3.4.3 Pinjarra Interdenominational Cemetery

This Cemetery (Site 97) is large enough (numerous comparable gravestones) and old enough (ca. 1904) to provide not only a clear picture of present colonization patterns but also some idea of past colonization and growth rates. The most widespread species is *Caloplaca aurantiaca*, and this is particularly significant since this species is consistently reported as being sensitive to mean levels of sulfur dioxide of greater than 30 $\mu g\ m^{-3}$. It should be pointed out that this characterisation of sensitivity has not been performed, to the writer's knowledge, under Australian conditions. However, there is no reason to suppose that this species would be any more or less sensitive under local conditions.

This site also has a number of suitable phorophytes for corticolous species. The Coral, Kurrajong and Jacaranda trees present are abundantly colonized by *Parmelia* and *Usnea*, and in one case, *Teloschistes* and *Collema*. Crustose types such as *Graphis*(?) and *Lecidia*(?) are also present.

It should be pointed out that no material was removed, nor any chemical tests performed (procedures normally necessary for accurate determination of species). However, in the case of the species of most interest, *Caloplaca aurantiaca*, the most careful examination was made. This included an examination of all determined Herbarium specimens of this and similar species at the University of W.A. and examination of other speciments from other sites. There is no basis for doubting that the species present in the majority of gravestones is *Caloplaca aurantiaca*.

Photographic records of the Cemetery lichens may be found in Section 2.3.6 (Volume 3).

The data for distribution of colony sizes and coverage may be found in Section 2.3.6 (Volume 2). However, before consulting this data a consideration of the methods used should be made.

### 2.3.4.3.1 Methods employed in gravestone measurements of *Caloplaca aurantiaca*.

Comparisons between colony sizes and percent coverage either along transects or for entire surfaces were presumed valid where the following conditions prevailed.

(i) The substrates were of visually similar composition.

(ii) The surfaces were of similar degree of smoothness (irregularities were obvious since these markedly influence rate and extent of colonization).

(iii) The surfaces were not exposed to run-off from other parts of the monument, for example head-stones.

(iv) The surfaces, if vertical, were of similar orientation (generally, only horizontal surfaces were employed).

The colonies measured were not, in general, circular because of the nature of the substrate, and the maximum dimension (longest axis) was employed. In cases where growth approached confluency and made the assessment of individual colonies difficult, the surface was not used (even though coverage could, of course, still have been estimated).

In determining the mean colony diameter and the error term associated with this, no allowance was made for the fact that few, if any, colony size distributions followed a Normal distribution (See Section 2.3.6, Volume 2). This difficulty is not a significant one for the purpose of the study. However, in making comparisons, it is necessary to consider the complex nature of some of the distributions obtained. Specifically, it is necessary to consider the modes according to rank in a multi-modal distribution. In some cases, where insufficient numbers of colonies were present for reliable population sampling, the complex shape of the curve may be attributable to too few data. However, it is clear from some of the better populated surfaces that the distribution curves are indeed multi-modal.

In fact the reasons for the differences in distribution, discussed above, are fairly obvious when the surfaces surveyed are inspected. The main reason is probably due to some differences in micro-habitat along the transects. These are not consistent but probably reflect some degree of shading from head-stones and other influences such as periodic controlled burns or other physical and chemical influences. It should be noted that occasionally the surfaces of gravestones are cleaned by the relatives of the incumbent deceased. The practice could probably be discouraged but, in any case, it would take a very vigorous cleaning indeed to remove *Caloplaca* from most surfaces.

A further observation which was made on these gravestones was the occasional presence of a crustose type with very small black apothecia. Where present in sufficient numbers these were also measured.

All graves in the Cemetery were carefully inspected so the omission of gravestones of more recent vintage may be taken to mean that these do not yet have macroscopically visible colonization. In some cases, more recent gravestones than those recorded do harbour lichens but, in these cases, it was determined to be due to the presence of fissures or crevices in the gravestone where water and other nutrients could persist. Colonization rates are also obviously influenced by the capacity of the surface to retain the colonizing lichen and, on particularly smooth surfaces (even where well sheltered), lichens do not colonize for many years.

One further point which deserves comment is the fact that on the older gravestones, there was frequently a region of moribund or senescing thallus surrounding obviously healthy (as judged by colour) apothecia. This older, and quite distinguishable, region of the thallus was not included in the measurement.

2.3.4.3.2 Distribution of *Caloplaca aurantiaca* on selected gravestone surfaces.

The mean colony diameters, their associated error terms, and where obtainable, percentage cover, are shown in Table 2.3.4.3-1 (Volume 2). The distributions themselves are plotted in a series of figures identified by grave site numbers or, where this was unknown, other identification (see Figs. 2.3.4.3-Grave-Site Series).

The data obtained fixes the number of years required for colonies to appear at about five. The determination of growth rate, as measured by colony extension is possible but it would be necessary to make observations at a later date to validate any interpretation attempted.

What is clearly established is the present distribution of this species and the time taken for colonization. What was not immediately obvious was whether or not the time taken for colonization was as short as would be expected in an atmosphere essentially free of sulfur dioxide or other emissions. In order to answer this question, grave-sites were examined in an area considered free from any significant atmospheric pollution. This is dealt with in the following section.

2.3.5. York Cemetery

Several hundred graves were given cursory examination and about 100 gravestones in the South-East corner of the Cemetery were examined in some detail.

Much more notable than in the case of Pinjarra gravestones was the tendency to readily colonize the Southern aspects. Distribution of species was entirely similar to Pinjarra (Site 97) but the rate of colonization was significantly slower. Gravestones did not exhibit *Caloplaca aurantiaca* beyond 1962. *C. aurantiaca* does appear to be the first colonizer. The colonies on both 1962 and 1961 gravestones were significantly smaller than for earlier years.

Thus gravestones at York are colonized about 12 years later than at Pinjarra. It is therefore concluded that colonization rates at Pinjarra are probably very different from those at York but, despite such observable differences, the two sites are probably sufficiently alike to warrant useful comparison.

2.3.6 Fairbridge Farm adjacent to the buffer zone.

This area was examined to ensure that observations were extended sufficiently to the North of the Refinery.

The lichens were generally sparse in Site 98, consisting mainly of isolated *Cladonia* species. However, to the North of the Pumping Station (Site 99) crustose epiliths were fairly abundant. Suitable phorophytes were generally lacking and colonization other than on rocks was restricted to lignicolous types such as Graphidaceae. *Cladonia* species were fairly abundant on ant hills. One observation of interest was the colonization of bones by a *Caloplaca* species.

The Fairbridge Cemetery (Site 100) which lies within Site 98 was not particularly useful, since the gravestones were relatively recent and were only sparsely colonized by *Caloplaca aurantiaca*. However, it would be worth revisiting this site to observe further developments.

The significance of this area (sites 98, 99, 100) is essentially that it is within about 4 km of the Refinery and must be considered to be, at least potentially, subject to the influence of stack emissions.

## 2.4 HIGHER PLANTS

### 2.4.1 Introduction and general observations

The areas surveyed included only those which appear to provide information of direct value to an environmental monitoring programme. The agricultural and reforested areas were not included since these are already well characterised. However, some observations on the more prominent species of the Pinjarra region are appropriate.

The surviving vegetation of the coastal plain includes *Banksia grandis, B. attenuata, Eucalyptus marginata, E. calophylla, E. redunca* (mainly to the South of the Refinery), *E. gomphocephala, E. rudis, Melaleuca parviflora* (a few isolated stands), *Xanthorrhoea preissii, Kingia australis, Melaleuca polygaloides* (in swamp areas), *Nuytsia floribunda* (prominent because in open paddocks but not present in large numbers).

The Darling Plateau and Ridge Hill Shelf has a fairly typical jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*) forest with some of the steeper rocky areas (as for example in the Oakley Brook area) having predominantly Sheoak (*Casuarina fraseriana*). *Xanthorrhoea preissii* and *X. gracilis* are relatively abundant also.

The following sections (2.4.2. and 2.4.3) deal with specific surveys of significant sites in the study area. While a greater coverage of the area could have been obtained by conducting a more cursory survey, it was considered of far more use to conduct the examination in a manner which would yield maximum useful information rather than to simply map the maximum area. It should be pointed out that while the most thorough of the surveys was conducted in the Oakley Brook area, this was carried out at a time when many aestivating species were not available for observation. While this does not seriously impair the value of the study, it may be worth considering a complete survey of the Oakley Brook area. This would require multiple surveys to achieve a complete species listing, but in view of the intrinsic value of this small area, which is in the immediate vicinity of the Refinery, the effort involved may be warranted.

