Aquatic fauna in Gnangara Mound discharge areas of the Ellen Brook catchment, Western Australia.

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by

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INTRODUCTION

We report here on the physicochemistry, invertebrate fauna, and other noteworthy features of selected springs and wetlands in the western catchment of Ellenbrook valley, from Gnangara Rd to Muchea. In recent years intensive surveys have been carried out on the more coastal wetlands of the Swan Coastal Plain (Balla & Davis, 1993; Davis *et al.*, 1993) and streams of the Darling Scarp (Bunn *et al.*, 1986). Like other parts of the Swan Coastal Plain, the study area contains both temporary and permanent water bodies and, similarly to the Darling Scarp, it contains springs, seepages and runnels ("streams"). But freshwater biology has been neglected in the western catchment of Ellen Brook*. Perhaps this is because nearly all the Ellenbrook wetlands are now either on private land, or in the RAAF Pearce Air Weapons Range. Nevertheless, plant biologists have surveyed this region and found the flora growing on mound springs to be important. The term "mound springs" was first used by early botanists, including C. A. Gardner in 1941 (from WA Herbarium specimen records of *Restio stenostachyus* W. Fitz.), to describe raised areas of boggy peat from which ground water flowed out continuously providing a stable, moist, habitat. In 1983 the significance of mound spring flora was officially recognised in *Report 13 of the Department of Conservation and Environment. Conservation Reserves for Western Australia as recommended by the Environmental Protection Authority. The Darling System - System 6*. The recommendations were: **C25.1** that the W.A. Herbarium survey the area, hold discussions with local land owners, and prepare a report on the conservation of the flora for the Environmental Protection Authority and the W.A. Wildlife Authority; **C25.2** that ways and means of protecting the conservation value of the freehold land be sought through planning procedures to be developed...; also the Conservation Council of W.A. proposed (in Appendix C of the same Report) that the Geological Survey should investigate the hydrology of the area with a view to preventing groundwater intake from affecting the springs. None of these recommendations were adhered to; the subject area was either grazed by cattle, levelled and sealed with limestone for pasture land, or has progressively dried up. One of the aims of the present study was to describe the remnant Ellenbrook

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* To avoid confusion, the *Ellen Brook* river is written as two separate words, while the western catchment of Ellen Brook is referred to, in one word, as *Ellenbrook*.

mound springs, emphasising the fact that they are different structures from the Great Artesian Basin springs which were given the same appellation (Greenslade *et al.*, 1985; Ponder, 1986). We are in the process of describing the structure of the Ellenbrook mound springs (Jasinska *et al.*, in prep.) for which we propose the name *tumulus* springs (from Latin *tumulus* small mound). The general aim, however, was to document and compare the invertebrate fauna of springs with their associated water bodies (runnels or ponds) and of water bodies removed a considerable distance from their source. Then to try and interpret the faunal patterns distribution in terms of interspecific interactions and the physicochemical characteristics of sites.

STUDY AREA

location

The study area is located on the eastern flanks of the Bassendean Dune system and extends from eastern Gnangara Rd (115°57'E and 31°48'S) to Muchea (115°58'E and 31°35'S) (Fig.1). The Bassendean Dunes rise to about 100 m AHD, the highest ridges being just east of the study area. Active groundwater discharge occurs at elevations of 40 to 60 m AHD, giving rise to a north-south line of wetlands. The ground water originates from the Gnangara Mound - an extensive unconfined aquifer reaching up to 70 m AHD: defined north - south by Gingin Brook and the Swan River respectively, east - west by the Darling Scarp and the Indian Ocean. The study sites include swamps, lake, dams, streams and springs on the eastern side of the Gnangara Mound. This is the western catchment of Ellen Brook.

geology

The groundwater discharge points studied here occur at the boundary between the Bassendean sands and the Guildford Formation. Bassendean sands consist of early to late Pleistocene shoreline and dune sands, mainly quartz with most of the calcareous components leached out. The Guildford Formation, sometimes referred to as Guildford clays, is mainly of fluvial origin (Fairbridge, 1953; Gozzard, 1982). The low permeability of the Guildford clays forces ground water to the surface high on the eastern flanks of the Gnangara Mound forming springs, bogs and other wetlands at the discharge points and a series of swamps along the drainage lines to Ellenbrook. There are also sporadic deposits of limestone, three to four metre thick, in the Ellenbrook catchment between Bullsbrook and Muchea. This is the Muchea limestone formed by the precipitation of carbonates from freshwater lakes and springs (Fairbridge, 1953).

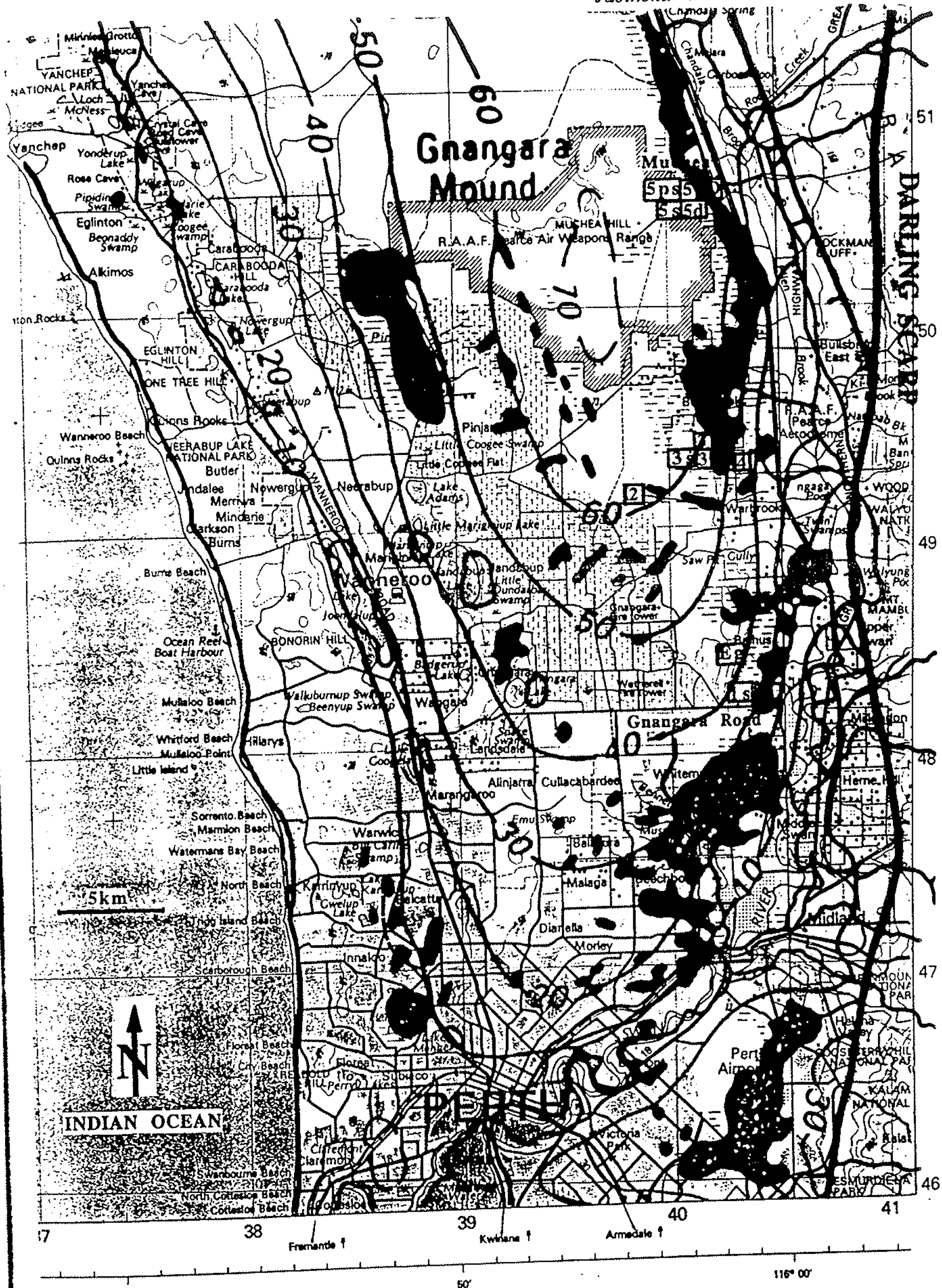

Fig. 1. Location of Ellenbrook study sites with respect to the Gnangara Mound [overlay - modified from Allen (1981)]. Map ref.: SHEET SH 50-14 PERTH.

climate

The climate is Mediterranean, with cool wet winters and hot dry summers. The average annual rainfall for Perth is 870 mm of which about 90% falls between May and October. Temperatures range from a mean winter maximum of 17.9°C (minimum 9.4°C) to a mean summer maximum of 29°C (minimum 17.4°C). The mean annual temperature is approximately 18.5°C (Bureau of Meteorology, Perth).

vegetation and land use

The western-most groundwater discharge of the Ellenbrook catchment occurs on the boundary, or just inside, the RAAF Pearce Air Weapons Range. The RAAF Pearce Air Weapons Range supports native *Banksia menziesii* bushland. From the RAAF Pearce Air Weapons Range boundary to the Swan River tributary there is predominantly rural land cultivated for vineyards, cattle grazing and miscellaneous farming. Highly productive springs typically have been excavated to form farm dams or, together with swamps and smaller springs and seepages, levelled and sealed with crushed limestone (Muchea limestone) resulting in lush green pasture land year-round - with some winter flooding. Semeniuk (1987) calls these seasonally inundated or waterlogged pastures "floodplains and palusplains" respectively. The few remaining areas of uncleared or incompletely cleared wetland vegetation include some swamps, bogs and mound springs with a paperbark (*Melaleuca* spp), black boy (*Xanthorrhoea preissii*) overstorey. The native paperbark understorey consists of a large variety of native plants, from mosses, liverworts and fungi, through to reeds, rushes, and dicotyledons such as *Drosera* and *Darwinia* spp. However cattle and pigs, particularly, have destroyed the undergrowth of most of these paperbark wetlands, allowing grasses and *Isolepis prolifera* (a weed species) to take over.

STUDY SITES

Locations of each of the study sites are indicated in Fig. 1.

The description for each site is structured as follows.

In the case of springs:

i. Location (private or public land, owners, address).

ii. Permanent or seasonal flow.

iii. Spring type using Williams (1983) classification based on flow regimes. **Helocrene** spring: water issues gently from the soil. **Rheocrene** spring: water flowing along a horizontal channel which intersects the ground surface producing a stream. **Limnocrene** spring: water wells up vertically to the ground surface.

iv. Substrate from which the water emerges (such as sand or peat).

v. Surrounding vegetation.
vi. Nearest destination of the spring water
vii. Catchment area (elevation, land use, vegetation).
viii. Other.

In the case of surface water bodies:

i. Location (private or public land, owners, address).
ii. Type of water body (flowing or not; lake, dam, channel/runnel).
iii. Approximate dimensions.
iv. Source of water.
v. Destination of any outflows.
vi. Catchment area.
vii. Immediate surroundings (land use, vegetation, stock access).
viii. Microhabitat where the sample was taken.
ix. Other.

