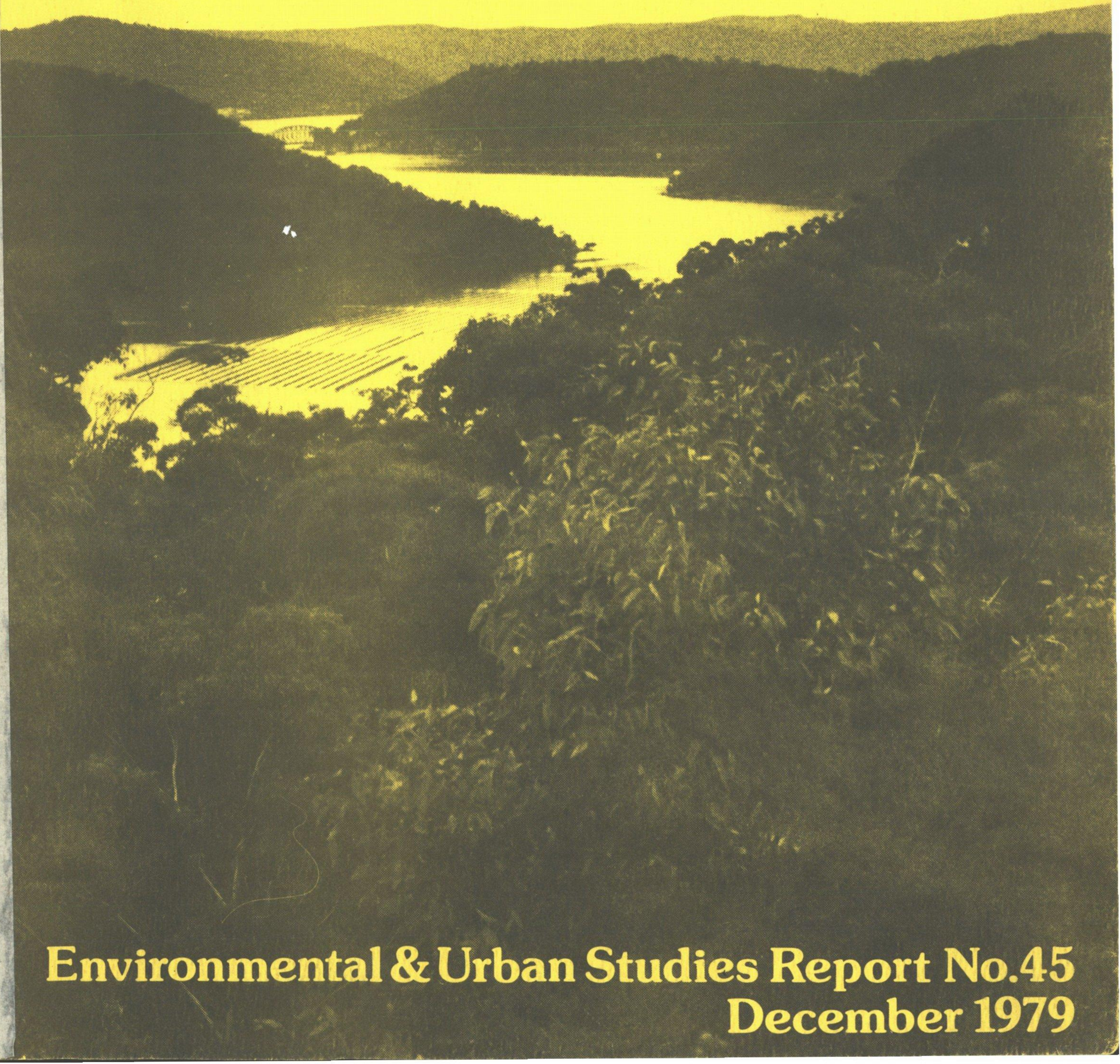
Faunal studies for the proposed Mount White~Kariong~Ourimbah sections of the Sydney~Newcastle freeway (No.3)



Environmental & Urban Studies Report No.45
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PART 1

Mount White to Kariong

FAUNAL STUDIES FOR THE PROPOSED MOUNT WHITE-KARIONG-OURIMBAH SECTIONS OF THE SYDNEY-NEWCASTLE FREEWAY (NO. 3)

Prepared for the Department of Main Roads

New South Wales

by

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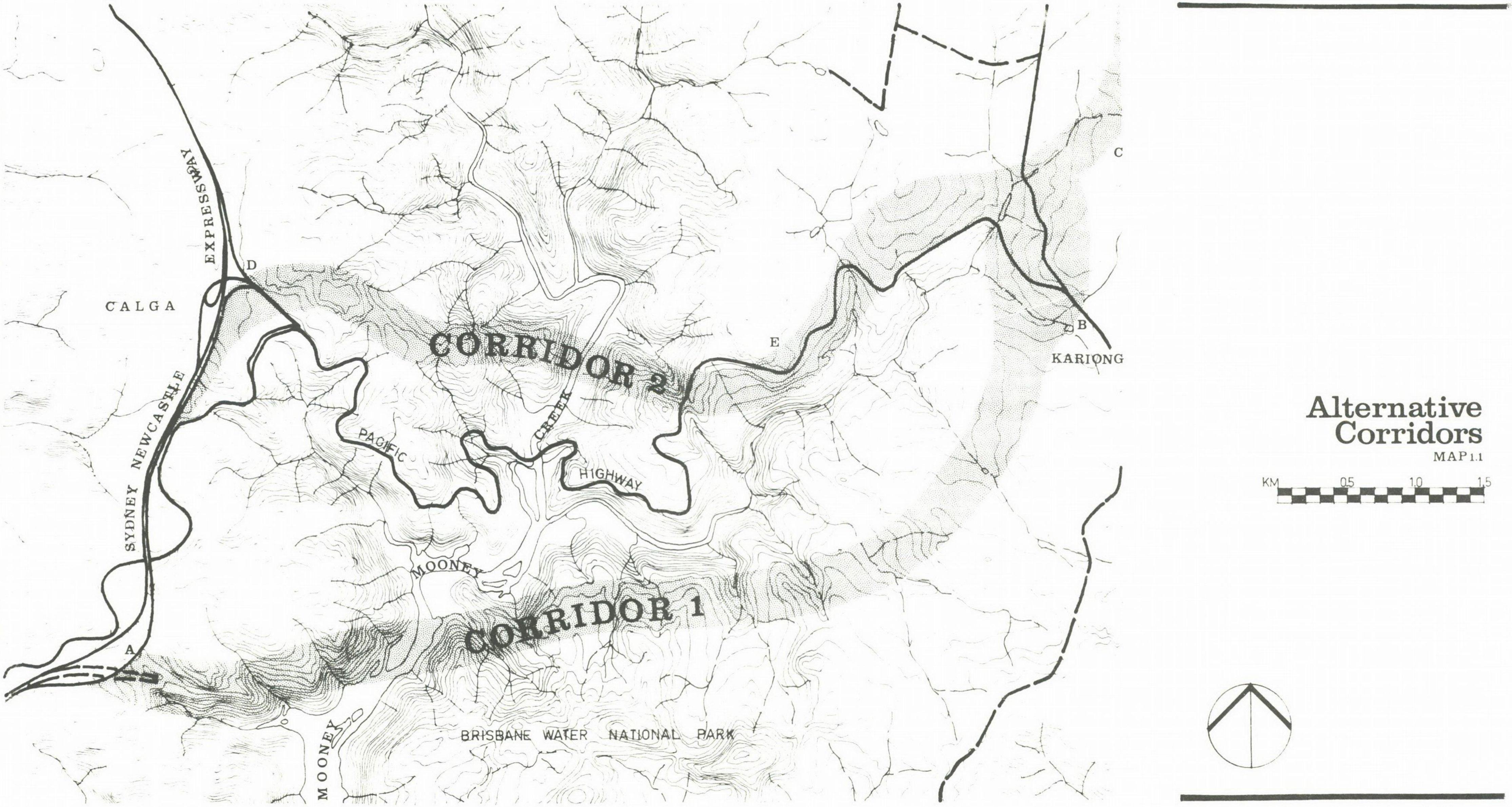

Alternative Corridors

MAP 1.1

1. INTRODUCTION

The Department of Main Roads of New South Wales has proposed two alternative corridors for the Sydney-Newcastle Freeway (Freeway No. 3) between Mount White and Somersby (Map 1.1). Corridor 1 would diverge from the existing Sydney-Newcastle Freeway some 3km South of Calga, while corridor 2 would leave at Calga. The two corridors re-join at Debenham Road, about 3km North of Kariong.