## 2.4.2 VEGETATION OF OAKLEY BROOK

### 2.4.2.1 INTRODUCTION

The vegetation of the valley occupied by Oakley Brook east of the refinery to the Darling scarp crest was surveyed to provide identifications of the major plant species present and to determine the nature and composition of a number of distinct plant communities recognised in the area investigated. The presence, within the valley, of plant communities characteristic of the Darling scarp provides opportunities for monitoring any changes that may occur to the vegetation of the scarp in the vicinity of the Pinjarra refinery.

### 2.4.2.2 THE OAKLEY BROOK STUDY AREA

Oakley Brook is a tributary of the Murray River and flows in a westerly direction off the Darling Plateau. It passes through the southern part of the refinery site, running parallel with the No. 1 conveyor and feeding the reservoir. The study area was located in the valley formed by the brook as it drops from the Darling Plateau to the Pinjarra Plain, and is bounded to the West by the N-S fence and to the East by the crest of the scarp and the wall of the Oakley Dam (Fig. 2.4.2-1). In the eastern part the brook falls steeply amongst the granite boulders and outcrops of the scarp face, but the gradient diminishes to the West and the valley broadens at the foot of the scarp.

The vegetation of the valley is basically a woodland of Wandoo (*Eucalyptus wandoo*), Marri (*E. calophylla*) and Granite Sheoak (*Casuarina huegeliana*), with an understorey of shrubs and perennial herbs. A preliminary survey of the area on 21st April 1979 revealed a number of plant communities which were investigated more thoroughly on 30th April, 1979. The species composition of the communities was established by noting the identity of plants occurring one metre either side of a 25 metre length of measuring tape laid out as a transect. Locations of the 13 transects from which survey data were collected are shown (Fig. 2.4.2-1). Only trees, shrubs and perennial herbs were recorded. Specimens were taken to permit confirmation of field identifications and to provide material for a reference collection (field herbarium) to be used in any future survey work in the valley. No attempt was made to identify non-flowering or non-fruiting grass-like plants of the families of the Poaceae, Cyperaceae or Restionaceae, which are virtually impossible to identify in their vegetative state. Quantitative observations of frequency or cover were not made for all species; however, the dominant species along each transect were noted. Appendix 4 lists the species encountered and their distribution in the various communities.

### 2.4.2.3 PLANT COMMUNITIES OF OAKLEY BROOK

The presence of distinct plant communities reflects the diversity of habitats found in the study area. Each community can be described both in terms of its characteristic species and of the habitat it occupies.

Growing along each bank of the brook as a narrow belt about 2 m wide is a community of tall shrubs 2 - 4 m high, dominated by *Darwinia citriodora, Agonis linearifolium* and *Trymalium spathulatum* with patches of the sedge *Lepidosperma tetraquetrum* and the rush *Juncus pallidus* (Appendix 4). Transects 3 and 8 were made along the bank community (Fig.2.4.2-1).This community shows its greatest development (in the study area) along the lower reaches of the brook, occurring only in those upstream regions where the gradient and flow rate are reduced. The most obvious feature of the creekside habitat is the permanence of the water supply, which accounts for the occasional presence of the moisture-requiring Maidenhair Fern, *Adiantum aethiopicum.*

The alluvial flats deposited below the 60 m contour support a fairly dense woodland of Flooded Gum (*Eucalyptus rudis*), Marri and occasional individuals of Wandoo, with a relatively species-poor understorey in which the most abundant species were the 1 - 1.5 m high shrubs *Hibbertia hypericoides, Hypocalymma angustifolium, Acacia pulchella* and *Phyllanthus calycinus,* and the tussock-forming sedge *Lepidosperma gracile* (Appendix 4). Plant density in the understorey was low, giving a cover value of approximately 50%. The gaps between plants usually showed a considerable accumulation of leaf litter except where disturbed by the foraging activities of wild pigs, which are plentiful in the area. The low density and the species-poor nature of the understorey are the result of competition from the canopy species, since the moist, relatively fertile alluvial flats provide favorable conditions for both Flooded Gum and Marri (Seddon 1972, Erickson *et al.* 1973). Two transects (numbers 1 and 2) were made in this community; both were near lichen site 16 (Fig. 2.4.2-1 and yielded a total of 23 understorey species (Appendix 4). A variant of this community was encountered on the northern bank about 200 m east of this site, immediately upstream of the conspicuous isolated granite outcrop and due North of lichen site 27; the Flooded Gum/Marri woodland of the narrow alluvial flat and the adjacent slope were almost devoid of a shrub layer. Scattered Zamia Palms (*Macrozamia riedlei*) and Blackboys (*Xanthorrhoea preissii*), with occasional small plants of *Hibbertia hypericoides*, growing in otherwise bare soil, constituted the understorey. Signs of grazing and foraging were seen but it is doubtful whether this situation can be fully explained by animal activity.

An open woodland of Wandoo and occasional Marri is the characteristic community which occurs extensively on the gravelly soils of the gentle lower slopes of the scarp face. Boulders and low granite outcrops occur throughout the woodland. The understorey is generally less than a metre high but it is denser and composed of more species than the alluvial flats. Again, *Hibbertia hypericoides, Acacia pulchella* and *Lepidosperma gracile* are the important species, but here *Dryandra armata, Calothamnus quadrifidus, Kunzea recurva* and *Baeckea camphorosmae* are also common. Many other species occur, but less frequently. In three transects in the Wandoo woodland (transects 4, 5 & 7), 31 understorey species were recorded (Appendix 4). The gravelly soils at the foot of the scarp - provide one of the typical habitats for Wandoo woodlands (Seddon, 1972; Erickson *et al.*, 1973). Transect 7 was in woodland bordering an unusual shrub community, about one hectare in extent, composed mostly of a dense growth of *Calothamnus quadrifidus* with some *Hibbertia hypericoides* and *Darwinia citriodora* and occasional plants of several other shrub species growing as a one metre high thicket on loose heavily-weathered granite rubble. The single transect (no. 6) revealed 23 species. This isolated patch, devoid of trees, was surrounded by typical Wandoo/Marri woodland growing on gravelly clay soil.

The Wandoo/Marri woodland of the lower slopes is replaced on the steeper slopes by one mostly of Marri, with Granite Sheoak (*Casuarina huegeliana*, in the immediate vicinity of granite outcrops) and very occasional individuals of Jarrah (*Eucalyptus marginata*). The under-storey contained many of the species encountered on the lower slopes but lacked several others, including *Phyllanthus calycinus, Mesomelaena tetragona, Melaleuca scabra, Dryandra armata* and *Calothamnus quadrifidus*; these last two species, abundant on the lower slopes, are replaced by *Dryandra praemorsa* and *Calothamnus sp.* at higher altitude where they are locally common. Other species encountered only on these steep upper slopes include *Leucopogon capitellatus, L. oxycedrus, Opercularia vaginata* and *Cyathochaeta avenacea.* Two transects, south of the brook and below the scarp crest (nos. 10 & 11), yielded a combined total of 30 understoreyspecies (Appendix 4).

A prominent feature of the upper part of the valley were the large granite outcrops and their associated talus slopes which provided habitats for several species which were not found at lower altitude or on deeper soils nearby, e.g. *Hovea chorizemifolia, Scaevola pilosa, Acacia lateriticola* and *Calytrix sp.*. Four other species associated with upper slope outcrops were also found in the granite rubble soil of the *Calothamnus quadrifidus* thicket near site 27. Outcrops had the greatest number of species of all the communities sampled and a total of 39 species was recorded from the three transects on the summit and North and East slopes (transect nos. 13, 9 & 12 respectively) of a large outcrop on the south bank of Oakley Brook (Fig. 2.4.2-1).

The survey yielded a total of 74 shrub and perennial herb species in the understorey, while five tree species formed the canopy of the woodlands in the vicinity of the transects.

2.4.2.4 GENERAL COMMENTS

The Oakley Brook study area contains a variety of communities and a relatively large number of tree and shrub species coexisting in a small area (approx. 1 $km^2$). This is in marked contrast to the situation on the Pinjarra plain surrounding the refinery on the North, West and South sides, where clearance has removed most of the natural vegetation, leaving a Man-made agricultural landscape poor in native species. A consequence of this is that there are few remaining native plants suitable for use as indicators of environmental change, although it is fortunate that Blackboy (*Xanthorrhoea preissii*) is still abundant and widespread in these areas. More detailed study of the tree and shrub species occurring along Oakley Brook may reveal several other indicator species which could be monitored together with the lichens of the area.