1s: SITE 1 SPRING (Appendix II: Plates 1 & 4)
Edgecombe's Grape Bin, Lot 15 Gnangara Rd, Ellen Brook. Permanent rheocrene spring. Flows along an epiphreatic conduit formed in quartz sand under about 0.15 m of dark, organic soil; intercepted for sampling before the spring emerged at the surface. Within a 30 m wide band of vegetation (consisting of reeds, rushes, bracken ferns, fig, *Eucalyptus* and *Melaleuca* trees) sandwiched between a cow paddock to the west (potentially part of the catchment area) and a lake to the east (into which the spring discharges). Spring about 15 m west of a lake, flowing down the side of a low ridge (crest at about 30 m above lake surface).

1L: SITE 1 LAKE (Appendix II: Plates 1, 4 & 5)
Edgecombe's Grape Bin, Lot 15 Gnangara Rd, Ellen Brook. Permanent lake, boomerang shaped, about 200 - 300 m long about over 1.5 m in depth. Intercepts the water table, receives discharge from 1s and other springs flowing down from a low ridge (≈30 m high) to the west, and also some drainage into the lake probably occurs from a hill with a vineyard (eastern border). About 50% of the lake's shores mainly to the south and west fringed by *Eucalyptus* and *Melaleuca* trees. Catchment as for 1s. Discharge not identified. Large areas of flooded grass and shrubs. Sheep grazing along the southern shores. Samples taken from flooded grass, including exposed patches and those shaded by flooded shrubs, between 15 and 30 m from the southern-most edge of the lake.

2: SITE 2 (Appendix II: Plate 2)
Melaleuca Park, Bullsbrook. A permanently dried up *Melaleuca* swamp. Catchment: *Banksia* dominated bushland and possibly the further away pine plantation. No surface water even after heavy rain in August/September. A man-made hole to the water table located: water table about 1.5 to 2 m below ground. Not sampled.

3s: SITE 3 SWAMP (Appendix II: Plates 2 & 6)
Public land, north side of Cooper Rd, about 1 km west of corner of Raphael Rd and Cooper Rd., Bullsbrook. Seasonally flowing helocrene/rheocrene seepages emerging from peat soil but also depositing small amounts of quartz sand on top of the peat. Present within the western side of a swamp that is overgrown with sedges and rushes including a few paperbark trees. Swamp surrounded by *Banksia*, *Eucalyptus* and *Melaleuca* woodland except on the southern side where it is separated from cattle pastures by a limestone road. Catchment area: *Banksia* dominated bushland of Melaleuca Park.

3r: SITE 3 ROAD (Appendix II: Plates 2 & 7)
Road Reserve/Public Land, Cooper Rd, Bullsbrook. Seasonal runnel (visible flow in winter/spring) flowing east for about 80 m, along a road made from limestone in late June 1992. Between 0.5 to 1 m wide and up to 0.30 m deep. Flowing along quartz sand channel with little organic debris except for few submerged sticks. Receives drainage from cattle pastures (palusplains) and from 3s. Sampled about 60 m east of 3s on the edge of a *Eucalyptus/Banksia* woodland, about 15 m down stream after it passes through a pipe under the road. 0.2 m deep at sampling point. Further down stream it joins with other runnels and, eventually, would discharge into Ellen Brook.

3b: SITE 3 BUSH (Appendix II: Plates 2 & 7)
Public land, north side of Cooper Rd, Bullsbrook. Seasonal runnel (barely visible flow in winter/spring) draining 3s through *Banksia/Eucalyptus* woodland; sampled about 60 m east of 3s and about 15 m northwest of 3r sampling point. Between 0.05 and 0.15 m deep, 0.3 to 0.5 m wide. Upstream channel formed in peat, downstream channel in quartz sand. Fringed by rushes, moss growing on the sandy bottom at the sampling point (5 to 10 cm deep). 2 m from the sampling point disappears into the sand.

4: SITE 4 NURSERY (Appendix II: Plates 2 & 8)
Private property (plant nursery), northeastern corner of Raphael and Cooper Roads., Bullsbrook. Permanent L-shaped dam, still water up to 1 m deep, about 5 m wide and approx. 30 m in total length. Fed with water from a submerged limnocrene spring. Bordering a

paddock with poultry, surrounded by kikuyu grass, no trees. Catchment area immediately to the west of the dam contains sealed road, horse pastures and, further west, *Banksia* bushland and site 3.

5s: SITE 5 SPRING (Appendix II: Plates 3, 9 & 10)
Bevan Peters' property, about 300 m south from Archibald St., Muchea. Permanent, limnocrene spring welling up through quartz sand. Vertical channel ≈70 cm diameter and over 3 m deep. Immediate surroundings (≈6 m^2): boggy peat overgrown with *Isolepis prolifera* lying east of, and against, a 2 - 3 m high escarpment from which ground water also seeps, especially in winter. Catchment: high sandy ridge with bracken fern and scattered eucalypts for about 50 m west of the spring; further west the still higher land is cleared and used for cattle grazing. Homestead is located about 100 m northwest of the spring. Much of the water flows down from the spring, for 4 to 5 m, into a farm dam. Area used by cattle.

5D: SITE 5 DAM (Appendix II: Plates 3 & 10)
Bevan Peters' property, about 300 m south from Archibald St., Muchea. Permanent dam, about 15 m long and 6 m wide, over 1 m deep. Source of water from 5s. Gently sloping banks. Southern bank with eucalyptus trees and bordering a paperbark thicket (swamp with native undergrowth removed by pigs and cattle). Eastern banks (boggy) overgrown with *I. prolifera*, grass growing on north and western banks. Submerged grass around the dam's edges. Dam used as source of drinking water by cattle. Permanent outflow stream flowing towards Ellen Brook. Samples taken among submerged grass, in 20 cm deep water, along the southern edge of the dam.

5ps: SITE 5 PIEZOMETER SPRING (Appendix II: Plates 3 & 11)
Bevan Peters' property, about 50 m south Archibald St., Muchea.
Permanent limnocrene/helocrene spring (slow but visible flow) issuing from a vertical channel made by a piezometer (PVC pipe 0.05 m diameter) in a small mound (0.5 m diameter and 20 cm high) consisting of boggy peat. Within 2 m of paperbark trees. Past area of mound springs, levelled, ploughed through and sealed with crushed limestone (≈1 m^3 of limestone per m^2 of ground) (pers. comm. from the owner, Bevan Peters) now supporting lush growth of kikuyu grass year round. Catchment: cattle pasture gently rising to the west of the spring. Water from this spring flows onto the pasture and eventually into a dam ≈10 m north of the spring. Few hundred metres northwest of 5s and 5D.

5pD: SITE 5 PIEZOMETER DAM (Appendix II: Plates 3 & 11)
Bevan Peters' property, about 50 m south of Archibald St., Muchea. Permanent dam, oval in shape ≈15 m diameter, over 1 m deep. Surrounded by kikuyu grass pasture (past area of

mound springs), very little of which is submerged. Very steep, almost vertical, banks. Source of water from 5ps and similar springs in the paddock. Used by cattle (though less frequently than 5D). Sample taken in 0.5 m deep water along the southern edge near some submerged grass (small amounts).

6: SITE 6 SWAMP CHANNEL (Appendix II: Plates 2 & 12)
Road reserve, on the western side of a road about 800 m west of and parallel to Raphael Rd, near Stock Rd, Bullsbrook. Permanent stagnant water, on peat substratum, in a channel running between road and swamp; the road divides the swamp. About 0.7 m wide and 0.3 m deep. Catchment: seasonal swamp supporting rushes and reeds; drainage from road (built on crushed limestone); 1 to 2 km west and southwest begins the *Banksia* dominated bushland of Melaleuca Park. Submerged grass and rushes at sampling point.

7: SITE 7 RUNNEL (Appendix II: Plates 2 & 13)
Road reserve, immediately east of railway line and opposite the junction of Railway Pde and Stock Rd, Bullsbrook. Permanent water, not flowing when sampled. Large drainage line receiving discharge from runnels of many properties (mainly horse and cattle pastures). Passes from west to east under the railway through a concrete tunnel. The railway is built on a ridge of crushed limestone. Sandy (though in parts clay) bottom, apart from submerged grass near the edges and sticks little organic debris present in water. At sampling point : 0.7 m deep, 3 to 4 m wide. Both banks overgrown with grass and eucalypts which shade the water. Probably discharges into Ellen Brook, unless dammed on a private property before reaching it.

Eg: EGERTON SPRING (Appendix II: Plates 1 & 14)
Egerton Stud, Multiplex property (in the northwest section), a swamp about 2 km south of the junction of Maralla Rd and Halden Rd (unsealed), Ellenbrook. Permanent limnocrene spring flowing out of a peat mound (mound spring). Low reeds and rushes, liverworts, and club mosses growing over the mound. Large area of peat mounds with many springs, pristine vegetation. Catchment: further west, the swamp abuts a high sandy ridge (≈100 m AHD) with *Banksia* bushland growing on the eastern slopes replaced by the Gnangara Pine Plantation immediately west of the property boundary. Water from the spring forms a stream which then flows out of the peaty area, onto the sandy substratum and discharges into a large dam (in comparison to the other dams encountered during this study). This site was sampled only once, for fauna, in summer, 1994.

METHODS

data collection

The present study was initially carried out on sites 2, 3s, 3b, 3r, 4, 5s and 5D. Site 2 was excluded from the study on the first sampling trip (2/8/92) because the water table was more than 1 m below ground surface. Also, it was impossible to collect water quality data from 3s because the water depth of these seepages was only a few millimetres; since 3s flowed into 3b some of the 3b water quality data could be used to describe 3s. During the December 1992 sampling trip, sites 3s, 3b and 3r were found to be dry. Consequently, sites 1s, 1L, 6 and 7 were added to the study. Due to time constraints, only sites 1s, 1L, 5s and 5D were re-sampled the following winter, 1993. Two new sites, 5ps and 5pD, which represented a past area of mound springs were also sampled in winter, 1993. Egerton mound spring was sampled just once in autumn 1994, when the opportunity to enter this pristine, but restricted-access area, finally became available. The specific dates on which data were collected for each site are listed in Table 1.

Table 1. Dates on which sites were sampled for fauna and various physicochemical parameters.

	physicochemical data collected				fauna collected				
SITE	2/8/92	18-21/12/92	1-2/6/93	21/8/93	2/8/92	18-21/12/92	1-2/6/93	21/8/93	9/3/94
1s	-	✓	✓	-	-	✓	✓	-	-
1L	-	✓	-	-	-	✓	✓	-	-
3s	-	-	-	-	✓	-	-	-	-
3b	✓	-	-	-	✓	-	-	-	-
3r	✓	-	-	-	✓	-	-	-	-
4	✓	✓	-	-	✓	✓	-	-	-
5s	✓	✓	✓	✓	✓	✓	✓	✓	-
5D	-	✓	-	-	✓	✓	✓	✓	-
5ps	-	-	-	✓	-	-	-	✓	-
5pD	-	-	-	✓	-	-	-	✓	-
6	-	✓	-	-	-	✓	-	-	-
7	-	✓	-	-	-	✓	-	-	-
Eg	-	-	-	-	-	-	-	-	✓

Methods used to record the various physicochemical parameters are listed in Table 2. The environmental parameters measured were pH, water temperature, dissolved oxygen, ions (K^+, Na^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}), phosphate, ammonium and nitrate/nitrite.