Corridor 1 would cross Mooney Mooney Creek just North of Native Dog Bay. The bridge would be about 560 metres long with its deck some 35 metres above water level. There would be eleven cuts and ten fills along this corridor between Mount White and Mount Penang, as shown in Map 1.2.

Corridor 2 would cross Mooney Mooney Creek about one kilometre North of the present Pacific Highway bridge. The bridge would be about 580 metres long with a deck some 77 metres above water level. It would thus be of similar length to that proposed for corridor 1 but would be set considerably higher over the creek. There would be six cuts and six fills along this corridor between Calga and Mount Penang (Map 1.2).

The Department of Main Roads asked the Centre for Environmental Studies, Macquarie University to establish what impacts, if any, these alternative freeway routes would have on the vertebrate fauna and suggest measures for their mitigation. The study was to be done over three seasons - winter, spring and summer. The Department also requested that priority be given to studies along sections A-B and D-E of the two corridors, with a lower priority to sections B-C and E-C respectively (Map 1.1).

Consequent to this request, the Centre for Environmental Studies appointed Dr. John Broadbent as Senior Investigator for the study and Ian Cranwell as Assistant Investigator.

MAP 1.2

Proposed Cut & Fill

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3. SUMMARY OF FAUNAL IMPACTS AND RECOMMENDATIONS

The following impacts have been identified by the study:

(1) Freeway construction along corridor 1 may cause the loss or modification of some 330 hectares of wildlife habitat including some 130 hectares of Brisbane Water National Park (see 7.1). Freeway construction along corridor 2 may cause the loss or modification of some 190 hectares of wildlife habitat, including some 120 hectares of the proposed Northern extension to Brisbane Water National Park.

(2) Faunally important areas affected by one or both freeway corridors are:

(a) Closed forest, which supported - totally or largely - several species of birds, reptiles and mammals (see 7.1.1). About 8 ha of this habitat lie within corridor 1, less than one hectare in corridor 2.

(b) Cool moist open forest, which supported a particularly diverse avifauna (see 7.1.2). This habitat was also favoured by total bird migrants, contained important feeding sites for the Glossy Black and Yellow-tailed Black Cockatoos and provided

habitat for the Red-browed Treecreeper. About 50 ha of this habitat lies within corridor 1, and about 20 ha in corridor 2.

(c) Mangroves, which play an essential role in estuarine ecosystems (see 7.1.3). About 13% of the total mangrove stand in Mooney Mooney Creek lies within corridor 1, considerably less than 1% within corridor 2.

(d) Closed Heathland, specifically the stand surrounding site 1.10 (see 7.1.4) in corridor 1. Two bird species considered rare or local in the Sydney region - the Brown Quail Coturnix australis *and Tawny-crowned Honeyeater* Phylidonyris melanops *were observed near this study site while the latter species was also observed near site 1.17. (See also Part 2 of this report).*

(e) Sand-mined areas beside Mooney Mooney Creek, which supported large populations of at least seven different frog species - two of which were not recorded elsewhere in the study area (see 7.1.5).

(3) Fragmentation of habitat may well be the most significant impact of freeway construction (see 7.2). Current theories on minimal viable populations coupled with the known spatial needs of some species would suggest that construction of the freeway may jeopardise the future survival of most larger mammals recorded from Brisbane Water National Park and its proposed extension. The

extent of this impact would be similar regardless of which corridor is chosen.

(4) *Wildlife mortality through vehicle-wildlife collisions may be expected to occur when freeway construction is complete (see 7.3). The importance of this impact is hard to assess although the isolation of Brisbane Water National Park and its proposed extension from other areas of natural vegetation - and hence sources of faunal replenishment - could make it significant.*

(5) *Erosion during and after freeway construction could have a significant impact on aquatic ecosystems, through sedimentation in Piles and Mooney Mooney Creeks (see 7.4). Oyster beds downstream of the study area could be adversely affected. The extent of this impact may be similar whichever corridor is chosen.*

(6) *The predictably heavy traffic flow rates along the completed freeway will result in pollution of nearby ecosystems (see 7.5). Increased levels of lead and other substances may be expected in soil, plants and animals close to the freeway while nearby waterways may receive both accidental spillage and vehicle-derived pollutants from the freeway. The environmental effects of these pollutants are not well understood.*

(7) *The proposed cut-and-fill method of construction is likely to alter the hydrogeology of catchments with consequent impacts on*

the flora and fauna (see 7.6). Two specific examples of this impact are the effect of fills on water movement through individual catchments and the disruption to water movement over shale beds within the Hawkesbury Sandstone caused by cuttings. This latter impact may be especially important since some upland swamps probably rely on this water flow for their existence. There is insufficient information to assess the relative hydrogeologic impacts of the two proposed routes, although the fact that corridor 1 crosses several more moderate-sized creeks than does corridor 2 would suggest that this corridor will have the larger impact.

(8) *Construction of the proposed freeway along corridor 1 may increase the incidence of fire in a previously unroaded part of Brisbane Water National Park (see 7.7). Construction along corridor 2 could - especially if the Pacific Highway between Calga and Kariong was closed to general traffic - actually lessen the likelihood of road-related fires in the area.*

N.3.

(9) *The proposed freeway may constrain the ability of fauna to respond to fire or drought, especially if fire and drought refuges occur principally on one or other side of the proposed freeway corridors (see 7.7 and 7.8).*

(10) *Dust generation may, by affecting the photosynthetic efficiency of nearby vegetation, have a transient, very local and limited impact on the fauna (see 7.9.2).*

(11) *Disposal of construction wastes toxic to vegetation and wildlife may have an impact, particularly if these substances reach flowing water (see 7.9.3).*

(12) *The proposed freeway may facilitate access to Brisbane Water National Park and its proposed extension by introduced mammals and birds, especially if areas cleared during construction are replanted with exotic species (see 7.9.4).*

The adverse faunal impacts described above should be largely mitigated by adoption of the following practices:

(1) *Construction of the freeway along corridor 2 (slightly modified if necessary) rather than corridor 1, to disturb less faunal habitat, affect fewer faunally-important areas and lessen hydrological impacts (see 8.2).*

(2) *Minimal clearance of natural vegetation before construction and replanting of cleared areas with local plant species after construction (see 8.3), to maintain the integrity of the existing vegetation and its value as faunal habitat, obviate the need to apply herbicides and fertilisers, greatly lessen if not eliminate mowing, and discourage invasion by fauna alien to the area.*

(3) *Selection of a bridge design for Mooney Mooney Creek crossing that would not hinder wildlife movement beneath the bridge by structural members (see 8.4).*

(4) *Minimal disturbance of vegetation beneath the proposed bridge crossing (e.g. by clearance, access roads, materials dumps, machinery parks) and prompt revegetation of any disturbed areas (see 8.4).*

(5) *Use of culverts of substantial dimensions or, preferably, bridges instead of fills to cross waterways in faunally significant areas and through Brisbane Water National Park or its proposed Northern extension generally (see 8.4 and 8.5.3). This practice will mitigate the likely adverse impacts of the freeway on the viability of large mammal populations, faunal movement in response to fire and drought, creek ecology and various hydrological factors.*

(6) *Closure of the Pacific Highway between Calga and Kariong when freeway construction is complete, apart from access to properties along Mooney Mooney Creek and for fire-fighting purposes. This measure should lessen the incidence of road kills (see 8.4) and road-related fires (see 8.7).*

(7) *Careful control of erosion during and after freeway construction. Specific recommendations given in section 8.5.1 should minimise this, potentially severe, impact on the aquatic eco-systems of Piles and Mooney Mooney Creeks and their tributaries.*

(8) Dispersal of runoff waters locally within the freeway corridor rather than via the creeks (see 8.6), to both lessen the scouring and erosive effects of increased water flows in these creeks and prevent their pollution by vehicle-related pollutants and accidental spillage.