Apart from its role as a reserve for known and potential indicator species, the study area contains some intrinsically important species. One is the large *Calothamnus* of the higher parts of the valley which appears to be an undescribed species; it is remarkable that such a conspicuous plant should have been overlooked in a site so close to Perth, but this may mean that it is a rare species of limited distribution, in which case the large populations observed in the valley are of great conservation importance. The taxonomic survey and revision of the genus *Calothamnus* currently being undertaken by Mr. T. Hawkswood of the Botany Department, University of W.A., should soon establish the identity and distribution of this species. Another interesting species occurring in the study area, is *Eucalyptus laeliae*, of which a single individual was observed by the brook near the foot of the scarp. It is one of the most recently described eucalypts in W.A. and was earlier confused with the powder-bark wandoo, *E. accedens*. It is limited to laterite-free soils in the Darling Range. The tree is characterised by its striking clear white bark and is of considerable horticultural importance, especially as the branches often have a drooping habit (Anon., undated) as is the case of the individual at Oakley Brook. The preservation of this tree as a source of seed for propagation is recommended.

A rare shrub, *Agonis grandiflora*, which is restricted to rocky soils along the Darling scarp between Lesmurdie and Harvey (Erickson *et al.*, 1973), may occur in the study area, although it was not located during the survey. In order to gain detailed knowledge of the Oakley Brook flora, it would be necessary to carry out a more thorough investigation of the area, preferable in spring or early summer when flowering material of most species would be available, thus facilitating identification. Such a survey would also encounter annuals and aestivating species (such as orchids) which were not in evidence during the present survey.

In addition to its purely botanical value, the study area is of considerable aesthetic value, by virture of its well-preserved natural vegetation, its varied topography and the presence of an attractive stream.

Maintenance of the natural plant cover of the area would also have the advantage of ensuring the continued supply of water for the reservoir, since disturbance of vegetation in the catchment (of which the study area is a part) may result in silting.

## 2.4.3 VEGETATION OF SELECTED SITES TO THE NORTH AND SOUTH OF THE REFINERY

### 2.4.3.1 DESCRIPTION OF STUDY AREAS

Surveys carried out on 1st September 1979, sampled remnants of the presumed original vegetation of the Pinjarra Plain. Two species lists compiled on Fairbridge Farm land adjacent to the NE corner of the Refinery site revealed a rich shrub and herbaceous flora in a woodland of Jarrah (*Eucalyptus marginata*) with Marri (*E. calophylla*). Two distinct soil types were observed in the area, one being a yellow-grey siliceous sand, the other a lateritic sand containing conspicuous fragments of laterite, indicating derivation from the Darling Scarp. Site numbers applied to these two areas were 98 and 99 respectively (see Appendix 5). Additional surveys were made in similar woodlands to the South of the Refinery, North of Napier Rd (sites 101, 102, 103, 106).

Site 98, a grey sand, yielded a total of 76 species. Of these, 3 were trees, 50 were shrubs or perennial herbs, 15 grasses or aestivating species identifiable only at this time of year when flowering. In addition 8 species of weeds were recorded, indicating the disturbed nature of the site and its proximity to cleared, farmed land. The total of 53 species of trees, shrubs and perennial herbs compares well with figures obtained from the Oakley Brook sites (see Figure 1). The canopy of Jarrah and Marri had been thinned by partial clearing and was in a rather degraded state, but the understorey appeared to be relatively undisturbed. Major understorey species included *Casuarina humilis*, *Stirlingia latifolia*, *Bossiaea eriocarpa*, *Dasypogon bromeliifolius*, *Conostylis spp.*, *Xanthorrhoea preissii* and *Lechenaultia biloba* (see Appendix 5).

The lateritic sands of site 99 were encountered North of the pumping station. Although contiguous with the preceding site, there were several major differences; the canopy was more dense and about half the understorey species had not been encountered in site 98. The understorey was dominated by *Hibbertia hypericoides*, *Baeckea camphorosmae*, *Grevillea wilsoni*, *Bossiaea ornata*, *Lechenaultia biloba* and *Pimelea* *suaveolens*. *Kingia australis* was more common in the understorey than *Xanthorrhoea preissii* (see Appendix 5). Of the 59 species recorded, 2 were trees, 44 were shrubs or perennial herbs and 13 were grasses or aestivating species.

Other species lists were compiled for a number of sites to the South of the Refinery, North of Napier Road. A distinction was again made between lateritic and non-lateritic sands and the resulting species lists are presented in the accompanying combined list (Appendix 5). Surveys in these Southern sites were generally more cursory than in the NE areas described above and this is reflected in the lower species totals obtained, although the greater density of the canopy in all the Southern sites may also have contributed to the decrease.

The classification of species into the categories: trees, shrubs, etc., is given on the accompanying list. In all cases shrubs and perennial herbs formed the most important component, contributing 66-83% of the species total. Again, the shrub totals are comparable with those of Oakley Brook.

The combined total for all sites is 118 native species and 11 weeds. The areas visited are of conservation importance as reserves of derivatives of the original vegetation of the refinery site and adjacent land, and can also be viewed as the sources of potentially useful indicator species.

## 2.5 SYMPTOMS ASSOCIATED WITH SULFUR DIOXIDE AFFECTS

### 2.5.1 Symptoms reported elsewhere

Reviews of sulfur dioxide toxicity in higher plants (Guderian, 1977; Wellburn *et al.*, 1976) and in lichens (Ferry and Baddeley, 1976; Nieboer *et al.*, 1976) indicate that loss of chlorophyll and impaired photosynthesis is common to each, with obvious discoloration occurring in most cases. However, lichens may first respond to low levels of sulfur dioxide by altered reproductive behaviour, for example, failure to produce spores, failure of spore germination, or an increase in vegetative reproductive structures such as isidia. For a discussion of sulfur dioxide effects on man, animals, and inanimate objects, the reader may consult Liu and Yu (1976).

### 2.5.2 Higher plants

Higher plants outside the Refinery site itself did not show any obvious evidence of damage from stack emissions. Some episodic, rather than chronic, damage to *Eucalyptus* and *Acacia* species was observable to the South of the stack (Site No. 36). This was undoubtedly due to a recent single, or a few closely spaced, episode(s) of fumigation. The damage caused was consistent with sulfur dioxide effects. *Eucalyptus* species exhibited a marked interveinal bifacial chlorosis of the older leaves, particularly on the North side of the tree. More severe effects resulted in areas of leaf margin necrosis, in some cases, extending over the entire leaf, with leaves eventually falling.

The episodic nature of the event, with fairly clear evidence that this was a single occurrence, was also observable in the

*Acacia* species affected. In this case the loss of chlorophyll proceeded from the leaf tip with an associated reddening of the leaf. Leaf fall was observable in the most severely affected plants. Again the effect was not observed in the younger leaves.

In each case the symptoms described are considered typical and are illustrated in Plates 2.5.2-1 to 5.

From the observed pattern of symptoms and the otherwise good health of the trees in this area it is apparent that this leaf damage resulted from a rare event. It seems unlikely that further damage in this area would occur with a doubling in stack height.

It was considered to be of some interest to transplant a sensitive species to a site of similar proximity to the emission source. For this purpose, *Subterraneum trifolium* cv. Seaton Park was transplanted, in 3 kg pots, to Site No. 21, which is within 200 m of the emission source. The period of observation reported here is from 12th April to 16th September 1979. During this time only marginal signs of toxicity were observed (see Plates 2.52-6 to 7). While the leaf illustrated (Plate 2.5.2-7) shows a pattern of chlorosis consistent with sulfur dioxide damage, only very few leaves were similarly affected and, as of 16th September, these transplants were thriving and were flowering normally.

It should be pointed out that during rapid growth of some plants, for example *Eucalyptus* species, a marked bifacial interveinal chlorosis normally occurs, but is associated with the young leaves only. This is illustrated in *E. marginata* leaves from Site No. 1 (Plate 2.5.2-8).

Other symptoms of damage to higher plants within the Refinery grounds were either so marginal as to cast considerable doubt on their origin, or were due to alkali spotting or insect damage. The alkali spotting, while not particularly severe (Plate 2.5.2-9) may foreshadow a more serious problem in which sodium levels may build up in the soil to the point where sodium taken up by the roots will lead to leaf margin necrosis in *Eucalyptus* species, and leaf tip necrosis in other narrow leafed species. This will probably first occur in the small Courtyard in the Administration Building (Site No. 39). Leaf tip necrosis caused by either salt uptake or toxic gases should not be confused with the slight leaf tip necrosis which is normal in many W.A. native species.

In conclusion it is suggested that while sulfur dioxide seems unlikely to present a significant problem for either the Refinery site or the surrounding area, there may be a restricted problem with salt accumulation in areas subject to alkali spray.