Qualitative faunal samples were collected in larger water bodies from the water column, benthos and submerged macrophytes using a standard FBA pond net. In addition, 3 x 200 mL water samples were taken from benthos, submerged macrophytes, and springs, using a pre-measured length of plastic tubing (1 cm diameter). In between sites, the tubing was rinsed with 100% alcohol to prevent cross-contamination of fauna. In the laboratory, samples were sieved through 45 µm mesh to remove fine organic debris and to concentrate the samples. The animals were sorted live. Whenever possible, specimens were identified using taxonomic keys. Protists and rotifers were not scored. For taxa which could not be identified due to the lack of taxonomic keys/descriptions, voucher specimens were drawn or permanently mounted on slides for each distinguishable species.

Table 2. Environmental parameters sampled, methods of measurement and units of precision.

parameter	**method/apparatus**	**precision**
temperature	mercury bulb thermometer	0.1°C
anions	atomic absorption spectrophotometer	0.1 mg/L
cations	ion chromatography	0.1 mg/L
DO (dissolved oxygen)	Winkler titration	did not work for most sites due to interference from tannins
pH	pH Scan 2 pH meter	0.01 pH unit
phosphate	ion chromatography	0.1 mg/L
nitrate/nitrite	ion chromatography	0.1 mg/L
ammonium	ion-probe comb ammonia gas sensing electrode with a Beckman pH meter	0.1 mg/L
TDS (total dissolved solids)	TDScan™ meter	1 mg/L

The presence or absence of water fowl, fish, frogs and tortoises was noted at each site (but the vertebrates present were not identified further). Further searches were carried out to find more mound springs and other aquatic environments of interest in the Ellenbrook area.

data analyses

The physicochemical data were ranked from highest recorded measurement to lowest for all parameters measured. The co-occurrence of species at the different sites was determined using a Microsoft Excel for Macintosh spreadsheet. Three or more sites which contained the same species were grouped. Using the physicochemical ranking of sites, when possible, common characteristics were identified for each group of three sites or more. Groups of sites with the same species but for which no common features could be identified, were excluded from a table attempting to categorise the sites using physicochemical and faunal data. In addition, pairs of sites (containing the same species) which formed a subset of the larger groups of sites were also indicated for each category.

To determine which sites were faunistically most similar, a series of matrices was compiled (Excel spreadsheets) to show the number of species in common between sites. To detect if there were any differences in the patterns of distribution between flying and non-flying species the matrix covering all Ellenbrook species was split accordingly. A separate matrix was set up to examine whether any two sites had an unusually large number of species in common that were not found anywhere else during the study. Aquatic invertebrates recorded at the Ellenbrook sites were compared with species lists from the more coastal wetlands, southwest wetlands (Davis *et al.*, 1993; Storey *et al.*, 1993; Edward *et al.*, 1994) and Darling Scarp streams (Bunn *et al.*, 1986).

RESULTS/DISCUSSION

physicochemistry: ions (Table 3)

All sites except for 1L had low conductivities ranging from 0.150 to 0.263 mS/cm. In contrast, the epiphreatic cave streams at Yanchep National Park on the western side of the Gnangara Mound had conductivities about twice as high (Jasinska, 1990). Because the catchment for Ellenbrook groundwater discharge areas is contained within the highly leached Bassendean sands low conductivities of springs and seepages are to be expected in this area. On the other hand, the Yanchep cave streams would have at least part of their catchment in the more salt-enriched Spearwood Dune system; furthermore, the aeolian calcarenite with which the cave streams come into contact would contain more salt than the Muchea limestone (dispersed within the Ellenbrook catchment) which is of freshwater origin (Playford *et al.*, 1976). The conductivity measured for 1L, the largest of water bodies sampled, was 0.845 mS/cm. This is probably due to greater evaporation rates, nutrient enrichment from sheep droppings and fertilizers draining from the grapevine plantation. Nevertheless, on the western side of the Gnangara Mound, Lake Yonderup in Yanchep National Park had considerably higher conductivities, 1.600 mS/cm, (own unpublished data). Lake Yonderup, and much of its catchment, is located in native forest and therefore could be expected to have much lower conductivity. However, as with the Yanchep cave streams, the groundwater recharge to Lake Yonderup flows through the Spearwood Dune system acquiring salts (mainly bicarbonates and sodium chloride) in the process; the salts from the groundwater recharge, then, would be further concentrated, in this shallow lake, through evaporation. Therefore, the geology of a catchment has a principal role in determining the water chemistry of springs and wetlands occurring at Gnangara Mound discharge points.

None of the sites appeared to be strongly anoxic: there was no smell of H_2S when the water was stirred to take samples. Dissolved oxygen, however, could not be measured because the high colloidal content (humic acids and fine particulate organic debris) of the water samples interfered with Winkler analysis. Nevertheless, the aquatic invertebrates collected seemed well adapted to low levels oxygen since it was rare to find dead or sluggish (movement) animals after keeping the live samples in tightly closed bags for 2 to 3 days in a dark cupboard.

The composition of major cations in Ellenbrook springs and surface waters was fairly typical for Australian waters (Hart and McKelvie, 1986). The dominant cations were either Na^+ or Ca^{2+} and, based on their importance relative to other cations, the sites could be divided into 3 groups:

i. Sites 4, 5s, 5d, 6 and 7: Na^+ clearly dominant, followed by Mg^{2+}; K^+ and Ca^{2+} occurring at low concentrations.
ii. Sites 1s, 1L, and 3b: Na^+ dominant , Ca^{2+} and Mg^{2+} present in high concentrations, K^+ at considerably lower concentrations.
iii. Sites 3r, 5ps and 5pd: Ca^{2+} dominant but Na^+ still present at relatively high levels.

All waters, except for site 1s, were coloured. The humic acids (negatively charged colloids) responsible for this brown colouration would be expected to play a major role in the water chemistry. One beneficial effect of humic acid colloids in water is that they reduce the toxicity of metal ions by binding to them (Hart and McKelvie, 1986). The levels of unmeasured anions, estimated by subtracting concentrations (in mEq/L) of total anions measured (SO_4^{2-} and Cl^-) from cations, were as high as the concentrations of Cl^-. According to the typical composition of fresh waters (Hart and McKelvie, 1986) these anions would be mainly HCO_3^- at sites with higher pH (>pH5): 1s; 1L; 3r; 5ps; 5pd; and 7. At the remaining sites with pH values too low (<pH5) for bicarbonates to be present in significant concentrations the large difference obtained by subtracting anions from cations (in mEq/L) would be due, most likely, to humic acids. Cl^- was either the dominant anion or co-dominant with HCO_3^-/humic acids at sites 3b, 4, 5s, 5d, 7. HCO_3^-/humic acids were the dominant anions for sites at 1L, 1s, 3r, 5pd, 5ps and 6. SO_4^{2-} was a minor ion at all sites; SO_4^{2-} was highest at 1s where it made up 15% of total anions.

Table 3. Physicochemistry of Ellenbrook sites. For each parameter the sites are ranked in descending order in terms of the values measured on a particular sampling occasion. Concentrations of anions not measured refers to the difference obtained from subtracting the sum of measured cations from the sum of measured anions (in mEq/L). These unmeasured anions are most likely HCO_3^- &/or humic acids (described in Methods).

K^+ (mg/L)	Na^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	pH	temp (°C)
1L 18/12/92 10.60	1L 18/12/92 171.80	1L 18/12/92 13.5	3r 2/8/92 67.33	1L 18/12/92 199.98	1L 18/12/92 7.00	7 18/12/92 28.0
5pD 21/8/93 5.00	3r 2/8/92 51.98	4 21/12/92 8.6	5pD 21/8/93 18.60	3r 2/8/92 89.00	3r 2/8/92 6.75	1L 18/12/92 23.5
5ps 21/8/93 3.80	3b 2/8/92 49.45	5s 1/6/93 8.5	3b 2/8/92 18.04	3b 2/8/92 79.07	7 18/12/92 6.25	6 18/12/92 21.5
4 2/8/92 3.52	4 21/12/92 46.90	1s 2/6/93 8.3	1L 18/12/92 16.30	4 2/8/92 65.60	1s 2/6/93 5.70	4 21/12/92 20.6
3r 2/8/92 3.13	6 18/12/92 42.60	5s 21/12/92 8.2	5ps 21/8/93 10.60	4 21/12/92 65.60	5ps 21/8/93 5.50	1s 18/12/92 19.0
5D 21/8/93 3.00	4 2/8/92 38.87	6 18/12/92 8.2	1s 18/12/92 9.20	6 18/12/92 58.15	5pD 21/8/93 5.30	5s 1/6/93 18.4
4 21/12/92 2.80	7 18/12/92 30.00	1s 18/12/92 7.9	1s 2/6/93 7.00	7 18/12/92 43.97	1s 18/12/92 5.20	1s 2/6/93 18.3
5s 21/12/92 2.80	5s 1/6/93 23.90	7 18/12/92 7.3	6 18/12/92 4.50	5s 21/12/92 39.36	5s 1/6/93 4.70	5D 21/12/92 18.3
5s 21/8/93 2.80	5s 21/12/92 23.50	3r 2/8/92 6.8	4 21/12/92 3.40	5D 21/8/93 35.10	5s 2/8/92 4.30	5pD 21/8/93 18.0
3b 2/8/92 2.35	1s 18/12/92 19.90	5pD 21/8/93 4.9	7 18/12/92 2.00	5s 21/8/93 34.04	6 18/12/92 3.90	5s 21/12/92 18.0
5s 2/8/92 2.35	5D 21/8/93 19.40	3b 2/8/92 4.8	5s 21/12/92 1.80	5s 1/6/93 32.62	5D 21/12/92 3.80	4 2/8/92 17.5
5s 1/6/93 2.30	1s 2/6/93 18.30	4 2/8/92 4.4	5s 21/8/93 1.80	5pD 21/8/93 30.49	5s 21/12/92 3.70	5ps 21/8/93 17.0
1s 2/6/93 2.20	5s 21/8/93 18.30	5ps 21/8/93 4.2	5s 1/6/93 1.80	5s 2/8/92 29.43	4 21/12/92 3.60	3r 2/8/92 16.4
1s 18/12/92 2.00	5s 2/8/92 18.17	5s 21/8/93 3.9	5D 21/8/93 1.70	1s 18/12/92 26.24	4 2/8/92 3.60	3b 2/8/92 16.4
7 18/12/92 1.30	5pD 21/8/93 16.70	5D 21/8/93 3.9	4 2/8/92 1.60	1s 2/6/93 23.05	3b 2/8/92 3.24	5s 2/8/92 15.5
6 18/12/92 1.10	5ps 21/8/93 7.90	5s 2/8/92 3.4	5s 2/8/92 0.40	5ps 21/8/93 17.02		

SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	NH_4^+ (mg/L)	anions not measured (HCO_3^- &/or humic acids) (mg/L)	conductivity (mS/cm)
1s 2/6/93 15.9	5s 2/8/92 1.50	6 18/12/92 0.82	1L 18/12/92 240.87	1L 18/12/92 0.845
1s 18/12/92 14.7	4 2/8/92 1.08	5s 21/12/92 0.64	3r 2/8/92 228.79	4 21/12/92 0.263
5s 21/12/92 8.1	6 18/12/92 1.04	5s 1/6/93 0.50	5pD 21/8/93 80.86	6 18/12/92 0.244
1L 18/12/92 7.6	5s 21/12/92 0.88	7 18/12/92 0.27	3b 2/8/92 77.84	7 18/12/92 0.207
7 18/12/92 6.8	3r 2/8/92 0.78	4 21/12/92 0.09	1s 18/12/92 69.09	1s 18/12/92 0.169
4 21/12/92 5.9	5s 1/6/93 0.76	5s 2/8/92 0.07	6 18/12/92 67.20	1s 2/6/93 0.150
6 18/12/92 3.7	7 18/12/92 0.73	4 2/8/92 0.04	4 21/12/92 65.71	5s 21/12/92 0.150
5s 1/6/93 3.5	5D 21/8/93 0.72	1L 18/12/92 0.02	1s 2/6/93 65.20	5s 1/6/93 0.150
	5pD 21/8/93 0.63	1s 18/12/92 0.01	5s 1/6/93 56.79	
	5s 21/8/93 0.50	1s 2/6/93 0.01	5ps 21/8/93 50.95	
	4 21/12/92 0.32	3b 2/8/92 0.01	7 18/12/92 44.38	
	3b2/8/92 0.13		5s 21/12/92 40.49	
	1L 18/12/92 0.11		4 2/8/02 22.72	
	1s 2/6/93 0.04		5D 21/8/93 20.51	
	1s 18/12/92 0.02		5s 2/8/92 19.52	
	5ps 21/8/93 0.02		5s 21/8/93 19.41	

physicochemistry: nutrients and eutrophic status (Table 3)
Inorganic phosphorus (PO_4^{3-}) and ammonium (NH_4^+) were measured successfully however, NO_3^- analysis failed due to interference from humic acids in the sampled water. Based on the Vollenweider (1968), (referenced in Wetzel, 1983), classification of lake trophic status, the Ellenbrook sites ranged from ultra-oligotrophic (1s, 1L, 3b, 5ps) oligomesotrophic (4 December), meso-oligotrophic (5s winter, 5pd) to eu-polytrophic (3r, 4 winter, 5s winter and December, 5d, 6 and 7). Macrophytes and/or floating aquatic plants were abundant at all sites but algal blooms were never sighted during the study nor observed by property owners.

Highest NH_4^+ (0.82 mg/L) was obtained for site 6 (stagnant at the time of sampling). Site 5s also had very high NH_4^+ (0.5 - 0.64 mg/L) levels once in winter and once in December. Site 7 had the next highest NH_4^+ levels of 0.27 mg/L. The remaining sites had NH_4^+ concentrations less than 0.1 mg/L. Since high NH_4^+ levels tend to occur when dissolved oxygen levels are low, sites 6 and 5s were likely to have the least dissolved oxygen of the Ellenbrook sites.

physicochemistry: pH and temperature (Table 3)
None of the sites were alkaline. The highest pH of 7 was recorded at 1L. However, 1s, the source spring for 1L was markedly acidic with pH of 5.2 to 5.7. These two sites had the least coloured water and therefore lower concentrations of the 'acidifying' humic acids. Both were in the top six Ellenbrook sites with the highest Ca^{2+} and Mg^{2+} concentrations which indicates equally high bicarbonate levels. The lower pH of 1s (compared to 1L) was probably due to its lower bicarbonate concentrations (indicated by lower Ca^{2+} and Mg^{2+} levels) and, even more so, due to its very high SO_4^{2-} (sulfuric acid) concentration which was twice as high as that of 1L. Sites 3r, 5ps, 5pd and 7 were only mildly acidic, the pH ranging from 5.3 to 6.75, all these sites received water from limestone-enriched immediate surroundings. On the other hand, at sites 3b, 4, 5s, 5d, and 6 pH values were less than 4 at least on one sampling occasion. The lowest pH of 3.24 was recorded at 3b. Curiously, Ca^{2+} and Mg^{2+} levels, which typically occur as bicarbonates, did not increase with pH at all sites: site 7 had a pH of 6.75 but comparatively low concentrations of Ca^{2+} and Mg^{2+} while 3b, which had the lowest pH of the thirteen sites, ranked third highest in terms of Ca^{2+} concentration. Complexing of ions with humic acids could be producing these peculiar results but also, site 3b might have had high levels of SO_4^{2-}.

Above 20°C temperatures were recorded, in December, from 1L, 4, 6 and 7, site 7 having the highest temperature of 28°C. The lower December temperatures recorded for the two other surface water bodies, 5d and 5pd, were probably caused by faster water turnover rates (both dams had active inflow and outflow streams). The groundwater temperature of springs ranged from 15.5°C to 19.3°C during the present study. 15.5°C was also the lowest temperature recorded. The lowest temperature of a surface water body was 16.4°C for sites 3b and 3r. Both these latter sites were far removed from their source springs, shallow and reflected the ambient temperatures at the time of sampling.

physicochemistry: seasonal variation (Table 4)

The main seasonal differences observed between sites were related to water level fluctuations. Sites 3b, 3s and 3r were completely dry by December. Sites 6 and 7 flooded and flowed slowly in winter, the water levels receded considerably and stopped flowing by December. Site 1L also flooded large areas of grass in winter. Sites 4, 5s, 5d, 5ps and 5pd all had a large and steady groundwater input and showed relatively little variation in water levels (or flow) between seasons.

Table 4. Seasonal variation in physicochemistry at sites 1s, 4 and 5s.

Site and sampling date		K^+ mg/L	Na^+ mg/L	Mg^{2+} mg/L	Ca^{2+} mg/L	Cl^- mM/L	NH_4^+ mg/L	pH	temp °C	phosph mg/L	TDS ppm	SO_4^{2-} mg/L
1s	18/12/92	2.00	19.90	7.9	9.2	0.74	0.01	5.2	19.0	0.015	90	14.7
1s	2/6/93	2.20	18.30	8.3	7.0	0.65	0.01	5.7	18.3	0.038	80	15.9
4	2/8/02	3.52	38.87	4.4	1.6	1.85	0.04	3.6	17.5	1.075		
4	21/12/92	2.80	46.90	8.6	3.4	1.85	0.09	3.6	20.6	0.321	140	5.9
5s	2/8/92	2.35	18.17	3.4	0.4	0.83	0.07	4.3	15.5	1.500		
5s	21/12/92	2.80	23.50	8.2	1.8	1.11	0.64	3.7	18.0	0.878	80	8.1
5s	1/6/93	2.30	23.90	8.5	1.8	0.92	0.50	4.7	18.4	0.762	80	3.5
5s	17/8/93	2.80	18.30	3.9	1.8	0.96		3.6	19.3	0.500		

Sites 1s, 4, and 5s were sampled both in the dry season (December) and in winter. There was little variation in ionic concentration between seasons and no general trend towards higher summer concentrations of ions in summer. The two springs registered different pH values on different sampling occasions; pH at site 5s fluctuated by, as much as, 1.1 of pH unit (3.6 to 4.7), the lower pH readings being taken in both wet and dry seasons.

In terms of temperature, site 1s was the most stable with a variation in temperature of only 0.7°C. Site 5s was the most variable and unlike the sites 1s and 4, its lowest (15.5°C) AND highest (19.3°C) temperatures were recorded in winter. This is quite inconsistent with the usual temperature constancy of ground waters (Allen, 1981). Spring 1s was located at about 20 m lower on the eastern slopes of the Gnangara Mound than 5s and therefore it is likely that it discharged water which spent more time in the aquifer than that from 5s. Longer residence time of water in the aquifer would reduce its temperature fluctuations. This is supported by the relative constancy of temperature, 0.3°C variation over the year, of groundwater streams in Yanchep caves which leave the Gnangara Mound at 11 m AHD.

fauna

The Ellenbrook sites contain a rich and diverse fauna. Individuals belonging to the class Turbellaria, phylum Tardigrada, and the genera of Hemiptera *Anisops*, *Micronecta* and *Sigara* were not identified to species (due to the lack of taxonomic descriptions and keys); instead each taxon was treated as one species, although more than one species were observed for each of these taxa in the Ellenbrook samples. Therefore, the total number of species collected at Ellenbrook sites is an underestimate. Still, 147 species of invertebrates (excluding rotifers and protozoans) were recorded for the 13 Ellenbrook sites (Appendix I). Of these 91 had not been collected from any of the Swan Coastal Wetlands surveyed by Davis *et al.*, (1993), southwest wetlands (Storey *et al.*, 1993; Edward *et al.*, 1994) nor the Darling Scarp (Bunn *et al.*, 1986). Half of the remaining 56 species were insufficiently identified in all of these studies for comparisons of co-occurrence. Ellenbrook sites had the most species (28) in common with the Swan Coastal Wetlands (Appendix I). The three areas with the highest number of species also had some of the highest numbers of species endemic to them. These three areas were: site 1L and 1s, sites 5s and 5d, and the Egerton mound spring. The physicochemistry of Egerton mound-spring was not measured, but it is interesting to note that of the two other areas site 1L had the highest pH recorded for the study, while site 5d was among the most acidic sites with a pH of 3.8. This illustrates that, at least in coloured waters, low pH does not have adverse effects on the overall diversity of aquatic invertebrates.

The most striking difference between the surface waters of Ellenbrook sampled in this study and the wetlands on the western side of the Gnangara Mound was the lack of amphipods in Ellenbrook ponds and runnels. However, amphipods from a new genus were found in the mound spring waters at Egerton (so far, the only location from which these amphipods have been collected). Janirid isopods which are common in the springs and cave streams at Yanchep National Park, on the western side of the Gnangara Mound, were not found in Ellenbrook springs. Cyclopoid copepods from the genus *Eucyclops*, although widespread on the western side of the Gnangara Mound, did not occur at Ellenbrook. Most of the cyclopoid species which include *Paracyclops* (8spp), *Mesocyclops* (1sp), *Mixocyclops* (4spp), *Microcyclops* (5spp) and a new monotypic genus from Ellenbrook had not been recorded from the west, southwest and Darling Scarp wetlands, except for 2 species of *Paracyclops* recorded from the Two Peoples Bay area on the south coast (Storey *et al.*, 1993). No calanoid copepods were collected from Ellenbrook.

96 species were recorded from single sites at Ellenbrook. Each site had at least 3 endemic species (at the level of this study). Site 1L had the highest number (17 species) of species that were not recorded from anywhere else during this study. The next highest number of species (14), endemic to a single Ellenbrook site, was recorded for Egerton spring. Springs and their

associated water bodies were no more similar in terms of fauna than any other pair of sites (Table 5). Only three species, at the most, were shared exclusively by 2 sites (Table 6).

Table 5. Numbers of species in common between Ellenbrook sites.