(9) Controlled burning of vegetation within the freeway corridor in co-operation with the National Parks and Wildlife Service, to prevent the spread of fires originating from the freeway into the National Park and its proposed extension (see 8.7).

(10) Closure of freeway to traffic should severe fires force wildlife onto the road (see 8.7).

(11) Control of dust during construction to minimise the probably small and transient impact this may have on nearby vegetation (see 8.8).

(12) Careful regulation and disposal of construction materials toxic to wildlife and vegetation (see 8.9).

(13) Explanation of all mitigation procedures adopted to staff and contractors, so that the rationale behind such practices is clear (see 8.1).

(14) Monitoring of mitigation procedures during and after construction, to assess their effectiveness and to promptly implement any necessary remedial action (see 8.1).

(15) *Close co-operation with the National Parks and Wildlife Service, to minimise all adverse environmental impacts during construction of the proposed freeway through Brisbane Water National Park or its proposed extension.*

4. WILDLIFE-HIGHWAY INTERRELATIONSHIPS — LITERATURE REVIEW

4.1 Introduction

Highways are vital to modern society, for they are a major factor in achieving and sustaining the high standards of living to which this society has become accustomed. However, it is not enough to consider highway construction on engineering factors alone. Other criteria - such as safety, aesthetics, and effects on the social and natural environment are matters of increasing public concern.

Highways are one of man's more visible impacts on the natural environment. In the United States, for instance, there were almost 4 million miles of rural and municipal highways and streets in 1973 - more than one mile of road for every square mile of land (U.S. Department of Transportation, 1973). As early as 1943, van Dersal calculated that 20 million acres (about 1%) of the total land area of the United States (1,903 million acres) were committed to highways and roads. The figure is likely to be higher today. Jordan (1968), in an account of North America's developing interstate highway system in the late 1960's, observed that:

> "The super-roads are gobbling up 1.6 million acres for right of way - an area larger than the State of Delaware. Enough material is being excavated to bury Connecticut knee-deep. The sand, gravel, and stone going into the roads would build a wall 9 feet thick and 50 feet high around the entire world."

In Australia, there were some 840,000 kilometres of roads open to general traffic by mid-1976, 190,000 of which were in New South Wales (Australian Bureau of Statistics, 1978).

These figures suffice to convey some idea of the huge impacts that highway systems have on the natural environment. For many, the most tangible evidence of this is the dead animals along our highways. A U.S. Fish and Wildlife Service biologist estimated that some 57 million birds are killed each year on the highways of the United States (Aldrich, 1975). While there is inadequate information on wildlife mortality on Australian roads (van Gessel, 1972; Vestjens, 1973; Disney & Fullagar, 1978), it may be that at least a million birds and a third of a million mammals are killed annually on our roads. Whether this impact has a lasting effect on wildlife populations is unknown.

Even after their use for transportation ceases, roadways may influence the environment for millenia. In France, for instance, a distinctive strip of vegetation extends through the forest between Orlean and Sens. This 60-foot wide band defines the path of an ancient Roman Road. Limestone slabs used in its construction have formed an alkaline soil (pH7.3 to 8.0), contrasting with acid podzolic soils (pH3.0 to 4.5) characteristic of the area (Milleret, 1963). The substantial cuts through Hawkesbury Sandstone which are such a prominent feature of the existing Sydney to Newcastle freeway may also survive for many millenia - perhaps long after their original purpose has passed.

These few observations make it clear that highways can have a considerable impact on the natural environment. Highway authorities, in the fullness of their responsibilities to the community, should seek to reconcile their own activities with the needs of the natural environment.

This review describes the various ways in which highways interact harmfully with the natural environment. These are manifold and often subtle: most are represented to a greater or lesser extent in the present Brisbane Water study. At the same time, the ways in which these impacts can be mitigated are also many and varied, and a sensitive and thoughtful understanding of the environmental issues involved will do much to help their satisfactory resolution. This review owes much to the substantial work of Leedy (1975) on the same subject.

4.2 Hydrological changes

4.2.1 Introduction

Water is the sustenance of life, and waterways the arteries of supply. And yet man is curiously negligent of this vital resource, as the state of most urban waterways testifies. Highways, in common with other construction activities, can have major hydrological impacts. McElroy et al. (1975), for example, found that the rate of erosion from construction activities was about 2,000 times that from undisturbed forest and was matched in this respect only by erosion from active surface mining. The increased rate of sedimentation in Narrabeen Lagoon in recent years has been attributed primarily to construction activities in the lagoon catchment (State Pollution Control Commission, 1978). The very nature of highways also creates more specific hydrological impacts - such as those related to groundwater, channelization and stormwater runoff.

4.2.2 Erosion and sedimentation

Vice, Guy & Ferguson (1969) followed erosion patterns within a 4.5 $mile^2$ catchment subject to highway construction. They found that although construction activities at no time covered more than 11% of the catchment, they nevertheless contributed 85% of sediment leaving the catchment. The construction activities produced an estimated 69,400 tons of sediment over a 3-4 year period. Wolman (1964) found that up to 3,000 tons of sediment were produced for each mile of divided highway constructed in urban areas of Maryland, U.S.A. Briggs (1969) calculated that if the eroding sections of highways in Wisconsin were joined end to end, they would extend from Madison to New York and back across the continent to Los Angeles. There were 21,000 sediment-producing sites on the State's 87,000 miles of roads - a total of 3,711 miles of bare banks. Using an average width of 16 feet, their combined area amounted to almost 7,300 acres. A follow-up study by Massie & Bubenzer (1974) four years later, showed a 20% drop in the total area subject to erosion - mainly through improved erosion control practices during new highway construction.

In Australia, Cordery (1976) studied sediment changes in a small creek just South of Sydney before, and about one year after, construction of a major highway across its catchment. The catchment had an area of 0.38 km^2 and the highway and its embankment on completion occupied about 20% of this area. Although sediment yields were not measured during construction, one year after completion there were levees of fresh sand at least 50cm deep on both banks and extending downstream a distance of 2km to the confluence with a very much larger stream. There were sandbanks up to one and a half metres deep at minor confluences along the creek, extending over hundreds of square metres of the former flood plain.

Sedimentation of this kind can have considerable effects on aquatic life. Congressional Record in recent years contains numerous references to the destruction of trout fisheries in Western streams of the United States, caused by erosion and sedimentation from highway construction parallel to the streams. Studies by the U.S. Fish and Wildlife Service suggest that it may take many years to re-establish the ecology of streams once the benthic life has been destroyed by sedimentation. Whitney & Bailey (1959) found that the reduction in game fish caused by highway construction in an area of Montana ranged from 95% in both numbers and weight of the large-sized fish to 85% in number and 76% in weight of the small-sized fish.

In Australia, Ellway & Hegerl (1972) followed the effects of sedimentation from sand dredging on the benthos and nekton of the Tweed River estuary in northern New South Wales. Three weeks after dredging began about 70% of the benthic flora from the dredging site to a point 450m downstream was dead. Sand removal operations ceased after four weeks but seven weeks after the start the bottom was devoid of nearly all sessile animals and algae. There was also a marked reduction in the number of fish species and, for most species, in the number of individuals also. There was some regrowth of algae and an increase in fish populations thirteen weeks after the commencement of dredging. After about 30 weeks both benthic and fish populations seemed to have recovered. Analogous effects to these may be predicted from uncontrolled erosion during highway construction.