### 2.5.3 Lichens

The only clearly observable influence of emissions occurred with the Refinery site itself at Sites 37-40. The observed effects, loss of chlorophyll and apparent necrosis in *Parmelia* species on rocks, moved to the Refinery in November, 1978 and in March, 1979, are possibly the result of either alkali spray or sulfur dioxide or both. Other lichens present, for example the *Caloplaca* species, appear to be relatively resistant and are apparently undamaged. The discolouration observed in the lichens at Site No. 38 is clearly shown in Plate 2.5.3-1.

It is the opinion of the Consultant that this damage is probably mainly due to alkali spray for the following reasons: (i) alkali spray damage is recognisable in higher plants in this area; (ii) damage of similar species attributed to sulfur dioxide in a separate study does not appear to be similar; (iii) lichen species transplanted in April to Site No. 21 (remote from significant alkali spray) has failed to exhibit symptoms of damage after 5 months' exposure to similar sulfur dioxide levels but much lower alkali levels. While the lichens transplanted to Site No. 21 are not similar species, they were expected to be at least as sensitive to sulfur dioxide.

Other lichens observed to show damage symptoms were apparently influenced by fire exposure from burning-off operations. In only one case was this explanation apparently unsatisfactory. This was at Site No. 96 where *Parmelia rutidota* and *P. subalbicans* growing on *Melaleuca* showed discoloration (browning) and presumed necrosis.

The distribution (presence or absence) of particular lichen species has been treated elsewhere (Section 2.3) since this is not considered a symptom, though it may be symptomatic.

The lichens at Site No. 21 (see Plate 2.5.3-2) were transplanted from Site No. 0 in April, 1979, mainly to establish their suitability as indicator species. They include the following species: *Cladia fernandii*, *C. aggregata, Siphula coriaceae*.

In conclusion it may be stated that, with the exception of Site No. 96, the only damage symptoms observed were to lichens within the Refinery Site itself. This does not, of course, imply that damage has not occurred in the past. Indeed, it is implicit, from the relative absence of certain species from some sites, for example the apparent absence of *Teloschistes* from Site No. 96, that damage might have been observable at an earlier time.

# 3. RECOMMENDATIONS

## 3.1 NATURE OF THE PROBLEM

Ideally, it is required to anticipate potentially harmful emissions, and their effects upon both living and non-living materials. The primary characteristics of any proposed monitoring system are that it be reliable and sensitive to both long and short term effects. Important, but secondary, characteristics are that it should be simple and practical in operation. The area to be monitored, and the time scale involved, should be accurately estimated.

It is intended to discuss the present problem in terms of these aspects, since it is by these critera that a satisfactory monitoring procedure may be decided.

### 3.1.1 Anticipated emitted species

#### 3.1.1.1 Stack emissions

Fossil fuels, in addition to the major hydrocarbon fractions, contain sulfur and nitrogen containing compounds, metals and metalloids. When burned in combination with other non-fuel substances, species such as halogens may reach high levels; fluoride emissions are an example of this. In the present case it seems unlikely that species other than sulfur dioxide would present a problem and even this emission is in the very low level category in terms of biological sensitivities. Mechanical damage to either vegetation or animals by particulate emissions can be safely excluded on the basis of the present operation which seems to be effectively managed in this regard. While metals, metalloids or halogens should not be excluded, there is no present evidence to suggest that these present a significant problem.

It is concluded that the primary effort should be directed towards the monitoring of sulfur dioxide but with some consideration being given to the monitoring of other effects, such as those of heavy metals, on a long term basis.

3.1.1.2 Other emissions

These include dust, heavy metals, alkali and salt. Although the salt has its origin in the alkali, their effects are quite distinct. The control of dust at this site, appears to be extremely effective. No evidence of heavy metals is present but neither would this be expected because these do not produce visible symptoms unless present at grossly abnormal levels.

It is concluded that alkali is a minor problem which is restricted to the Refinery site (see Section 2.5). Over the longer term, accumulated sodium may lead to salt effects in plants. Animals, including man, would certainly not be affected. The greatest potential concern may be the possibility of heavy metal accumulation associated with alkali spray. However, this would only be expected to the extent that residual catalyst is present in the alkali used.

3.1.2 Anticipated effects of emissions

The only significant chronic effects anticipated are those due to sulfur dioxide and, at the levels encountered, these should be restricted to only the most sensitive plants. It is in fact doubtful if any plants other than lichens or mosses in the immediate vicinity of the Refinery (within about 1 km) could be affected at the levels encountered. It is not suggested that fumigation damage of the type already described (see Section 2.5) may not occur again. However, it would be expected to be a rare event which would occur (on the basis of the past experience and the increase in stack height), within a radius of 1,000 m, and would not be as severe as the particular event already reported.

It is concluded that chronic effects will not be readily observable except for the case of sulfur dioxide and even then only in a very restricted range of plant species such as the lichens.

3.1.3 Anticipated area for monitoring

The area for monitoring must include the area within which effective levels of emitted species can be expected to occur. However, the complete inclusion of marginal but sensitive regions such as distant townsites is obviously desirable. The definition of this area may be based upon the predictions of a previous report (Dames and Moore, 1977), with some consideration being given to any shortcomings which may have become evident.

The present Consultant is of the opinion that it is reasonable to accept, for monitoring purposes, the area over which the ground level concentration factor, C' (see Glossary), is expected to exceed about 1.5 $\mu g/m^3/g/sec$. Estimating on the basis of the Dames and Moore (1977) Report, the boundary of the monitored area is at about 3,000 m from the centre. The value of C' = 1.5 permits a 100% safety factor with respect to the calculated value for $C'max_1$ of 3.09, where $C'max_1$ = maximum permissible one hour concentration factor (see Glossary).

It might be expected that a further extension of the monitored area would supply a further useful safety factor. However, the following points should be considered.

(i) The geometry of a larger monitored area may demand a greater number of monitor sites than is considered either feasible or necessary. For example, inspection of the distribution of ground level concentration estimates (see Dames and Moore, 1977), and of the stack plume observation data in the present report, shows quite clearly that about 500 m is the maximum practical interval between monitor sites, and eight is certainly the minimum number of directions for monitoring.

(ii) The present survey indicates that effects would not be expected in vegetation at as great a distance as 3,000 m.

(iii) Sensitve sites such as townsites which are beyond this range of 3,000 m should in any case be monitored.

(iv) Provided that monitor stations are readily moved, assessment of the monitored area by instrumental checks can be used to quickly correct any serious errors in the estimation of the area for monitoring.

(v) It should be recalled that even marginal long-term effects on sensitive species are a result of very high peak values (see for example, de Wit, 1977) which will not occur at distances remote from the emission source.

(vi) There is little point in setting up monitor sites unless a significant number can be expected to yield positive results. Unless a significant number of sites can yield positive results in a recognizable pattern which is relatable to the emission source, the validity of the entire monitoring system is likely to be quite properly called into question.

(vii) The control monitoring sites together with those associated with other sensitive sites (for example, Pinjarra townsite) would certainly be expected to supply sufficient negative data to fulfil the requirement to demonstrate areas not affected by emissions.

It is concluded that, ideally, the primary monitoring sites should have a radical distribution in each of eight equidistant directions, and should occur at about 500 m intervals to an outer limit of 3,000 m. Sensitive areas such as the North and South Pinjarra Townsites should also be monitored at selected sites. Consideration should also be given to monitor sites on the present property boundaries. Further specification of the monitor sites is considered in connection with the selection of the monitoring system.

3.1.4 Anticipated time-scale for monitoring

The time over which monitoring is desirable is difficult to assess, but there is no doubt that there is a requirement to be aware of both long-term and short-term effects. The long-term should certainly extend over an entire human generation which, while it may be variously described, may be considered as 25 to 32 years.

The short-term effects are perhaps properly gauged in terms of the growth periods of annual plants and/or, the periods over which these reproduce. This will vary according to species but a period of less than 4 weeks seems unnecessarily short. Without anticipating instrumental methods, no consideration can be given to the shorter time scales of significance to animal or human health. However, it would appear that adequate provision has already been made, using a continuous monitoring procedure.

It is concluded that the time-scale for monitoring should extend for periods ranging from about 4 weeks to not less than 25 years.

3.1.5 Reliability and practicality of the monitoring system

Reliability refers to continuous operation at the level of performance expected. The time-scale of operation must be considered in relation to this question.

Practicality refers to the time, effort, expertise, and expense of initiating and operating the system. Simplicity is a valuable characteristic insofar as unsophisticated systems tend to be operationally reliable and permit reasonable flexibility in choice of operating personnel.