	1s	1L	3s	3r	3b	4	5s	5d	5pD	5ps	6	7	Eg.
1s	19												
1L	5	30											
3s	2	3	15										
3r	4	3	4	11									
3b	2	2	2	1	9								
4	4	11	4	3	2	31							
5s	5	3	2	1	2	7	23						
5d	3	10	2	1	1	15	7	31					
5pD	3	7	2	3	1	8	4	10	17				
5ps	1	1	0	2	0	1	0	0	1	6			
6	0	5	1	0	0	7	3	7	1	0	17		
7	1	4	0	1	0	7	2	4	3	2	3	19	
Eg.	3	3	3	1	2	4	5	4	3	0	4	2	22
Total spp	**19**	**30**	**15**	**11**	**9**	**31**	**23**	**31**	**17**	**6**	**17**	**19**	**22**

Table 6. Numbers of species unique to pairs of sites, endemic to each site, and numbers of species per site with a flying stage in their life cycle.

	1s	1L	3s	3r	3b	4	5s	5d	5pd	5ps	6	7	Eg.
1s													
1L	1												
3s													
3r			1										
3b	1												
4													
5s	2		1			2							
5d		1				3	1						
5pD				1				2					
5ps				1									
6		1				1		1					
7						2		1		1			
Eg.	1						1				1		
Total # of species	**19**	**30**	**15**	**11**	**9**	**31**	**23**	**31**	**17**	**6**	**17**	**19**	**23**
total # of species endemic to one site	**7**	**17**	**7**	**3**	**5**	**7**	**5**	**8**	**4**	**3**	**6**	**10**	**14**
# of endemic species with a flying stage	**0**	**3**	**5**	**0**	**0**	**5**	**0**	**7**	**0**	**0**	**3**	**5**	**0**
total # of species with a flying stage	**2**	**12**	**7**	**3**	**1**	**19**	**1**	**19**	**6**	**0**	**8**	**10**	**2**

Physicochemical factors may influence the distribution of some species in the Ellenbrook sites (Table 7). For example, ostracods and the cyclopoid copepod *Paracyclops* sp 1 were recorded only in waters that had come into contact with limestone close to the sampling point. A few species were also restricted to waters with one or more of the five characteristics (Table 7) listed below:

1. Low pH (4.70 or lower);
2. Waters with the following cationic dominance $Na^{+} >> Mg^{2+} > K^{+} \approx Ca^{2+}$;
3. Surface water bodies with stable flow and oxic environment;
4. Waters low in NaCl;
5. Permanent waters, but with pronounced seasonal water level fluctuations, high summer temperatures (above 20°C), high conductivity (0.2 mS/cm or higher), Na^{+} dominated waters.

However, out of the 147 species recorded, the distribution of only 15, and of the ostracods as a group, could be related to the physicochemical properties of the waters sampled (Table 7).

Predation appeared to play a significant role among the copepods: wherever *Macrocyclops* sp1 occurred (4, 5d, 6) no other cyclopoid species were found. At site 4 two other cyclopoid species were found only in the zone of the dam which received water directly from a spring and was isolated from the rest of the dam by a fine mesh. In this area no specimens of *Macrocyclops* sp1 were found. Site 1L was unusual in having *Daphnia carinata* and no other cladoceran spp. This might be the result of predation by fish, *Gambusia affinis* and *Favonigobius suppositus,* also collected at 1L, or of competitive exclusion by *Daphnia carinata.* Despite the presence of the introduced carnivorous fish, *Gambusia*, site 1L had the highest number of endemic (i. e. not found at any of the other Ellenbrook sites) species and third highest species diversity. This could be a function of: the large size of 1L (lake); greater number of microhabitats (although only the open water, submerged grass, and benthos microhabitats were sampled); or, possibly, caused by the fish through the reduction in interspecific competition between its prey, and/or by lowering the numbers of smaller predators.

There was no discrete suite of species that occurred in springs but not in surface water bodies. The major difference between spring and surface water faunas was the absence of all insects, except for dipteran larvae (ceratopogonids and chironomids), from springs. The most ubiquitous species were *Cherax ?quinquecarinatus* (gilgie) and *Chironomus* aff. *alternans* (dipteran larva) which were recorded from 8 sites each. As already stated, fauna from a pond did NOT resemble the fauna of the source spring more than that from other sites. At the same

Table 7. Physicochemical characteristic(s) common to the sites of occurrence of the species listed. Selection of species and physicochemical parameters defining the groups of sites is described in Methods section.

unifying physicochemical characteristic(s) species present at 3, or more, sites, with similar physicochemical characteristics (sites listed in brackets) <u>group of sites with common physicochemical characteristic(s)</u>	Species found only at 2 of the sites belonging to the group (specified in cell to the left) identified by a particular physicochemical characteristic(s) (sites listed in brackets)
low pH *Paracyclops* sp3 (3s,3b,4,5s) *Limnophyes pullulus* (3s,3r,4) Olig sp5 (5s,5d,6) *Macrocyclops* sp1 (4,5d,6) <u>3s, 3b, 4 , 5d, 5s, 6, Eg</u>	*Rhantus suturialis*(5d,6) *Ischnura ?heterosticta*(4,5d) *Pantala flavescens* (4,5d) *Orthetrum caledonicum* (4,5d) *Tardigrada*(4,5s) *Olig* sp4 (5s,5d) nem. sp14(3s,3r) nem. sp1(6,Eg) harp spB (3s,5s) harp spA (3b,5s) *Microcyclops* sp5 (5s,Eg) *Biapertura rigidicaudis* (4,6) ?Pod.sp1 (4,5s)
$Na^{+}>>Mg^{2+}>K^{+}\approx Ca^{2++}$ nem.sp3 (4,5s,5d,6,7,Eg) Olig sp5 (5s,5d,6) *Macrocyclops* sp1 (4,5d,6) <u>4, 5s, 5d, 6, 7, Eg*</u>	*Microcyclops* sp5(5s,Eg) *Orthetrum caledonicum* (4,5d) Tardigrada(4, 5s) Olig sp4 (5s,5d) *Biapertura rigidicaudis* (4,6) *Hydrozetes* sp.(5d,7) *Pantala flavescens*(4,5d) *Chostonectes gigas*(4,7) *Rhantus suturialis*(5d,6) *Austroagrion coerueleum*(4,7) *Ischnura ?heterosticta*(4,5d)
water draining from limestone enriched surroundings *Paracyclops* sp1 (1s,1L,3r,4,5pd,5ps,7) ostracoda[1] (1s,1L,3r,5ps,5pd,7,Eg) <u>1s, 1L, 3r, 4, 5ps, 5pd, 7, Eg*</u>	*Paracyclops* sp2 (3r,5ps) nem. sp4(5ps,7) *Austroagrion coerueleum* (4,7)
stable water body, oxic environment *Ilyocryptus spinifer* (var) (4,5s,5d,5pd) *Micronecta* spp. (1L,4,5d,5pd) Aloninae sp (5s,5d,5pd) *Kiefferulus martini* (4,5d,5pd) <u>1L, 4, 5d, 5pd, 5s</u>	?Pod.sp1 (4,5s) Olig sp4 (5s,5d) Olig sp9 (5d,5pd) Olig sp10 (5d,5pd) *Orthetrum caledonicum*(4,5d) *Pantala flavescens*(4,5d) Tardigrada (4,5s) *Agraptocorixa* (1L,5d) *Ischnura ?heterosticta* (4,5d)
low NaCl Aloninae sp (5s,5d,5pd) Orib. sp. s2 (1s,5s,Eg*) <u>1s, 5s, 5d, 5pd, Eg*</u>	*Lobohalacaris* sp nov (1s,5s) Noth. sp. s1 (1s,5s) Olig sp4 (5s,5d) Olig sp9 (5d,5pd) Olig sp10 (5d,5pd)
permanent water with considerable seasonal variation in water levels, high summer temp., high: TDS,Na,Cl,Mg *Sigara* sp (1L,4,6,7) <u>1L, 4, 6, 7</u>	*Biapertura rigidicaudis* (4,6) *Chostonectes gigas* (4,7) Bidessini (1L,6) *Austroagrion coerueleum*(4,7) Mollusca[1] (1L,7)

Eg* - water quality data for Egerton spring was not obtainable and therefore it is possible that the "unifying characteristic" identified for a suite of sites where a particular species occurs may be incorrect if the sites include Egerton spring.

1 - signifies a taxonomic group rather than individual species.

time, none of the sites had a completely exclusive suite of species. The presence/absence of species, within Ellenbrook catchment, therefore was most likely determined primarily by a combination of habitat structure and interspecific interactions rather than past patterns of colonisation of sites. This suggestion is supported by the fact that aquatic invertebrates with a winged stage in their life cycle were no more widespread than the non-flying fauna (Table 6). However, the absence of the cosmopolitan Swan Coastal Plain amphipods, of cyclopoid species from the genus *Eucyclops* from the Ellenbrook sites and the presence of a new monotypic amphipod genus at Egerton sites suggests that this area had a different history of colonisation than the more southern and coastal wetlands of the Swan Coastal Plain and has become too isolated for many types of animals to colonise it.

At all sites frogs were heard calling and water fowl including ducks, geese, ibis and heron were common. Site 1L was especially rich in water fowl diversity and abundance.

Apart from Egerton mound springs, no other mound springs with the original native flora could be located. Nevertheless, 4 other areas of degraded mound springs were found [also see Ahmat (1993)]:

i. Tomlinson's property, Humphrey St., Muchea (Appendix II: Plate 15)
ii. Banfield's 'Many Springs' property, Lot 3232 Raphael Rd., Bullsbrook (Appendix II: Plate 16)
iii. Private property Muchea MK016978. Map ref. Muchea 2034-1SE, Bullsbrook .
iv. Bevan Peters' property, Archibald St., Muchea (Appendix II: Plate 17).

The common features of these four sites included discrete groundwater discharge from boggy peat which deposited white quartz sand along the bottom runnel leading away from the spring and a white precipitate settling on sticks, roots, and other submerged debris. Local land owners refer to this precipitate as magnesia. Indeed, judging from the water quality (Table 3) it is likely to be a magnesium/calcium carbonate complex. The surrounding peat does not flood nor dry out seasonally providing a stable, mesic environment. Except for B. Peters' mound springs, the ground was levelled either supporting the growth of grass or *Isolepis prolifera*.

B. Peters' mound springs are situated in a paperbark woodland where some invasion of weed species has occurred but considerable numbers of native species can still be found in the undergrowth. The boggy peat of the mound springs still forms mounds (up to 2 m high), however, many mound springs have dried up over the last fifteen years (Bevan Peters pers. comm.). Furthermore, cattle tramples and grazes this mound spring area periodically (although) the owner would not object to a fence being put up around the mound spring area to keep the animals out). Another, freshwater habitat is present in this mound spring area: where the raised peat has been burnt in the past, permanent pools several metres in diameter are present. Although, not sampled, they were observed (in the field) to be teeming with invertebrates and would also constitute a likely breeding area for frogs which were abundant through out the paperbark woodland. Gilgies, *Cherax quinquecarinatus* (but quite a different variety from that present in the more coastal wetlands), and their burrows were also located in this mound spring area.