4.2.3 Groundwater

Parizek (1971) found that the presence of deep cuts and extensive fills in highway constructions can produce a variety of transformations on the terrain and in the hydrogeologic regime, including the beheading of aquifers, development of extensive groundwater drains, damage and pollution of water supplies, changes in groundwater and surface-water divides and basin areas, reduction of induced streambed infiltration rates, obstruction of groundwater flow, and changes in runoff and recharge.

Such changes in the existing pattern of groundwater distribution could considerably modify the associated vegetation and its fauna.

4.2.4 Channelization

A highway crossing a stream can disturb its natural state, increase flood peaks, change flow patterns, and consequently often require the enlargement, relocation or realignment of the stream.

Several authors have studied the impacts of channelization on aquatic animals. Platts (1968) found that the restrictions to passage and access caused by road culverts prevented the movement of both adult and juvenile fish between their rearing and production areas. Patrick (1973) found that channelization can:

a. Remove the natural diverse substrate materials necessary for the development of many types of aquatic organisms.

b. Increase sediment loads thereby decreasing light penetration and primary production.

c. Create a shifting bed load that is inimical to bottom-dwelling organisms.

d. Simplify the current pattern and thus eliminate habitats of diverse currents.

e. Lower the stream channel and so drain adjacent swamp areas and aquifers. These swamp areas may help to maintain stream flow during times of low precipitation and may also be important breeding or feeding sites for fauna.

f. Lower the stability of banks, causing cave-ins and loss of trees and other overhanging vegetation. These latter can be an important source both of food and shade to stream life.

Tarplee, Louder & Weber (1972) described detrimental effects of stream channelization on aquatic organisms but indicated that, without further interference, a coastal plain stream and its fish population will return reasonably near to its former condition.

The rate of water discharge through culverts is also an important consideration, for flow conditions should allow for the upstream passage of migrating fish and other fauna. Dryden & Jessop (1974), for example, found that water velocities through a culvert under the Dempster Highway prevented fish migration during 40 days of the year. The U.S. Department of Agriculture, Forest Service (California Region) (1974), in an inventory of fish and wildlife habitat improvement needs, noted that:

> "Many fishes in the course of their life cycle, migrate upstream at certain times of the year to reach suitable spawning or feeding areas. Their access to these waters is often prevented by various stream crossing structures installed by man, such as culverts, weirs, dams, and certain types of bridge abutments. Most such barriers can be modified at reasonable expense to provide adequate fish passage. Elimination of these barriers is an important factor in restoring and maintaining our trout and salmon resources".

The way in which channelization can lead to the drainage of adjacent swamplands has been mentioned already. An example is provided by the U.S. Department of the Interior, Fish and Wildlife Service (1973), which sampled 28,953 miles of highways in Western Minnesota and found that 99,292 acres of associated wetlands had been drained by channelization during highway construction.

4.2.5 Stormwater runoff

Lanyon (1972) pointed out that while highly efficient stormwater drainage may be beneficial to a highway, it can be detrimental to the waterways into which the runoff is discharged. There are two reasons for this. On the one hand, the flow rate may be much greater than that which occurred before highway construction, with consequent problems of bank erosion, increased scouring and associated changes in the nature of the creekbed. Such impacts can have profound effects on the associated fauna.

On the other, stormwater may introduce highway pollutants into the waterway. Newton, Shephard & Coleman (1974), for example, found that street runoff in Oklahoma City was a significant non-point source of lead in the headwaters of one branch of the North Canadian River. A more comprehensive study by Hedley and Lockley (1975) showed that the annual drainage from 36,000m^2 of a heavily-used highway in Britain contained 170 tonnes of motor vehicle pollutants, 76 tonnes of rocksalt and suspended sediments (from salting operations) and three tonnes of industrial fall-out. Among the motor vehicle-derived pollutants were iron (from vehicle corrosion), zinc (from tyres and motor vehicle components), lead (from car exhausts) and rubber (from tyres). Biochemical oxygen demands of the runoff water ranged from 4mg/l to 64.5mg/l.

Vehicle-derived pollutants are considered more fully in section 4.4 below

4.3 Habitat

4.3.1 Loss or alteration

Highway construction requires the clearing, grading and surfacing of large areas of habitat, whether agricultural land, forest or grassland. For example, the U.S. Council on Environmental Quality (1974) estimated that each mile of interstate highway can require the alienation of up to 48 acres of wildlife habitat. Way (1970), in the United Kingdom, estimated that each mile of motorway commonly required 20 acres of land, while Wolman (1964) found that 10-35 acres of land were disturbed for each mile of divided land highway constructed in urban areas of Maryland, U.S.A.

4.3.2 Fragmentation

The role of highways as a barrier to animal movement is a matter of increasing public concern. The most detailed study to date is that by Oxley, Fenton and Carmody (1974), who determined by trapping and direct observation the willingness of twelve species of small and medium-sized forest mammals to cross eight roads. The roads differed in traffic volume (4 to 600 vehicles/hr), surface (gravel/ bitumen), and clearance (i.e. the distance an animal had to move between forest margins on crossing the roadway). The studies suggested that clearance rather than traffic volume or road surface was the most important factor inhibiting the movement of forest mammals across roads. Small forest mammals very seldom ventured on to roads where the distance between forest margins exceeded 15 metres. While medium-sized forest mammals (e.g. Snowshoe Hare *Lepus americana,* Porcupine *Erethion dorsatum,* Racoon, *Procyon lotor*) appeared reluctant to cross roads with a clearance of more than 20 metres, they would occasionally cross much wider roads (over 93 metres). Oxley et al. (1974) concluded that divided highways with clearances of 90 metres or more may be as effective barriers to the dispersal of small forest mammals as bodies of fresh water twice that width.

In Australia, Barnett, How and Humphreys (1978) found that certain small mammals appear even more reluctant to cross roads. Thus the Fawn-footed Mosaic-tailed Rat *Melomys cervinipes* did not cross an old fire trail 3 metres wide "which had long been closed by fallen trees, covered by low ground vegetation and had a slight litter cover". Even the brown marsupial mouse *Antechinus stuartii* and the bush rat *Rattus fuscipes* were reluctant to cross this trail and only the latter was prepared to cross a 4.5m wide unsealed road (which carried up to 20 vehicles/day).

Some large mammals also appear reluctant to cross highways. Ward (1973), for example, found that elk would not cross an interstate highway in the United States. Roads may also restrict the movement of some birds. Thus Diamond (1975) stated that:

> "Many species, especially those of tropical rain-forests, are stopped by narrow dispersal barriers. For such species even a highway swath through a reserve could have the effect of converting one large island into two half-sized islands".

A highway, by acting as a barrier, may so reduce the effective size of a wildlife refuge that extinction of some of the associated fauna may occur either through such phenomena as fire, epidemic disease or drought or through loss of genetic viability.

The matter of genetic viability may need explanation. It is true that small populations are viable in the sense that they survive over many generations. Indeed animals in zoos will, through breeding, maintain their species for decades. However such populations lack the genetic variability within them to adapt to a changing environment, to continue evolution and to avoid random extinction by, say, the introduction of a lethal mutation. Genetic variability prevents such catastrophes, and in itself sets a lower limit on population size. There is no consensus on how large this minimum population should be. Main and Yadav (1971), who studied kangaroo and wallaby populations on islands off the coast of Western Australia, concluded that 200-300 animals constituted a minimum viable population. Theoretical studies of animal population genetics however suggest that the minimum breeding population of any species is about 1,000 individuals. To allow for natural fluctuations in populations and restrictions enforced by social behaviour, a figure of at least 5,000 individuals is generally considered adequate (Tyndale-Biscoe & Calaby, 1975). Soulé (1972), for example, found significant loss of genetic variability in populations of lizards ranging from several hundred to several thousand individuals, and he concluded that populations in the order of 10,000 were needed to secure long term retention of genetic variability.