The Consultant has no hesitation in concluding that no single monitoring system will fulfill all of the criteria. However, the use of lichen indicator species will certainly provide adequate monitoring of sulfur dioxide in the long-term, and would also approximate the short-term requirement. The further requirements not met by the use of lichens will be discussed following the next section which deals with the proposal for a lichen-based monitoring of long-term, and short-term, sulfur dioxide effects.

## 3.2 LICHEN-BASED MONITORING OF SULFUR DIOXIDE EFFECTS

### 3.2.1 General suitability of lichens

Some, but not all, lichens have a broad spectrum of sensitivity to air pollutants and most have an extraordinary level of resistance to physical and biotic factors such as heat, desiccation, potential pathogens, and grazing animals. Thus, while lichens need be accorded the most minimal of care, they may be extremely sensitive to emitted species such as sulfur dioxide, fluoride, and heavy metals.

For the present purpose it is proposed that selected lichens should be adapted for the monitoring of sulfur dioxide and also serve as useful indicators of other possible emissions such as heavy metals. The manner in which lichens might be utilized for these purposes is discussed in the following section.

### 3.2.2 Options for the use of lichens for air quality monitoring

The range of possible options are many, but only those considered to have practical application will be discussed here.

#### 3.2.2.1 The choice between indigenous and transplanted lichens

The following points should be considered.

(i) Past agricultural influences have resulted in an absence of suitable indigenous species in all but a few locations.

(ii) Comparisons based upon natural communities within a relatively small area where soil types and substrates are not comparable cannot provide reliable data.

(iii) Despite the above limitations, there will always be considerable interest in indigenous communities, particularly where these are as significant as in the area to the East of the Refinery.

It is concluded that while indigenous species should be regularly surveyed in certain selected areas, the basic monitoring system should rely upon transplanted species.

3.2.2.2 Distribution of monitoring sites

Permanent quadrats should be established for both indigenous communities and transplants. The selection of quadrats for the existing communities is based upon assumptions about relative sensitivities, existing community diversity, and general suitability for long-term surveillance. The recommended locations are indicated in Figure 3.2.2.2-1. The selection of transplant sites is in accordance with the distribution considered most suitable from the points of view of geometry, topography, exposure, and accessibility (see Figure 3.2.2.2-2). The choice of directions, intervals, and range was previously discussed in Section 3.1.4.

3.2.2.3 Frequency of examination of quadrats and transplants

Indigenous species do not require frequent examination and it is suggested that, because of seasonal growth patterns, this might be done in August or September only.

Transplants require, in the initial stages, regular examination at about 30 day intervals for at least the first 3 months after transplanting and for at least the first 3 months following the opening winter rains. The intervals between examinations could then be increased to perhaps 60, or even 120, days depending upon the outcome of initial observations.

3.2.2.4 Parameters to be surveyed

For the present purposes, lichens should be used both as biological indicators and as chemical traps which are sampled and chemically analysed.

Indigenous species should be examined both as communities and as individual species. Specifically, the individual species should be estimated according to the Braun-Blanquet Scale (see Glossary) and the community estimated according to the Index of Atmospheric Purity (see Glossary). It would be useful, but not absolutely essential to photograph the members of the community at each examination. It is, of course, essential to obtain initial photographic records.

Transplanted species should be examined for all visible changes, especially those involving colour, growth rate, and reproductive structures. Carefully standardized photographic records should be obtained on each occasion. It would also be useful to sample at longer intervals, probably annually, for sulfur and heavy metal analysis. Suitable techniques employing X-ray Fluorescence and Atomic Absorption are currently under investigation with respect to minimizing the sample sizes required.

### 3.2.2.5 Assessment of monitor sites by instrumental methods

The validity of the proposed pattern of monitor sites should be subjected to an early check by instrument monitoring of sulfur dioxide along sample transects. This could be accomplished in a few days since it will be rapidly obvious if the pattern is inadequate. Ideally, this check should precede siting of transplants.

### 3.2.2.6 Choice of species and transplant procedures

The choice of indigenous species for inclusion in quadrats is obviously restricted. However, there appear to be a number of species which should be sensitive to sulfur dioxide. These include species of *Parmelia*, *Usnea*, *Heterodea*, *Caloplaca*, and *Cladonia*. However, given the very low levels of sulfur dioxide and the location of these species, it is not expected that any toxic symptoms will be observed.

Species for transplantation are selected on the basis of their presumed sensitivity to sulfur dioxide, preferred substrate, and availability. The proposed species (see Table 3.2.2.6-1) include an *Usnea*, which is found in the vicinity of the Refinery, and one other, *Usnea barbata*, which is obtainable from the Eastern wheat-belt. Both are lignicolous and therefore particularly suited to long-term transplanting.

It is also recommended that terricolous species would be valuable so that some assessment of uptake from ground-level fall-out could be made. The latter are perhaps of more significance to the question of heavy metals. It is proposed that *Cladia fernandii* and *Siphula coriaceae* be employed for this.

There is ample evidence from both the literature and local observations to suggest that *Usnea* species will be a good choice for the monitoring function. There is no data to support the assumption that the *Cladia* and *Siphula* species will be similarly appropriate. However, these seem to be evident only in pollution-free areas, and their growth habits and morphology suggest that they might in fact be peculiarly sensitive. The use of saxicolous species has also been considered and it is strongly recommended that a sensitive *Caloplaca* species, *C. aurantiaca*, be employed.

The use of further indicator species would also be of some interest and, while not strictly necessary, would have a negligible effect on the cost of setting up the total system.

The transplant procedures for epiphytes present no difficulties as these have been extensively used elsewhere (see for example, de Wit, 1976). Procedures already tested for terricolous and saxicolous species seem appropriate. Lichens with the associated surface soil layer or rock fragment are simply transferred.

The attachment of the lignicolous species at about eye level (1.6 m) to a board, which is, in turn, attached to a fence post, would be both appropriate and convenient. The terricolous and saxicolous species, in a fibre glass container, should be attached to the post top. While it is true that this will not represent actual ground-level fall-out, the post-top is preferred because of better standardization of exposure and protection from fire.

It is concluded that suitable lichens are available for use as indicator species, and that the methods proposed are applicable. However, some initial assistance with instrumental monitoring will be necessary.

3.2.2.7 Relating of toxic symptoms to atmospheric concentration of emissions

A great deal of effort has been directed towards the relationship between symptoms and experimental dosage. For a review of experimental procedures, Richardson and Puckett (1973) can be consulted. In the present case it is considered that the investigation of symptoms prior to the field observations would be premature. However, it is recommended that the sulfur dioxide sensitivites of the proposed indicator species be ranked at an early stage. This may, or may not, prove to be of value in early recognition of symptoms in the field. The point which should be emphasised here is that the accurate interpretation of any symptoms seen in the field will require investigation after the fact and an initial experimental approach, other than to rank sensitivites, would not seem appropriate. In this regard it should be remembered that for very low levels of sulfur dioxide, which is the present case, gross symptoms of the kind obtainable by a short experiment, will probably not be seen. It is more likely that the effects will be subtle, probably involving some aspect of reproduction or growth rate, and are not likely to be observed in any initial experiments which are necessarily constructed in an arbitrary, albeit scientific, manner.

It is concluded that a sensitivity ranking of the suggested indicator species (Table 3.2.2.6-1) be experimentally obtained at an early stage, but that attempts to relate field symptoms to emission concentrations cannot be undertaken usefully until field data is obtained.

## 3.3 HIGHER PLANT-BASED MONITORING OF SULFUR DIOXIDE EFFECTS

The use of higher plants as indicator species in an area of very low sulfur dioxide levels cannot be recommended. However, the following comments may be considered.

(i) Future occurrences of damage symptoms of the type reported (Section 2.5) cannot be excluded but other than observation of planted and indigenous species there is no adequate monitoring system involving higher plants which can be recommended.

(ii) While no damage symptoms are likely to be observed, there does appear to be some merit in the use of a species of local agronomic significance such as clover.

(iii) The use of a rapidly growing higher plant species would give a more rapid visible response than lichens, thus giving shorter term monitoring than could be obtained with lichens. The frequency of examination would probably need to be weekly.

(iv) Bearing in mind that a response is only likely in the case of severe fumigation, the use of higher plant indicator species at, or near, the boundaries of the fenced Refinery site itself might be appropriate.

(v) The species and procedure tested (Section 2.5), is recommended as appropriate if it is decided to employ transplants.

It is concluded that there are significant arguments both for and against the use of higher plants as indicator species. However, there seems little justification in their use where there is an adequate lichen-based monitor system.