The night fish, *Bostockia porosa*, was present in a farm dam derived from the mound spring at Tomlinson's property, and this same dam also contained long necked tortoises and gilgies.

The mound springs at Egerton issued from much less boggy peat than at the other sites but still provided a stable mesic environment: water oozing from whole surface of the mounds as well as flowing out of discrete channels in places. No white precipitate was deposited by the spring water. The mounds were more extensive and coalesced. Discharge from the springs flowed into a channel >1 m below the points of groundwater discharge. There were no weeds present and some plant species were identified later at the W.A. Herbarium: *Lycopodium serpentinum* (bog clubmoss), *Drosera pulchella*, *Baumea riparia*, *Lepidosperma* (2 spp), *Aotus cordifolia*, *Agonis linearifolia* and four liverworts *Riccardia aequicellularis*, *Jungermannia inundata*, *Goebelobryum unguiculatum* and *Hyalolepidozia longiscypha*. Some of this flora is common in the southwest of WA but has been recorded only from mound springs so far north, the previous northern limit of their distribution being the mound springs at Muchea.

CONCLUSION

Despite extensive rural development in the Ellenbrook catchment area, the springs, ponds and runnels sampled revealed a rich and diverse fauna. 91 species of the total 147 collected from the Ellenbrook study sites had not been previously reported for Swan Coastal Plain nor southwest wetlands. Many species of invertebrates were collected from springs, however these did not constitute a discrete groundwater fauna and were different from the species present in groundwater cave streams at Yanchep on the western side of the Gnangara Mound. High level of heterogeneity in invertebrate species assemblages was observed between sites. Even the fauna of a source spring was quite different from that of the water body into which it flowed. Three of the surveyed areas: sites 1s/1L off the Gnangara Rd, Egerton mound springs and springs, pools and dams at Bevan Peters property at Muchea, are of high conservation value and should be protected and studied further. All of these three areas are composed of a mosaic of microhabitats (of which only a fraction has been sampled and described so far) that are likely to contain different aquatic faunas. Entire mound springs were located only at Egerton and at B. Peters property in Muchea. The Egerton mound springs support the original flora and contain a new, monotypic, amphipod genus, while the mound springs at B. Peters property have a degraded flora but are much more boggy, and forming more discrete mounds, than the Egerton mound springs and would make a fascinating hydrogeological study. Many perennial springs and ponds as well as temporary swamps and runnels are present in the area and these are heavily utilised by water fowl, tortoises, frogs and fish (inc. the native *Bostockia porosa*). The fauna and physicochemistry of wetlands and springs of Ellenbrook catchment differ considerably from those elsewhere on the Swan Coastal Plain and warrant protection and further study.

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Much of this study depended on obtaining advice and cooperation from local property owners. We are grateful to the many Ellenbrook land-holders who freely shared their knowledge concerning the whereabouts of springs and the recent history of the area. Special thanks are extended to Mr. Bevan Peters and Mrs. Margaret Peters who were very helpful, and patient, over the 3 years during which their property was sampled extensively. Mrs. Judy Tomlinson, and her family, helped in locating extra springs and caught gilgies and fish (*Bostockia porosa).* Aquatic Biology 311 students were involved in the sampling and sorting of some of the Ellenbrook sites during 1992 and 1993. This project was financed by the Water Authority of Western Australia and The University of Western Australia as a component of E. J. J.'s Ph.D. thesis.

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APPENDIX I

Appendix I: List of invertebrates identified from Ellenbrook study sites. Species which were also recorded in aquatic surveys of the W.A. south coast (Storey *et al.*, 1993; Edward *et al.*, 1994), Darling Scarp streams (Bunn *et al.*, 1986) and other Swan Coastal Plain wetlands (Balla & Davis, 1993; Davis *et al.*, 1993) are indicated.
* - refers to a taxon, also recorded in other studies, which was not identified to species.

	1s	1L	3s	3r	3b	4	5s	5d	5pd	5ps	6	7	Eg	total occurences	south coast of WA	other Swan Coastal Plain wetlands	Darling Scarp streams	# of studies (max#=4) which recorded the species
CHELICERATA:																		
Acarina														-				-
Halacaridae														-				-
Lobahalacaris sp nov	1						1							2				1
Oribatida														-				-
Orib. sp. s2	1						1						1	3				1
Nothroidae														-				-
Noth. sp. s1	1						1							2				1
Noth. sp. L1					1									1				1
Noth. sp. 3											1			1				1
Pionidae														-				-
Acercella falcipes		1												1		1		2
Piona sp. nov. m		1												1		1		2
Unionicolidae														-				-
Newmania sp		1												1	?			1 (?+1)
Hydrozetidae														-				-
Hydrozetes sp.								1				1		2				1
Limnesiidae														-				-
Limnesia sp nov													1	1				1
CRUSTACEA														-				
Amphipoda														-				-
Amph. gen nov													1	1				1
Cladocera														-				-
Daphniidae														-				-
Daphnia carinata		1												1	1	1		3
Simocephalus exspinosus australiensis									1					1		1		2
?Podonidae														-				-
?Pod.sp1						1	1							2				1
Macrothricidae														-				-
Ilyocryptus spinifer (variety)						1	1	1	1					4		1		2
Ilyocryptus ?sordidus													1	1				1
Macrothrix breviseta (variant)						1								1	1	1		3
Chydoridae														-				-
Aloninae							1	1	1					3		?		1 (?+1)
Biapertura ?setigera								1						1	1			2
Biapertura rigidicaudis						1					1			2	1			2
Chydor. new sp.									1					1				1
Copepoda: Cyclopoida														-				-
Macrocyclops sp1						1		1			1			3	?	?	?	1 (?+3)
Mesocyclops sp1		1												1				1
Microcyclops sp1		1												1	?	?		1 (?+2)
Microcyclops sp2	1			1			1							3				1
Microcyclops sp3					1									1				1
Microcyclops sp5							1						1	2				1
Microcyclops sp6													1	1				1
Mixocyclops sp1				1										1				1
Mixocyclops sp2	1		1	1										3				1
Mixocyclops sp3							1							1				1
Mixocyclops sp4													1	1				1
Paracyclops sp1	1	1		1		1			1	1		1		7	?			1 (?+1)
Paracyclops sp2				1						1				2	?			1 (?+1)
Paracyclops sp3			1		1	1	1							4				1

Paracyclops sp4							1							1				1
Paracyclops sp5													1	1				1
Paracyclops sp6													1	1				1
Paracyclops sp7													1	1				1
Paracyclops sp8													1	1				1
Cyclopoida gen. nov				1										1				1
Copepoda: Harpacticoida														-				*
harp. spA (gigant at Egerton)					1		1						1	3				1
harp. spB			1				1							2				1
harp. spC	1													1				1
harp. spD			1											1				1
harp. spE	1													1				1
harp. spF						1								1				1
harp. spG	1													1				1
harp. spI	1	1				1	1	1	1					6				1
harp. spJ					1									1				1
harp. spK											1			1				1
Decapoda														-				-
Cherax quinquecarinatus (variant)		1				1	1	1	1		1	1	1	8	?	?	?	1 (?+3)
Palaemonetes australis		1												1	1	1		3
Isopoda: Phreatoicida														-				-
Paramphisopsus palustris		1												1		1		2
Ostracoda														-				-
Condocypris novaezelandiae		1												1	1	1		3
Cypretta sp1		1												1		1		2
Cyprididae sp1	1	1												2	?			1 (?+1)
Cyprididae sp2				1										1				1
Cypridopsidae sp1										1				1				1
Darwinula sp1	1												1	2		1		2
Ilyodromus sp1									1					1	?	1	?	2 (?+2)
Ilyodromus sp2										1				1		1		2
Ostracoda sp1												1		1				1
Ostracoda sp2									1					1				1
Sarscypriodopsis ?aculeata		1												1	1	1		3
MOLLUSCA: Gastropoda														-				-
Planorbidae: Planorbinae														-				-
Physastra sp1		1												1	?			1 (?+1)
Ancylicdae														-				-
Ferrissia sp												1		1	?	?	?	1 (?+3)
Physidae														-				-
Physa sp1												1		1		?		1 (?+1)
Physa sp2		1												1				1
NEMATODA														-				*
nem. sp1											1		1	2				1
nem. sp2											1			1				1
nem.sp3						1	1	1			1	1	1	6				1
nem. sp4										1		1		2				1
nem. sp5	1													1				1
nem. sp6	1													1				1
nem. sp7							1							1				1
nem. sp8		1												1				1
nem. sp9					1									1				1
nem. sp10					1									1				1
nem. sp11	1				1									2				1
nem. sp12			1											1				1
nem. sp13			1											1				1
nem. sp14			1	1										2				1
nem. sp15										1				1				1
nem. sp16													1	1				1