In order to determine the areas needed to support viable populations of mammals, it is necessary to know not only the minimum population size needed to maintain genetic variability but also the area required by each member of that population for survival. Once again, this information is scanty and inadequate. Edwards and Ealey (1975) established home ranges for the Swamp Wallaby *Wallabia bicolor,* a species present in Brisbane Water National Park, of between 4.5 hectares (males) and 7.2 hectares (females). While these ranges overlap to some extent, they compare reasonably with the figure of 10 hectares/animal suggested by Slatyer (1975) for the Grey Kangaroo *Macropus giganteus* in the humid areas of South-eastern Australia. The Greater Glider *Schoinobates volans* needs about 1.2 hectares/animal (Tyndale-Biscoe & Calaby, 1975).

If we accept 5,000 individuals as the minimum population size for long-term survival, then these figures suggest suitable habitat requirements of 22,500-36,000 hectares for swamp wallabies and 6,000 hectares for Greater Gliders. Carnivorous animals such as the Tiger Cat, *Dasyurus maculatus* have very much lower population densities than herbivores of similar size, and may thus require larger areas still for survival.

The construction of a major highway across an area which, in itself, is large enough to sustain viable populations of its associated fauna, may thus leave areas too small to support some of that fauna.

4.4 Pollution

4.4.1 Lead from vehicle emissions

The biological effects of vehicle-derived lead are much-discussed and contentious. Current knowledge would suggest, though, that lead has at most a limited impact on wildlife near to major highways.

Lead is added to petrol as tetramethyl and tetraethyl lead at rates of about 0.6g/l in order to improve combustion in vehicle engines. After combustion some 75% of this lead is exhausted to the atmosphere as particles of lead halide or complexes of ammonium halide and lead halide.

Earlier this decade, some 300,000 tons of lead were being discharged annually into the air of the United States alone from the exhausts of motor vehicles (Craig & Berlin, 1971), while it has been estimated in Australia that 6,000 tons of lead were used as a petrol additive in 1971 (Noller & Smythe, 1974).

Many studies since the early 1960's have largely defined the pattern of lead deposition beside highways (e.g. Warren & Delavault, 1960; Cannon & Bowles, 1962; Chow, 1970; Singer & Hanson, 1969; Daines et al., 1970; Lagerwerff & Specht, 1970; Motto et al., 1970; Sylvester & DeWalle, 1972; Ter Haar, 1970; Maclean, Halstead & Finn, 1969; Quarles, Hanewalt & Odum, 1974). These studies showed that:

a. Lead concentrations are highest in soil immediately beside a highway and decrease exponentially with distance such that there is at least 50% decrease in level some 50m from the road. Even so, the areas of habitat affected by increased lead levels may be considerable in national terms. Smith (1976) calculated that, assuming the influence of lead extends for 50m on either side of a highway, the size of the roadside ecosystem in the U.S.A. with elevated lead levels may approximate 3.04×10^7 hectares or 118,000 square miles.

b. In addition to distance from the road, numerous other factors can determine lead levels. Among the more important of these are traffic volume, proximity to other roads, prevailing winds, turbulence, and topography.

c. The lead is concentrated in the uppermost portion of roadside soil. Frequently the lead content at 10-15cm is only 35% or less of that at 0-5cm, although this varies with soil conditions.

d. Although the lead particulates probably reach the soil surface in the relatively soluble halide form, they appear to react rapidly with either soil anions (e.g. phosphates, carbonates and especially sulphates) or soil organic and clay complexes to become insoluble. This would preclude rapid mobility in the soil and restrict plant or microbial uptake.

The biological implications of lead accumulation alongside highways are still being assessed. In respect of roadside vegetation, it appears that lead may be accumulated from both the air and soil.

Contamination of above ground plant parts from the air may be via gravity settling, impaction or precipitation. The relative importance of these transfer mechanisms is unclear, but the first is generally considered the most important. Contamination from the air generally appears to be topical as it can be largely removed by washing. Plants from close to a highway have been found with lead levels over 900 times the background level, although a more common figure is 50-200 times.

Studies in Australia and New Zealand confirm the relevance of these findings on the distribution of lead near to highways and its accumulation in roadside vegetation to these countries (Wylie & Bell, 1973; Noller & Smythe, 1974; David & Williams, 1975; Ward, Reeves & Brooks, 1975).

In respect of the fauna, several studies have been made on the possible effects of roadside lead on elements of the invertebrate fauna. The examination of non-soil, roadside insects and spiders has given variable results regarding lead accumulation (Maurer, 1974; Giles, Middleton & Grau, 1973; Williamson & Evans, 1973). The studies of Price, Rathcke & Gentry (1974), however, suggested that lead uptake was greatest among those species which preyed on other insects, while those which chewed plant parts or sucked sap contained progressively lower lead levels. These results indicated that some biological concentration of lead through food chains was taking place. The authors suggested that, since insects make a significant contribution to energy flows through ecosystems, their ability to concentrate lead could prove harmful to vertebrate predators later in the food chains. This view received some support from the studies of earthworms along two Maryland highways by Gish & Christensen (1973). These workers found that the earthworms accumulated up to 331.4ppm lead and concluded that such levels could be toxic to animals which fed on earthworms (e.g. birds, amphibians, reptiles, and mammals).

Concurrently with these studies, investigations have been made into the effects of roadside lead on vertebrate species, mostly small mammals. Those found near to busy highways accumulated large amounts of lead (Jefferies & French, 1972; Quarles, Hanawalt & Odum, 1974; Mierau & Favara, 1975; Welch & Dick, 1975; Getz, Verner & Prather, 1977; Edwards et al. 1971; Welch & Wilber, 1972). The lead was accumulated particularly in the bones, with lesser accumulations in the kidneys, liver and, sometimes the brain (Quarles, Hanawalt & Odum, 1974; Mierau & Favara, 1975; Welch & Dick, 1975; Getz, Verner & Prather, 1977), as had been anticipated by earlier studies (Hueter et al., 1966; Smith, Szajnar & Hecker, 1970). When more than one species of small mammal occurred in the same locality, there were often differences between species in the amounts of lead accumulated. These differences were probably due to such factors as metabolic level, type of diet, amount of food consumed, proportion of range in high lead areas and life span (Jefferies & French, 1972; Quarles, Hanawalt & Odum, 1974; Getz, Verner and Prather, 1977).

None of these studies clearly demonstrated any effect of lead uptake on the health, reproductive ability or ecology of the animals examined. Quarles, Hanawalt & Odum (1974) found very few shrews in an area of high lead levels and surmised that this may have been attributable to the lead. However, the lead levels recorded in most of these studies showed only sublethal effects on experimental animals (c.f. Jefferies & French, 1972; Quarles, Hanawalt & Odum, 1974). Perhaps of greater concern is the possibility of biological concentration. As has been mentioned already, carnivorous insects and small mammals both showed higher lead levels than their herbivorous associates in the same localities. It is unfortunate that extensive studies on lead levels in birds-of-prey and scavengers especially, which frequently hunt along highways, have not yet been made.

4.4.2 Other vehicle-derived pollutants

There are many sources of surface contaminants on a roadway, including materials from industrial operations, accidental spillage, land use activities, fallout of air pollutants, vehicle wear-and-tear. These materials are then carried into receiving waters by storm-runoff (see 4.2.5). Shaheen (1975) noted that in urban areas less than 5% of the weight of traffic-related deposits originated directly from vehicle wear-and-tear; however, these pollutants are among the most important by virtue of their potential toxicity. Shaheen considered that:

> "Much of the grease and all of the petroleum and n-paraffins result from spills or leaks of motor vehicle lubricants, antifreeze and hydraulic fluids. Traffic-related lead is deposited principally through the use of leaded fuels, although some results from the wear of tyres in which lead oxide is used as filler material. Zinc is also used as a filler in tyres and at high concentrations in motor oil as a stabilizing additive. Copper, nickel and chromium are wear metals from metal plating, bearings, bushings, and other moving parts within the engine. Considerable copper is deposited as a result of wear of brake linings which have copper added to increase mechanical strength and promote more rapid dissipation of heat. As reported in recent studies of motor vehicle operations, asbestos arises from wear of clutch and brake linings and tyre wear is the source of traffic-related rubber found in roadway deposits".