## 3.4 FURTHER COMMENTS ON MONITORING REQUIREMENTS

Some consideration could be given to occasional checks on sodium levels in leaves of planted species, for example *Eucalyptus*, in and around the Refinery site itself. Higher plants are, of course, more suitable for the monitoring of mobile metals such as sodium. Heavy metals are not sufficiently mobile for higher plants to be similarly useful for these.

The suggested reliance upon visible symptoms in transplanted lichens together with the chemical analyses recommended should prove to be a useful procedure for both the specified emission and any which may not have been anticipated, since lichens tend to have a wide spectrum of sensitivities to toxic chemicals (see for example, James, 1973).

Although farm fence posts have certain limitations, their use for monitoring sulfur dioxide effects should certainly be considered. In most regions of the property surrounding the Refinery, the older posts are frequently well colonized with *Parmelia* species, and in many cases *Usnea* species. The similarity of microhabitat should enable comparisons between posts at different locations.

## 3.5 SUMMARY OF RECOMMENDATIONS

Criteria for emission monitoring and the general suitability of lichens and higher plants are discussed. It is recommended that permanent quadrats be established for surveillance of indigenous lichens. It is further recommended that lichen transplants be employed to establish a grid of monitor sites for sulfur dioxide and possibly other potentially significant emissions. Ranking of potential indicator species by experimental fumigation is suggested but no initial attempt to establish the relationship between sulfur dioxide concentration and toxic symptoms is recommended.

Higher plants are not recommended for use as indicator species but it is acknowledged that there is possibly some point in the use of species of agronomic relevance to the study area.

# GLOSSARY OF TERMS

Abundance: cover (see Braun-Blanquet Scale).

Aestivating: appearing in Summer (or Spring).

Affinity Index (A): similarity assessment of similarity between communities. $A = \frac{c}{a \times b}$, where a = number of species in first community, b = number in second, c = number common to both.

Apothecia: a flat or cup-shaped fruiting structure (apothecium = singular).

Braun-Blanquet Scale: six category scale for estimating cover and abundance of a species in a record + (<1%), 1(1-5%), 2(6-25%), 3(26-50%), 4(51-75%), 5(76-100%).

$C'\ max_1$: maximum permissible hourly average of C'.

C': ground level concentration factor for sulfur dioxide (see Dames and Moore, 1977).

Chlorosis: yellow colour due to loss of chlorophyll.

Cortège Moyen Specifique (Fr.)(CMS): mean number of lichen and bryophyte species growing with a particular species in the survey area; used in calculation of Index of Atmospheric Purity.

Corticolous: growing on or inhabiting bark.

Crustose: having a thallus which is a more or less inseparable crust on the substratum.

Ecotone: boundary line or zone between two communities.

Edaphic: concerned with the soil.

Epilith: an organism which lives upon a rock.

Epiphyte: an organism which lives upon a plant.

Eutrophiation: enrichment with nutrients and a buffering of pH.

Farinaceous: mealy (dry and powdery) in appearance.

Foliose: leaf like and usually attached by the lower surface.

Fruticose: erect or pendent and attached only at the base.

Fumigation: (i) subjecting of material to fumes as in a fumigation trial to assess sensitivity of species to toxic fumes; (ii) descent of a stack plume to the ground within a short distance of the stack, resulting in high ground level concentrations of plume gases.

Heavy metals: high atomic weight metals such as lead, cadmium and mercury, which are frequently considered as a group because of their high toxicity.

Higher plant: Plants higher on the evolutionery scale than lower plants. The former includes grasses, herbs, trees; and the latter includes fungi, algae, lichens, liverworts, mosses.

Index of Atmospheric Purity (IAP):

$$IAP = \frac{n}{100} (\Sigma_n^1 Q \times f), \text{ or } \Sigma_n^1 (Q \times f)/10$$

where f = frequency of each species at the site,

n = number of species at the site,

Q = CMS.

Index of Lichen Abundance (ILA)

$$ILA = \Sigma_n^1 = (\frac{Q_a}{Q_s} \times c) \times 10$$

where c = cover on scale chosen by investigator,

n = number of species at site,

$Q_a$ = average number of species growing with a species, regardless of substratum,

$Q_s$ = average number on the substratum under consideration.

Indicator species: a species whose presence or absence shows whether or not particular conditions prevail or have prevailed at a site.

Indigenous: belonging naturally, as in ∿ to the region.

Interveinal: between the veins, as in the veins of a leaf.

Isidia: minute outgrowths on the thallus associated with vegetative reproduction (isidium = singular).

Lecanorine: term applied to an apothecium with a thalline margin as in the genus *Lecanora*.

Lecideine: term applied to an apothecium with only a proper margin as in the genus *Lecidea*.

Lichen: a plant-like association between a fungus and an alga or blue-green alga.

Lichen desert: area affected by pollution source from which all lichens, or at least all macrolichens on trees, are absent.

Lichenicolous: growing on lichens.

Lignicolous: growing on decorticate wood.

Moribund: dying.

Microhabitat: particular ecological niche within more broadly defined habitat, e.g. bank crevice, rock overhang.

Minimal area: the least area which includes all characteristic species of a community.

Morphotype: morphologically differentiated groups of specimens of a taxon, of undetermined or no taxonomic importance.

Muscicolous: growing on or over mosses.

Necrosis: death of cells or tissue, due to any agency.

Papilionaceae: family of plants having the butterfly-like flowers characteristic of peas, beans, etc.

Pasquill stability classes: a classification of atmospheric stability which relates to the tendency of stack plumes to move up or down (e.g. as in looping or fumigating). A, extremely unstable; B, moderately unstable; C, slightly unstable; D, neutral; E, slightly stable; F, moderately stable.

Permanent quadrats: marked out quadrats studied over a period of time.

pH: measure of acidity or alkalinity.

Phorophyte: the host tree of an epiphyte.

Polymorphic: occurring in a variety of morphological forms.

Proper margin: an apothecial margin not containing algal cells, which is frequently the same colour as the disc and different from the colour of the thallus.

Quadrat: a circumscribed area for sampling or study.

Record: (1) list of species in a community with degrees of presence (phytosociological); (2) report of a species from a particular locality (biogeographical).

Rhizinae: hair-like organs of attachment on the lower surface of the thallus.

Richness Index (RI): $RI = \frac{\text{number of genera} \times 10}{\text{number of species}}$

Saxicolous: inhabiting rocks.

Senescing: deteriorating in association with old age.

Silicolous: growing on siliceous rocks.

Skiophilous: (sciophilous): shade-loving.

Soredia: powdery granules which are associated with vegetative reproduction.

Species-area curve: graph of number of species found against size of area surveyed: used to determine minimal area.

Substrate (or Substratum): material base upon, or within, which an organism grows.

Terricolous: growing on the ground.

Thallus: the plant-like body of a lichen; may be crustose, foliose, or fruticose.

Transect: a line or narrow belt, along which sampling is carried out.

Transplant: material moved in a living state, with or without its immediate substrate, to a new site.

Xeric: pertaining to a limited water supply or drought conditions.

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# ADDENDA

System 6 Update - Floristic Community Type Mapping Information DRAFT ONLY

## AREA INFORMATION

System 6 Area (C or M) or Update Area (Update) PINJARRA

| | |
|---|---|
| Conservation Area | |
| Nature Reserve | |
| Reserve No | |
| National Park | |
| Reserve No | |
| Local Government | |
| Reserve No | 41184 lot 348 |
| Other | NPNCA |
| Proposed Conservation Areas | |
| Local Government | Shire of Murray |
| Reserve No | 34033 |
| Other | DOLA lot 324 · VCL |

Conservation Area

| | |
|---|---|
| Nature Reserve | |
| Reserve No | |
| National Park | |
| Reserve No | |
| Local Government | |
| Reserve No | |
| Other | |

## TOTAL AREA

| | |
|---|---|
| Bushland Area | hectares |
| Completely Degraded | |
| | |
| | |

## AREA MAPPED FLORISTIC UNITS

| Units | Site (Condition) Code | Bound | Area (ha) |
|---|---|---|---|
| | NO SITES | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Boundaries determined by use of

| |
|---|
| aerial photograph |
| orthophoto |
| vegetation map |
| soil map |

Calm map PINJARRA

## PINJARRA1 INTERIM PROTECTION AREA

extracted from Keighery, B.J. and Trudgen, M. (1992) Remnant Vegetation on the Alluvial Soils of the Eastern Side of the Swan Coastal Plain

**Location 38 - Phillips Rd, Industrial Area west Pinjarra,** FIG 19, Photos 20-24.

**Veg: r LF, m W, b W & WM (mi LHt, me Ht, H & S) Cond: Good**

GENERAL COMMENTS

This Location is at the junction of Bassendean Sand and the Pinjarra Plain. The area to the north of the block, adjacent to Pinjarra Rd, is apparently a continuation of the Bassendean Sands wetland to the north of the road. The area to the west of Phillips Rd shows the greatest affinities with the wetlands of the Pinjarra Plain by the presence of *Kingia* to the west of Phillips Rd. The vegetation in the Bassendean Sands section of the Location is Mixed Low Open Heath with scattered *Melaleuca preissiana*.. This area is a recorded site for of the DRF, *Diuris purdiei*. This Location is generally in Good Condition with severe localised disturbance The associations of the Pinjarra Plain flats present at this Location are: *Melaleuca* Open Heath, Melaleuca Open Scrub, *Pericalymma ellipticum* Open Heath, Herblands and Sedgelands. The flora of the Location was minimally assessed as the Location was visited in Winter when the area was under water. To the east Flooded Gum Low Forest is found.