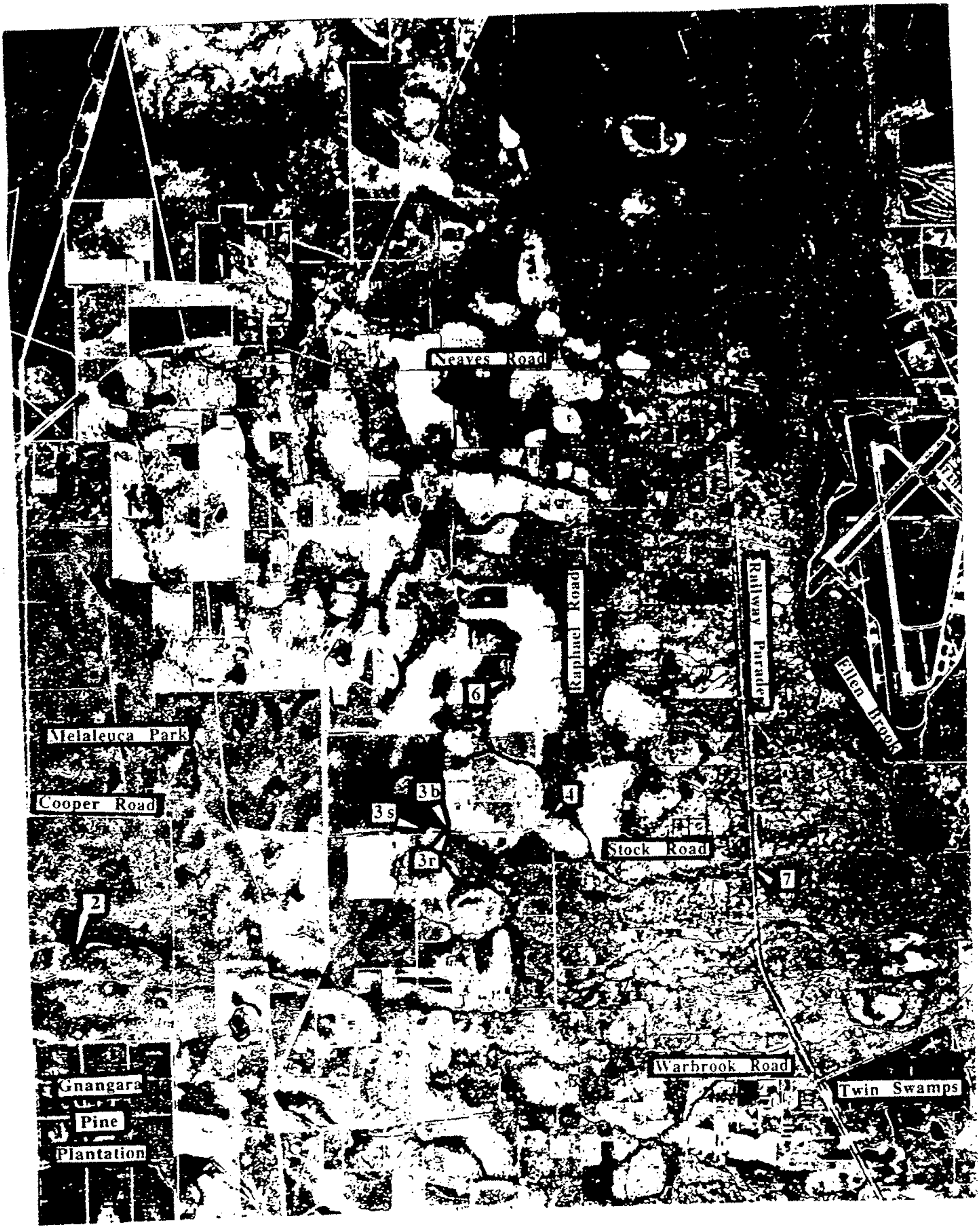
ANNELIDA: Oligochaeta														-				*
Olig sp1	1													1				1
Olig sp2	1													1				1
Olig sp3			1											1				1
Olig sp4							1	1						2				1
Olig sp5							1	1			1			3				1
Olig sp6							1							1				1
Olig sp7							1							1				1
Olig sp8												1		1				1
Olig sp9								1	1					2				1
Olig sp10								1	1					2				1
Olig sp11													1	1				1
Olig sp12													1	1				1
Olig sp13													1	1				1
Tardigrada sp(p)						1	1							2				1
Turbellaria spp		1	1			1		1			1		1	6				*
INSECTA														-				-
Anisoptera														-				-
Libellulidae														-				-
Orthetrum caledonicum						1		1						2	1	1	1	4
Pantala flavescens						1		1						2				1
Corduliidae														-				-
Hemicordula tau								1						1	1	1		3
Diptera														-				-
Ceratopogonidae sp(p)	1	1				1		1						4	?			1 (?+1)
Chironomidae													1	1				1
Chironominae: Chironomini														-				-
Chironomus aff. *alternans*		1	1	1	1	1	1	1	1					8	1	1		3
Kiefferulus intertinctus								1						1	1	1		3
Kiefferulus martini						1		1	1					3	1	1		3
Chironominae:Tanytarsini														-				-
Tanytarsus sp			1											1	?	1	?	2 (?+2)
Orthocladiinae	1													1	?	?		1 (?+2)
Limnophyes pullulus			1	1		1								3	1	1	?	2 (?+1)
Tanypodinae														1				1
Paramerina levidensis				1					1					2	1	1	1	4
Ablabesmyia ?notabilis			1											1		1	?	2 (?+1)
Apsectrotanypus ?masculosa						1								1				1
Coleoptera														-				-
Dytiscidae														-				-
Dytisc. larvae			1						1				1	3				1
Hydrophydrus elegans		1												1		1		2
Chostonectes gigas						1						1		2				1
Megaporus solidus											1			1	1	1		3
Dytisc sp1												1		1				1
Dytisc sp2												1		1				1
Dytisc sp3												1		1				1
Dytisc. sp4												1		1				1
Hydroporinae														-				-
Bidessini		1									1			2				1
Hyd. por..sp1								1						1				1
Hyd. por. sp1						1								1				1
Hyd. por. sp2						1								1				1
Hydrophilidae														-				*
?*Coelostoma* sp1								1						1				1
?*Coelostoma* sp2											1			1				1
?*Coelostoma* sp3											1			1				1
Hydr. larva		1												1				1
Hydroporini: ?*Sternopriscus*								1						1			?	-
Rhantus suturialis								1			1			2	1	1	1	4
Hydrochidae														-				-
Hydrochus sp												1		1				1

Ephemeroptera														-				-
Ephem sp								1						1	?			1
Tasmanocoenis sp												1		1		1	?	2 (?+1)
Hemiptera														-				-
Corixidae														-				-
Agraptocorixa spp		1						1						2	?	?		1 (?+2)
Micronecta spp		1				1		1	1					4		?	?	1 (?+2)
Sigara (Tropocorixa) spp		1				1					1	1		4		?		1 (?+1)
Notonectidae														-				-
Anisops spp		1				1		1			1			4		?		1 (?+1)
Trichoptera														-				-
Triplectides australis		1				1		1	1			1		5	1	1		3
?Leptoceridae sp1			1											1	?			1 (?+1)
Zygoptera														-				-
Coenagrionidae														-				-
Austroagrion coerueleum						1						1		2				1
Ichnura aurora						1								1	1			2
Ischnura ?heterosticta						1		1						2				1
Xanthagrion erythroneurum		1												1		1		2
Lestidae														-				-
Austrolestes sp1						1								1				1
Austrolestes analis								1						1		1		2
TOTAL SPP	19	30	15	11	9	35	23	31	17	6	23	26	23	147	18	30	3	

APPENDIX II

SCALE 1:20000

PLATE 1. Aerial view of sites 1s, 1L and Eg. Photo ref.: 5016 run 14 WA 3315 (C) 04/01/1994.



SCALE 1:40000

PLATE 2. Aerial view of sites 3s, 3r, 3b, 4, 6 and 7. Photo ref.: 5220 run 3 WA 2995 10/08/91.

SCALE 1:20000

PLATE 3. Aerial view of sites 5s, 5d, 5ps, 5pD and of mound spring area (m.s.) on Bevan Peters property. Photo ref.: 5004 run 13A WA 3315 (C) 04/01/94.

PLATE 4. Site 1 spring (1s). Left: shallow excavation (0.15m deep) showing a fast flowing rheocrene spring. Right: view to the west from 1L showing the ridge from which 1s flows.

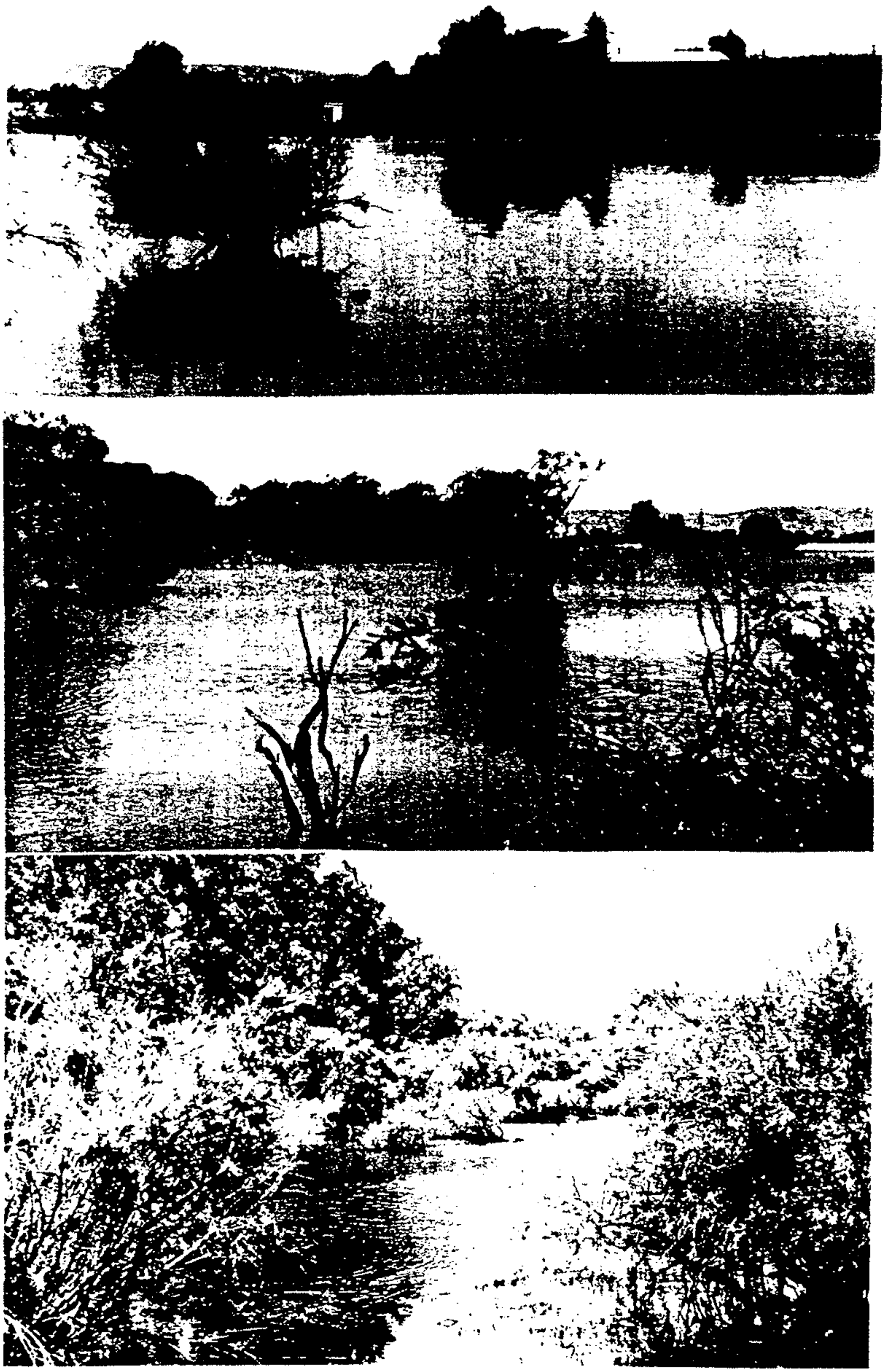


PLATE 5. Site 1 Lake (1L). Top: eastern shores with dense stands of *Typha*, replaced by a vineyard higher up on the slopes; Middle: view to the north (Darling Scarp in the distance). Bottom: view to the north-west (sampling point) showing much submerged vegetation.

PLATE 6. Site 3 swamp (3s). View to the west from Cooper Rd showing native wetland vegetation.

PLATE 7. Site 3 road (3r) and site 3 bush (3b). Top: view to the west showing one of the 3r tributaries flowing from 3s along the limestone road. Middle: view to the south (sampling point for 3r) showing the inflow pipe under the road from the other 3r tributary that drains paddocks. Bottom: view to the north, 3r sampling point in the foreground, 3b in the bush only a few metres behind the group of people draining 3s in the west and, at this stage, is perpendicular to 3r.

PLATE 8. Site 4 nursery (4). Top: view to the west, PVC pipes lead away water from the spring encased in a frame supporting fine mesh, the spring water also passing through the mesh thus producing the dam. Bottom: view of the dam looking to the east.