Additionally, greases and petrol leaking from vehicles may leach or dissolve out substances from the asphaltic binders used in paving materials (Scheidt, 1971).

Accidental spillage of substances transported on highways may also cause pollution. Substances dangerous to the environment derived from this source include explosives, flammable petroleum products, poisonous gases, radioactive materials, pesticides, herbicides and a wide range of industrial chemicals. There have been many examples of truck accidents where spillage was discharged via the highway into adjacent waterways, causing widespread pollution and associated fish kills. A general assessment of the accidental spillage problem and its environmental implications is given by Hopkin (1976).

There is as yet too little information to assess the environmental significance of such sources of pollution. Lagerwerff & Specht (1970) found that the pattern of cadmium, nickel and zinc deposition in roadside soil and grass closely resembled that for lead (4.4.1), in that concentrations decreased rapidly both with distance from the highway and with depth in the soil. The latter observation suggests that, as with lead, the metals are present in an insoluble form and so are likely to have less environmental impact than might be otherwise expected. Huntzicker <u>et al</u>. (1974) estimated that some 550kg of zinc are deposited daily in tyre dust on or near roadways in the Los Angeles urban area.

Gish & Christensen (1973) also found that the concentrations of cadmium, nickel, lead and zinc in roadside soils decreased with distance from the highway and increased with traffic volume. Earthworms in these soils particularly concentrated cadmium (11 x soil concentrations) and zinc (6 x soil levels). In respect to the concentrations of the metals these authors detected, and their known toxicity, Gish & Christensen suggested that animals feeding on earthworms over extended periods along many highways could acquire toxic levels of lead and zinc. As noted previously (4.4.1), this possibility has not yet been examined.

4.4.3 Biocides

Biocides may be used either during the construction of a highway or in its maintenance. Thus pesticides may be used especially to protect wooden structures and structural elements from attack by termites, while herbicides may be used to control roadside vegetation. The latter have, on occasion, been carried by wind into neighbouring properties with consequent damage to crops, shrubs and trees. Excessively applied biocides may reach adjoining waterways, with harmful effects on the aquatic biota.

The environmental significance of biocide use in highway construction and maintenance is poorly understood and needs careful assessment.

4.4.4 Construction dust

Eller (1977) examined the effect of increased dust levels on the spectral properties and temperatures of leaves. Leaf temperature is a major determinant of photosynthesis in plants. Since respiration tends to increase much faster with rising temperature than does photosynthesis, any increase in leaf temperatures will decrease net photosynthesis and hence productivity. This, in turn, will ultimately have repercussions through the food chain.

Eller found that the temperatures of clean leaves were 3 to 12°C above that of the surrounding air and that a layer of dust caused a further increase of 2 to 4°C. At average temperatures this difference should have little influence on photosynthesis or respiration. However dust may exert a strong influence on net photosynthesis and productivity under more extreme temperatures, when a change of a few degrees could have a marked effect on photosynthesis.

This impact is likely to be very local in nature and, at least in respect of highway construction, transient in effect.

4.5 Wildlife mortality

One of the most direct effects of highway use on wildlife is the death of animals from vehicle-wildlife collisions. Some estimates as to the magnitude of this impact have been given already. At least three studies of wildlife mortality on roads have been made in Australia; in each case the incidence of dead animals was established while travelling over a particular route. The most comprehensive study is that of Vestjens (1973), who surveyed wildlife mortality during monthly trips along 300km of road between Canberra and Lake Cowal for two years. Vestjens estimated an average casualty rate of one bird every thirteen kilometres, one mammal every thirty kilometres, one reptile every 176 kilometres and one amphibian every 1,112 kilometres. Bird casualties peaked through the months of November to March each year, as young birds left the nest. Vestjens considered that his survey underestimated the true casualty rate for several reasons, mostly related to the rapid removal of injured or dead animals from the road before censusing.

Disney & Fullagar (1978) found casualty rates very similar to those of Vestjens along the Hume Highway between Yass in New South Wales and Seymour in Victoria. On two separate occasions they recorded a dead bird every 12 and 33 km respectively and a dead mammal every 45 and 35 km respectively. Van Gessel (1972), in a study of wildlife casualties on the New England Highway between Newcastle and Brisbane recorded a dead animal every 6 km. A notable feature of all three surveys was the high incidence of predators and scavengers among the animals killed - owls, birds-of-prey, cats, dogs and foxes - these presumably being killed while seeking dead animals on the road. Finally, Pearse (1972) described the death of 73 wombats during a twelve-month period on a section of the Alpine Way in Kosciusko National Park, despite the presence of several "Wildlife on Road" signs.

While the figures for wildlife mortality may seem spectacular - especially when extrapolated to national estimates - it is often argued that the loss is not significant in terms of the overall populations of most species. This is because only a small proportion of the overall range of a particular species is usually affected by highways. While this may be true in general, wildlife mortality on roads could at times cause local extinctions. An example would be a wildlife refuge or even National Park which is too small to sustain highway losses relative to the replacement rates of its wildlife population.

An important facet to wildlife mortality on highways is the attendant damage to property and, at times, the loss of human life. Puglisi (1974), for example, estimated that some 130,000 deer-vehicle collisions occur each year in the United States, with an estimated property loss exceeding $34.5 million. Harding (1975) estimated that wildlife-vehicle collisions on or off the roadway in the United States during 1973 were responsible for 118 human deaths, 7,778 cases of injury and 65,381 cases of property damage. Cost-benefit studies have demonstrated a positive benefit for some accident prevention structures in Colorado (Woodward & Reed, 1974). These studies showed that benefits derived from reduced automobile repair costs could equal structure cost in 7.5 years or less.