This Location is generally in Good Condition with severe localised disturbance due to ;

- tracks associated with 3 SEC transmission lines (Photo 22), weed infestation along the tracks and line, evident on the aerial photo. These weed species are unknown as the wetland at the time of inspection was innundated with water to 1 m deep.
- roadsides very infested with **Eragrostis curvula*
- much of the area to the west of Phillips Rd is in Poor to Very Poor Condition, with patches in Good Condition.

**Site 38a**

**me Ht (H, S)** ***Melaleuca uncinata, M. polygaloides,Pericalymma ellipticum* and *Kunzea recurva* Open Heath over *Leptocarpus coangustatus* and *L. canus* Sedgeland .**

Comments:

The *Melaleuca uncinata, M. polygaloides*, and *Kunzea recurva* occur in very dense patches at times there are patches bare of these species and the *Leptocarpus coangustatus* and *L. canus* occur alone.

Shrubs: 4#*Melaleuca uncinata*, 4#*M. polygaloides*, *Pericalymma ellipticum*, 4#*Kunzea recurva*, 4#*Melaleuca lateritia*, *Hakea varia*, 5#*H. ceratophylla*, *H. sulcata*, *Viminaria juncea*, *Xanthorrhoea ?preissii* and *Calothamnus lateralis*
Adjacent *Melaleuca pauciflora*

Herbs: *Cassytha* sp, *Triglochin procera*, *Conostylis aculeata*, *Tribonanthes 'purple'*, *Villarsia* sp

Sedges: *Leptocarpus coangustatus* , *L. canus*, 4#*Mesomelaena tetragona*

CONDITION **Good**. This is conditional because of the presence of free water, unburnt for a considerable period as the *Melaleuca uncinata*, *M. polygaloides*, and *Kunzea recurva* attained over 2 m..

Aerial Photograph: Run 8 5160
Soils: Flat, dark brown clay sand over clay, P1a (Wells and Hesp, 1989)
Drainage: Poor, water to 4 cm deep
Aspect: Flat

**Site 38b**

**mi LHt** — ***Pericalymma ellipticum* and *Hakea sulcata* Open Heath over Low Open Shrubland over Open Herbland over Open Bunch Grassland over Sedgeland .**

Comments:
The *Pericalymma ellipticum* and *Hakea sulcata* occur in very dense patches at times. Throughout this association are patches of the *Melaleuca* species, *Kunzea recurva* and *Viminaria juncea*. One small patch of *Kingia australis* was found to the W of Phillips Rd. This area has many patches of severe localised disturbance

Shrubs: *Pericalymma ellipticum*, *Hakea sulcata*, *Xanthorrhoea ?preissii*, *Stirlingia latifolia*, *Synaphea* sp, *Daviesia decurrens*, *Hakea candolleana*, *Acacia incurva*, *Dryandra ?sessilis*, 4#*Kunzea recurva*, 6#*Petrophile media* var. *juncifolia*

Herbs: *Conostylis aculeata*, *Stylidium* species, *Patersonia occidentalis*, *Chamaescilla corymbosa*, 4#*Lomandra odora*, *Tribonanthes 'purple'*, *Hypoxis*, Asteraceae species.

Grasses: 4#*Neurachne alopecuroidea*

Sedges: 4#*Mesomelaena tetragona*, *Tricostularia neesii*, *Hypolaena exsulca*, *Loxocarya ?pubescens*, *Lyginia barbata*, *Schoenus* species.

CONDITION
Rating **Good.**
Comments: This is conditional because of the presence of free water retarding the growth of weedy annuals. Many rabbit mounds and associated weedy annuals. Herbs and sedges obviously heavily grazed by kangaroos and rabbits.

Aerial Photograph: Run 8 5160
Soils: Grey brown sandy clay sand, B2/P1a (Wells and Hesp, 1989)
Drainage: Poor, water 1 cm to 2 cm
Aspect: Very gently sloping to the east.

**Site 38c**

**m W** — ***Jacksonia sternbergiana* High Open Shrubland with scattered Marri over *Xanthorrhoea preissii* Open Low Open Shrubland over Low Open Shrubland over Very Open Herbland over Very Open Bunch Grassland over Open Sedgeland .**

Trees: *Eucalyptus calophylla*, *Nuytsia floribunda*

Shrubs: *Hovea trisperma*, *Eriostemon spicatus*, *Bossiaea eriocarpa*, *Gompholobium tomentosum*
Adjacent, towards wetland 4#*Grevillea bipinnatifida*

Herbs: *Conostylis aculeata*, *Stylidium piliferum*, *Phlebocarya ciliata*, *Drosera erythrorhiza*, *D. stolonifera*, *Caladenia* sp, *Burchardia umbellata*, **Hypochaeris glabra*
Adjacent, towards wetland *Burchardia multiflora*, *Tribonanthes australis*, *Hypoxis* , *Sowerbaea laxiflora*

Sedges: 4#*Mesomelaena tetragona*, *Hypolaena exsulca*, *Lyginia barbata*, *Schoenus* species,.*Lepidosperma ?angustifolium*

CONDITION
Rating: **Good**
Comments: Herbs and sedges obviously heavily grazed by kangaroos and rabbits.

Aerial Photograph: Run 8 5160
Soil: Pale grey sand over dark grey sand, B2?P1a (Wells and Hesp, 1989)
Drainage: Well drained
Aspect: gentle E facing slope

<u>Site 38d</u>
**mr OSc** ***Melaleuca raphiophylla, M. polygaloides*, and *M. viminea* Open Scrub with scattered *Eucalyptus rudis* over Lepyrodia *muirii* Open Sedgeland .**

Trees: *Eucalyptus rudis*

Shrubs: *Melaleuca raphiophylla*, 4#*M. polygaloides*, *M. viminea*

Herbs: *Cassytha* sp (10%-20% cover)

Sedges: *Lepyrodia muirii*
To the east of this area there is apparently a ***Eucalyptus rudis* Low Forest**. This was not visited due to the increasing depth of water.

CONDITION
Rating: **Good**
Comments: This is conditional because of the presence of free water. The height of the shrubs, >2 m indicates that the site has been unburnt for a considerable period. the *Melaleuca viminea* and *M. polygaloides* reach to 3 m.

Aerial Photograph: Run 8 5160
Soil: B2/P1a (Wells and Hesp, 1989)
Drainage: Poor, water to 1 m deep
Aspect : Flat

20/11/95

## REPORT ON BIRD SPECIES SEEN AT PINJARRA

On 17 November, 1995, Margery Clegg and Bryan Barrett of the WA branch of the Royal Australasian Ornithologists Union, walked in three areas of bush to the north and west of Pinjarra. During the day 33 species were noted, of which the most common species were Western Gerygone, Inland Thornbill and Brown Honeyeater. While we were there few birds called, consequently we think other species may have been present in the dense undergrowth but were not calling.

Walking around Block 1 we felt sure that White-browed Scrubwrens should be present and possibly Scarlet Robins. Some species were common to all three areas. The Aboriginal land and Block 1 were adjacent to each other, being only separated by an open ditch. Birds were seen flying from one to the other and we believe the two should be treated as one from an ornithological point of view.

It should be noted that the summer migrants will be absent for the period of the cold weather, i.e. Shining Bronze Cuckoo, Sacred Kingfisher and Rainbow Bee-eater. Most of the other species noted are more or less sedentary and having taken territory will remain there as long as there is a food supply.