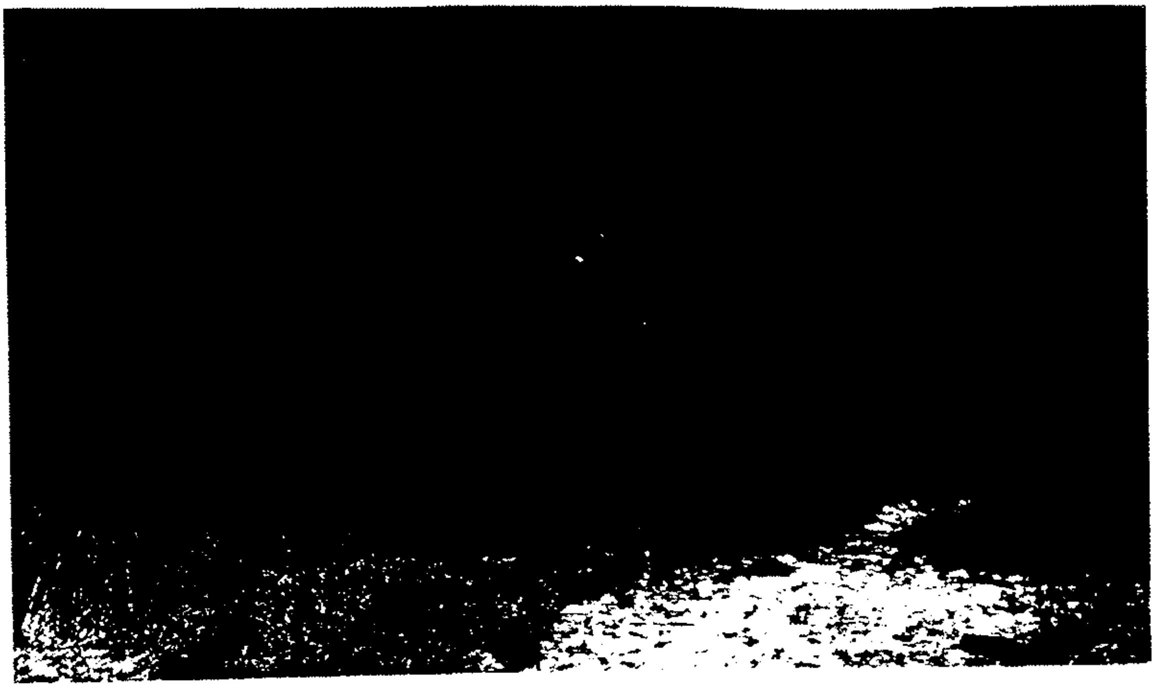
PLATE 9. Bevan Peters' spring (5s). Top: highly active boil of the spring; bottom: View to the south: dense growth of *Isolepis prolifera* about spring. *Melaleuca* woodland in the background.

PLATE 10. Bevan Peters' dam (5D) and spring (5s). Left: view to the west (catchment area) from the eastern banks of 5D. Right: view to the east (towards Ellen Brook); 5s flowing into 5D.

PLATE 11. Piezometer dam (5pD) and piezometer spring (5ps). Top and bottom: view to the east: past area of mound springs, excavated dam on the left , areas of soil and grass forming small mounds (in the photograph, one from each pair of piezometers is inserted in a mound) which discharge groundwater. 5ps is located in the middle of the group of three people (Bevan Peters, B. K. & E. J. J).

PLATE 12. Site 6 swamp channel (6). Top: view to the north; channel lying between a limestone road and a swamp. Bottom: stagnant pools of dark water in the channel.

PLATE 13. Site 7 Runnel (7) - substantial drainage line passing under the railway (through limestone). Top: view to the west; railway tracks followed by rural catchment area). Bottom: view to the east (towards Ellen Brook): pastures, Darling Scarp in the distance.



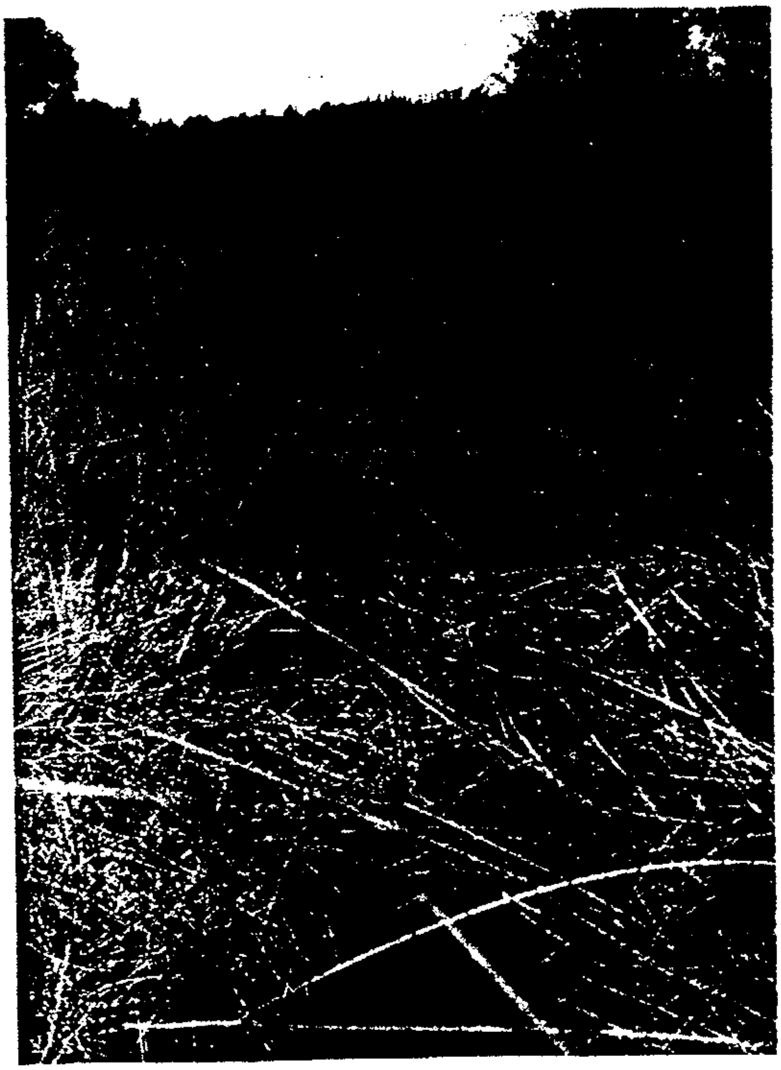


PLATE 14. Egerton Spring (Eg.) - pristine mound springs. Top: view to north-west: swamp in the vicinity of mound springs, tall *Melaleuca* forest in the background. Bottom: dark-water runnel flowing between mound springs obscured by dense native vegetation.

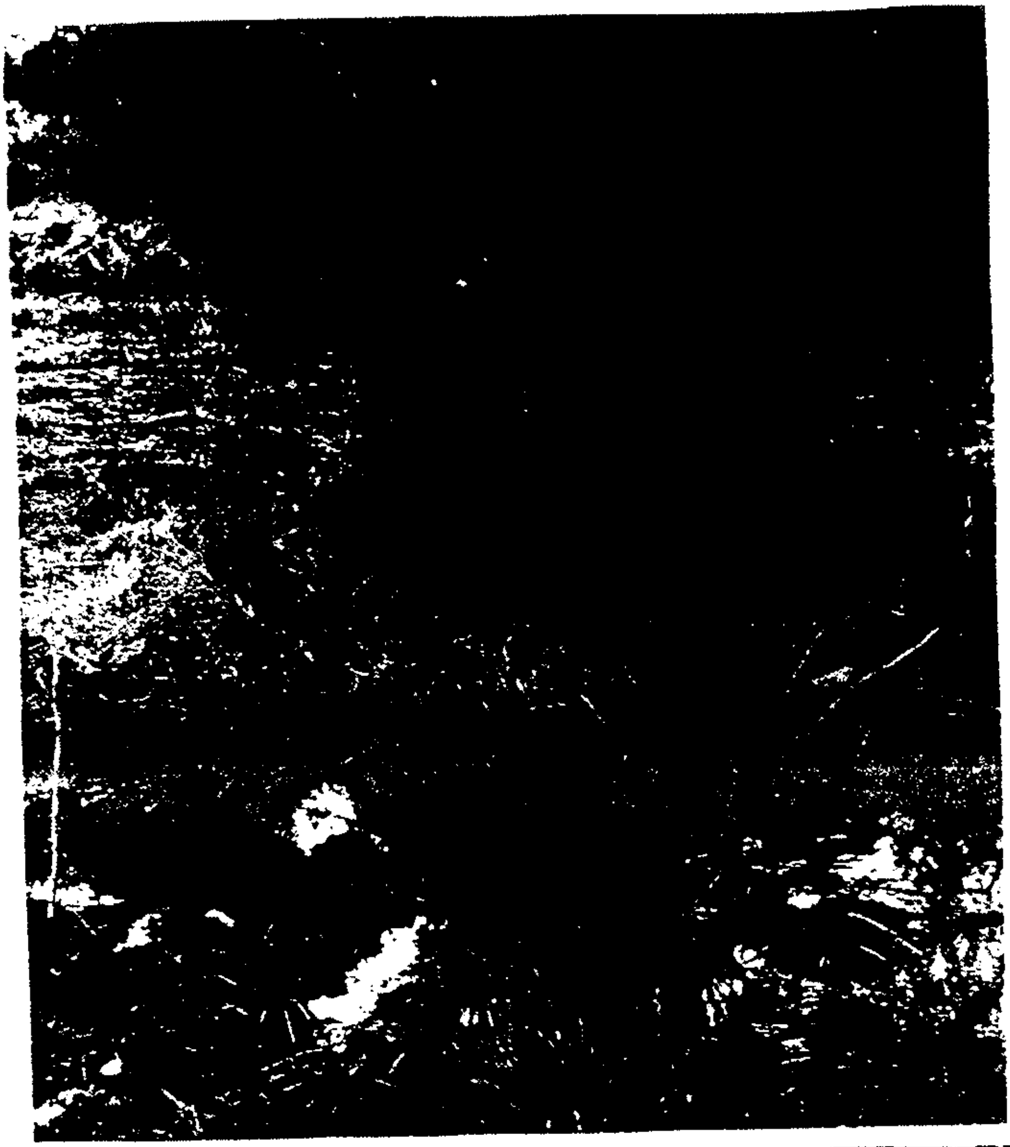


PLATE 15. Tomlinson's property: a very active, excavated mound spring (which later flows into the farm dam). Top: head of the spring beginning at the foot of a clump of vegetation. Bottom: "magnesia" precipitate (probably a Ca^{2+}. Mg^{2+} and carbonate complex).

PLATE 16. Banfield's "Many Springs" property: past area of mound springs. Top: view to the east; springs issuing from boggy ground among *Agonis* shrubs in the middle of a pasture. Bottom: head of a spring emerging from boggy peat and bringing white quartz sand to the surface, "magnesia" precipitate on submerged roots and debris. *Isolepis prolifera* has replaced native plants.

PLATE 17. Mound spring area at Bevan Peters' property. Top: view to the south; *Melaleuca* woodland containing the mound springs. Bottom left: thick undergrowth obscures the form of mound springs in the *Melaleuca* woodland; in the foreground, permanent pools (fauna-rich) exist in depressions burnt out in the peat over the years. Bottom right: mound spring overgrown with ferns oozing water rich in "magnesia".