MAP 5.1

Study Area & Sites

5. STUDY AREA

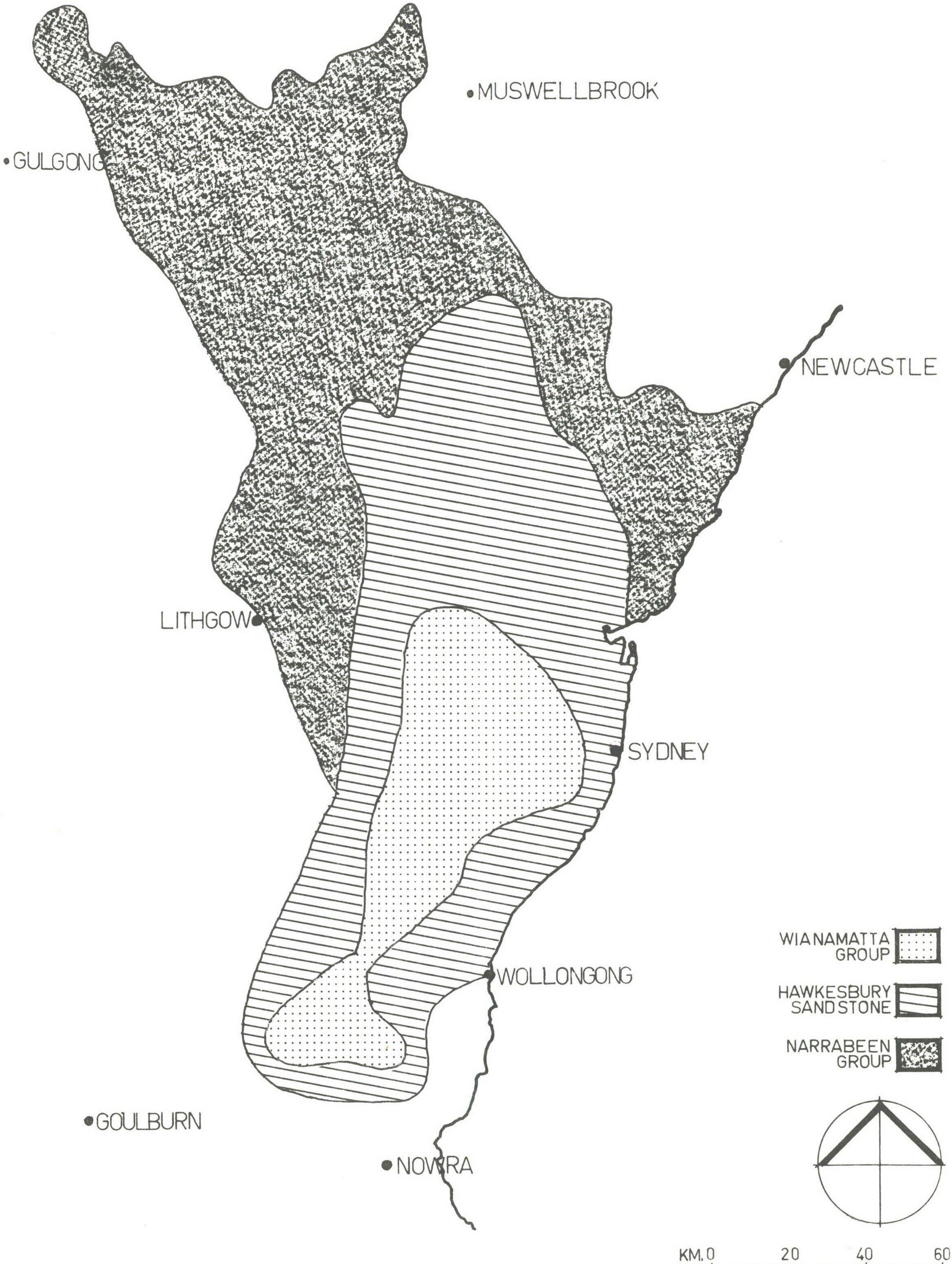
5.1 Location

The general location of the study has been described already (see 1). At the request of the Department of Main Roads particular attention was given to the fauna within the two proposed freeway corridors. For faunal reasons it was desirable and necessary to take a somewhat broader view than this, and the study area referred to in this report is that area covered by the detailed vegetation map compiled by the National Herbarium. This area is shown diagramatically in Map 5.1.

5.2 Geology

The study area lies wholly within the Sydney basin, one of seven geological provinces recognised in New South Wales (Packham, 1969; Branaghan & Packham, 1970). The surface rocks belong to two sequences within this province - the Hawkesbury Sandstone and Narrabeen Group - both of which were deposited during the Triassic period.

The Hawkesbury Sandstone occupies an area of some 12,500 km^2, geographically centred on Liverpool, and with its northern erosional fringe close to the study area (Map 5.2) (Standard in Packham, 1969). It also reaches its maximum thickness of about 240 m in this same general area.



Regional Geology

MAP 5.2

The Hawkesbury Sandstone is composed of highly lenticular beds of quartz-rich sandstone; it has an argillaceous matrix with a secondary quartz-siderite cement.

Although dominantly sandstone, the Hawkesbury Sandstone contains significant amounts of dark grey shale and siltstone, similar in appearance to the Ashfield shale which overlies it. The former shale may be finely interlaminated with the sandstone, as units less than 0.6m thick, but also commonly occurs in beds up to 12m in thickness (Photographs 5.1 and 5.2). In the Mount White-Calga area the shale beds appear to be most persistent and more numerous than elsewhere but they have not yet been mapped in detail. These beds have an important influence on the vegetation, and hence the fauna, as will be discussed later (see 7.6.1).

Underlying the Hawkesbury Sandstone are rocks of the Narrabeen Group. These rocks are exposed mainly on the lower slopes of deep valleys - for example along Mooney Mooney Creek and its larger tributaries (Map 5.3). The Narrabeen Group rocks present in the study area represent the Terrigal Formation, which is typically developed near Gosford itself. This formation comprises mostly shales, shaley sandstones and sandstones. Sandstones from the upper horizons of the formation tend to be very quartz-rich and not unlike those of the Hawkesbury Sandstone. However, they are more poorly sorted and tend to have a much higher proportion of unstable rock fragments, and this increases towards the base of the formation. Feldspar is quite common, as well as fragments of devitrified volcanics, mainly acid or intermediate in origin, siliceous and shaley cherts, and reworked silts and shales. Hematite

PHOTOGRAPHS 5.1/5.2: Shale beds exposed along existing freeway

MAP 5.3

Geology

occurs in patches and is frequently the source of the brown or red colours associated with the Terrigal Formation sediments.

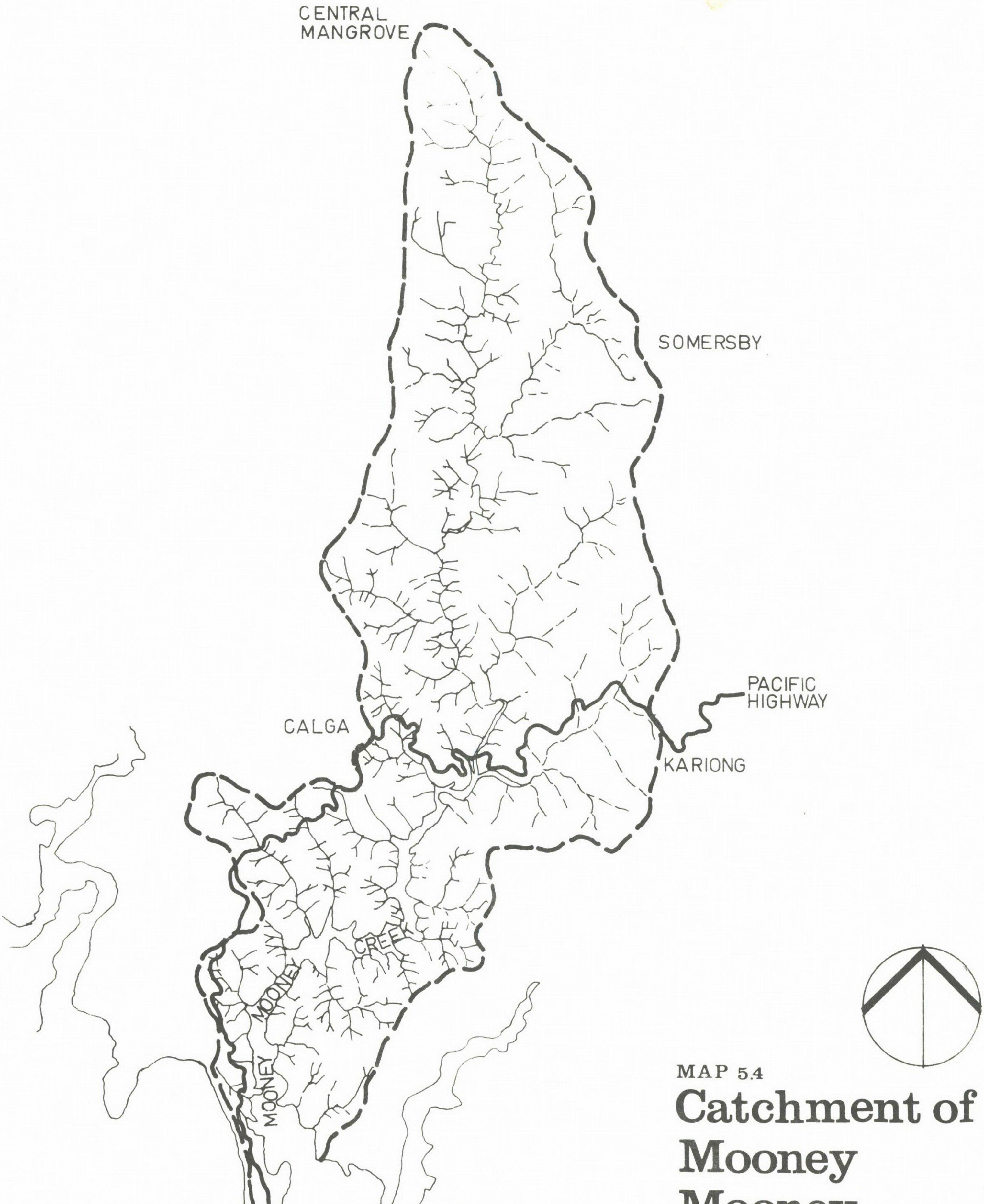
It can be seen from Map 5.3 that there is a marked difference in the extent of the Narrabeen Group rocks exposed along Mooney Mooney Creek above and below the Pacific Highway bridge crossing. Above this point the exposure is up to 0.5km wide on either side of the creek whereas below the bridge the exposure along each bank is scarcely 100 metres wide. As Narrabeen Group rocks generally produce soils which support a more luxuriant vegetation than those derived from the Hawkesbury Sandstone, this feature has important floral and hence faunal implications (see 7.7.2 and 7.8.2).