The list of species seen and the areas in which they occurred were:
A = Aboriginal land, B1 = Block 1, P1 = Pinjarra 1.

| | |
|---|---|
| Australian Kestrel | A, B1 |
| Laughing Turtle-Dove | B1 |
| Crested Pigeon | B1 |
| Galah | B1 |
| Red-capped Parrot | A, P1 |
| Port Lincoln Parrot | A, P1 |
| Shining Bronze Cuckoo | A |
| Laughing Kookaburra | P1 |
| Sacred Kingfisher | B1, A,P1 |
| Rainbow Bee-eater | B1, A, P1 |
| Tree Martin | B1 |
| Black-faced Cuckoo shrike | B1, A, P1 |
| Rufous Whistler | B1, A, P1 |
| Grey Shrike-thrush | P1 |
| Grey Fantail | A, B1, P1 |
| Willie Wagtail | B1, P1 |
| Splendid Fairy-wren | B1 |
| Western Gerygone | B1, A, P1 |
| Inland Thornbill | B1, A |
| Western Thornbill | B1 |
| Yellow-rumped Thornbill | P1 |
| Red Wattlebird | B1, A, P1 |
| Brown Honeyeater | B1, A, P1 |
| Western Spinebill | A |
| Striated Pardalote | B1, A |
| Magpie-lark | P1 |
| Grey Butcherbird | A |
| Australian Magpie | B1, A, P1 |
| Australian Raven | B1, A, P1 |

In addition, the following few species were noted either flying over or very close to one or other of the areas:

Little Pied Cormorant
White-faced Heron
Pacific Black Duck
Australian Hobby
White-faced Heron footprints were noted in damp mud on P1.

66 Tudor Ave ...
Riverton 6148

B Barrett

Department of Environmental Protection

**Head Office:**
8th Floor, Westralia Square
141 St Georges Terrace
Perth, Western Australia 6000
Tel (09) 222 7000 Fax (09) 322 1598

**Waste Management Division:**
Ground Floor, 32 St Georges Terrace
Perth, Western Australia 6000
Tel (09) 222 0422 Fax (09) 222 0455
or PO Box Y3030, East, St Georges Terrace
Perth, Western Australia 6832

**Regional Offices:**
Bunbury • Karratha • Kalgoorlie • Kwinana

Shire Clerk
Shire of Murray
P O Box 21
PINJARRA WA 6208

*Your Ref*
*Our Ref* 67/91
*Enquiries* K McAlpine

Attention: Mr B Flugge

Dear Brett

**SYSTEM SIX UPDATE PROGRAMME - FLORA SURVEY INFORMATION**

Thank you for providing permission for our botanical team to survey the bushland on Recreation reserve 34033. As arranged between yourself and Mr Kevin McAlpine of this Department, the bushland in this reserve was visited in August last year with a follow up visit in November.

The botanical survey provides us with information on the natural plant communities found in the area, and their condition. This information is needed to assist the Department of Environmental Protection in its programme to update the conservation recommendations for System 6 and the coastal plain portion of System 1. The main objective of the programme is to ensure that the proposed conservation estate is representative of the ecological communities extant in the region.

As part of this programme the Department has advertised for the public to submit areas of bushland that they consider to be of regional significance. Our botanical team is surveying these submitted areas as well as those it considers may be important based on other factors such as their location and soil type etc. The botanical survey provides us with information on the natural plant communities found in the area, and their condition. Please note that the area is one of many sites that we have surveyed. The fact that we visited and surveyed the site does not indicate that it will necessarily be included in the updated System Six Recommendations.

The update programme has employed the botanical survey methodology used in Gibson et al. (1994), 'A Floristic Survey of the Southern Swan Coastal Plain', to provide the main information base upon which to review the adequacy of the existing System recommendations and to assess other bushland areas.

Two survey sites were located on the reserve and metal fence droppers were left in each corner of the 10 metres by 10 metres square survey sites. We may wish to revisit these sites at a later date, if so, we will contact you prior to our visit. A general description of the vegetation and an assessment of its condition was also completed.

The information collected during the visits will be used to assess the relative conservation values of the bushland areas. The final selections for inclusion in the updated System Six Recommendations will be the best possible examples of bushland containing plant community types that are either unrepresented or poorly represented in the current and proposed conservation system.

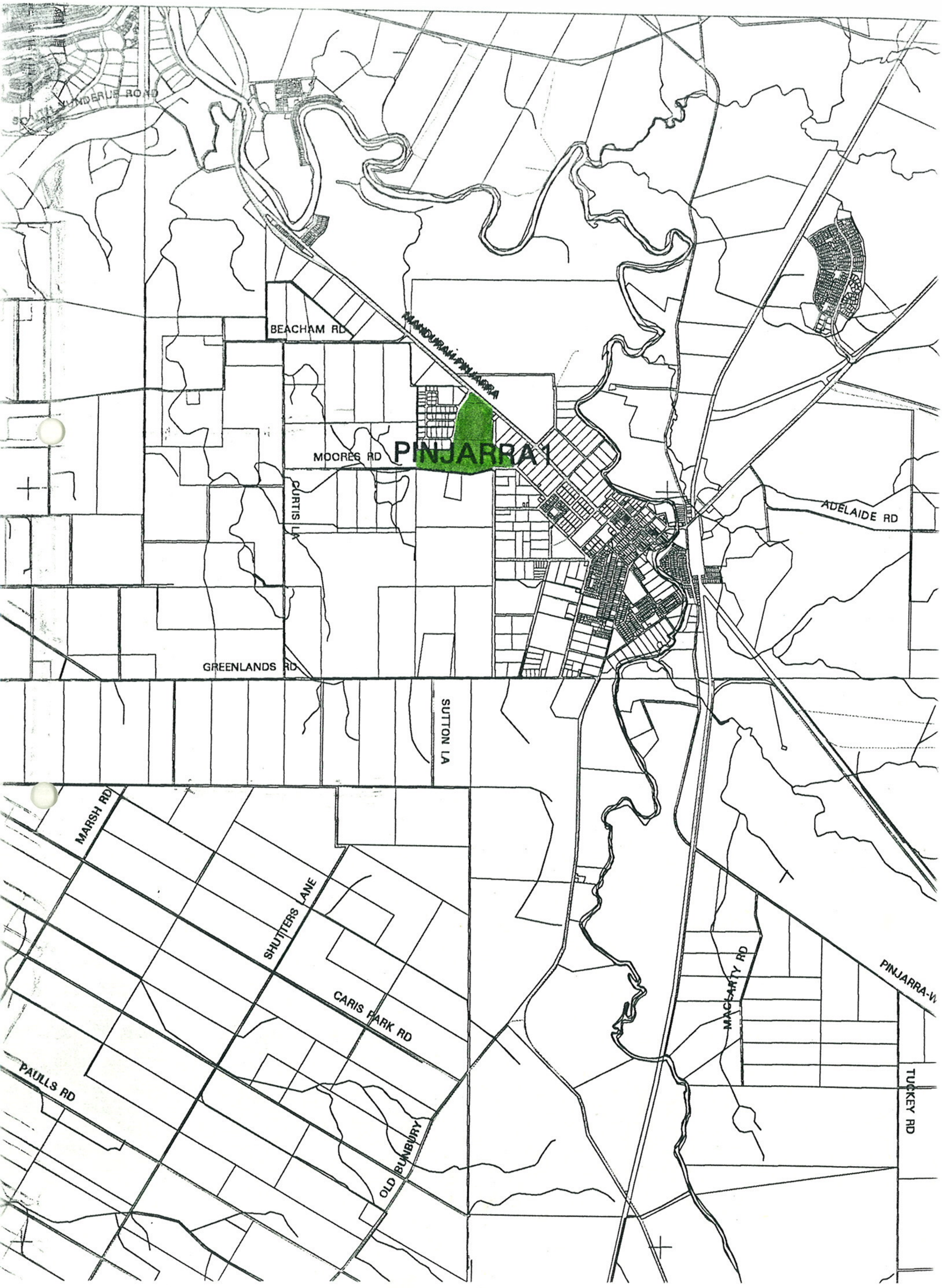
If you are interested in the information we have collected, the location of the survey sites or any other additional information on the System Six Update Programme please don't hesitate to contact Miss Natalie Thorning (222 7051) or Mr Kevin McAlpine (222 7055).

Once again, thank you very much for your support for this programme.

Yours sincerely

G Whisson
A/DIRECTOR
POLICY COORDINATION

11 January 1996



BEACHAM RD
MANDURAH-PINJARRA
MOORES RD
PINJARRA 1
CURTIS LA
ADELAIDE RD
GREENLANDS RD
SUTTON LA
MARSH RD
SHUTTERS LANE
CARIS PARK RD
PAULLS RD
OLD BUNBURY
MACLARTY RD
PINJARRA-W
TUCKEY RD

A 6132 Not Vested
A 34033 Vested Shire of Murray 1984 21 yrs
A 41184 Vested National Parks & Conservation Auth. 1989

PINJARRA I.P.A