5.3 Soils

Most of the soils in the study area are derived from the Hawkesbury Sandstone and are consequently skeletal, coarse-textured, shallow and sandy. In some areas podzols of variable depth and development are found, often with peaty humus accumulations where drainage is impeded.

Yellow to red podzolic soils derived from Narrabeen Group rocks, characterise the valley slopes of the Mooney Mooney Creek drainage system. These soils are deep and fertile with high clay and loam contents, enabling them to absorb and retain moisture.

Quaternary and recent sediments of unconsolidated sands and silts, generally well-drained and often of considerable depth, occur along the drowned valleys of the major watercourses.



MAP 5.4

Catchment of Mooney Mooney Creek

These provide a suitable substrate for such distinctive plant communities as mangroves and rushlands/reedlands.

5.4 Topography

The topography of the area has been derived through dissection of the Hawkesbury Sandstone plateau by streams over a long period of time, the stream patterns often being determined by joints and faults in the sandstone. As the sandstone is relatively resistant to weathering, the streams and rivers have tended to form very steep, deeply incised valleys. These latter typically have slopes in excess of 25% and are characterised by frequent cliff-lines.

5.5 Hydrology

The study area lies wholly within the catchment of Mooney Mooney Creek (Map 5.4) which is estuarine at this point. The water here is never truly marine, being brackish in nature and subject to marked changes in salinity in response to rainfall.

The headwaters of Mooney Mooney Creek arise near Central Mangrove and drain into the Hawkesbury River near Brooklyn, about 11km below the study area. The catchment for Mooney Mooney Creek extends over some 130 km^2 of land. Although no water flow data are available for Mooney Mooney Creek it is clearly an insignificant component of the Hawkesbury River basin, to which it belongs.

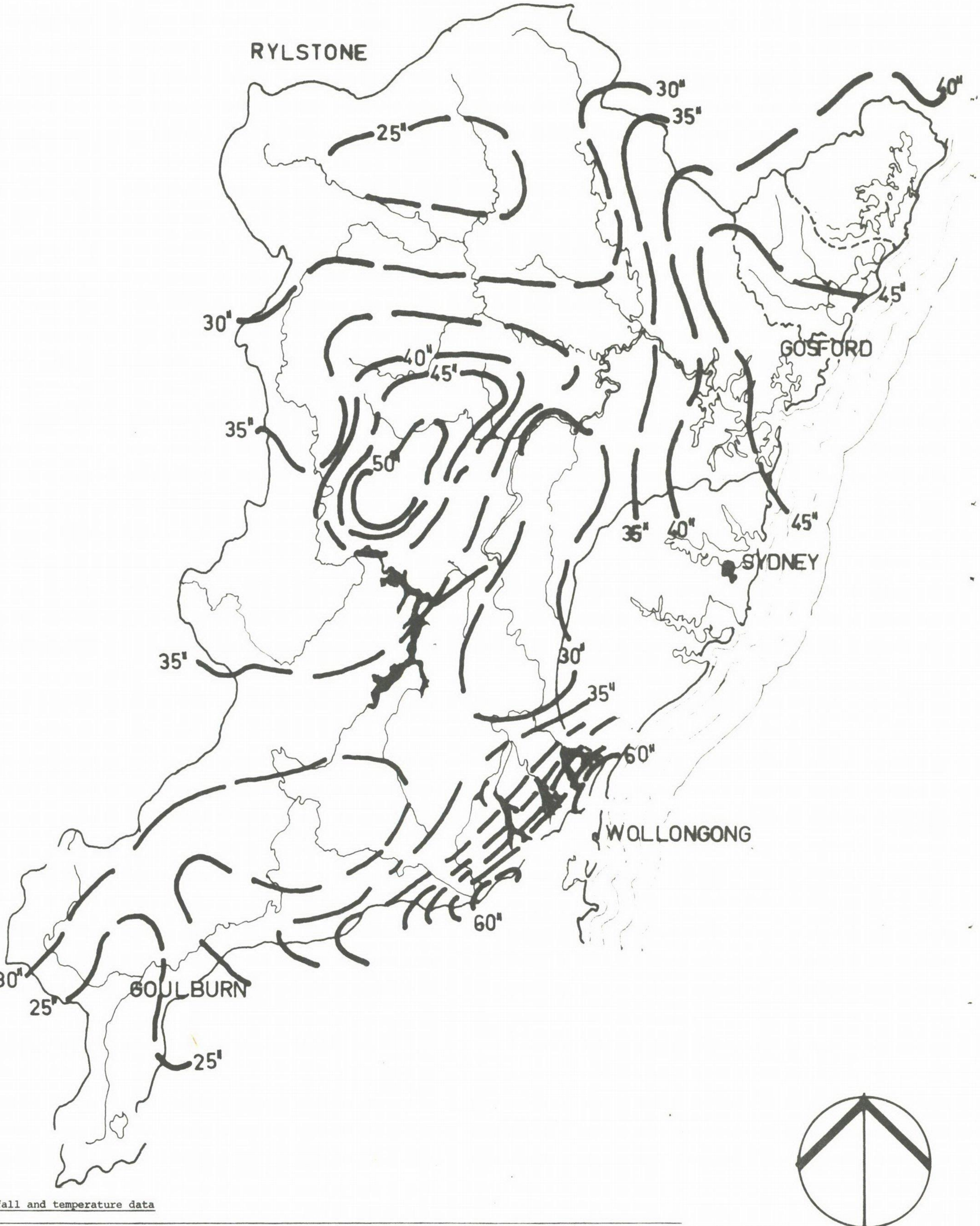
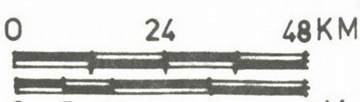


TABLE 5.1: Rainfall and temperature data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Median Rainfall (mm)													
Gosford	85	113	114	87	90	80	66	62	57	58	74	73	1252
Narara	110	110	120	94	79	79	58	58	60	65	78	76	1249
Mean Daily Temperature (°C) Narara													
Maximum	27.1	26.8	26.0	24.0	20.1	17.6	17.4	18.7	21.2	23.9	24.7	26.6	22.8
Minimum	16.3	16.9	14.8	11.3	7.6	6.2	3.9	5.4	7.2	10.8	12.8	14.7	10.7

MAP 5.5

Rainfall



Approximately 11% of the rainfall falling on the Hawkesbury catchment finds its way to streams. Direct storm runoff provides the supply for short-term rises in streamflow, while the normal dry-weather flow derives from percolating groundwater. Since most of the streams in the study area continue to flow for long periods after direct runoff ceases, groundwater evidently provides a significant contribution to the flows in these streams.

5.6 Climate

5.6.1 Rainfall

The study area lies within one of three relatively high rainfall areas in the Sydney region (Map 5.5) with an annual rainfall of about 125cm. Two meteorological stations that submit records to the Australian Bureau of Meteorology (1975; 1977) are located near the study area - Gosford (Station No. 61023, latitude 33°25'S, longitude 151°20'E, elevation 4m) and Narara (Station No. 61087, latitude 33°24'S, longitude 151°20'E, elevation 30.5m). Data from these two sources are summarised in Table 5.1. Using the Gosford figures, it can be seen that the study area experiences a relatively wet season between January and June, during which about 60% of the annual rainfall is received on average. March tends to be the wettest month, with a median rainfall of 114mm, while September is usually the driest, with a median rainfall of 57mm.

Very intense rain may occur over the Hawkesbury River system when an active depression is located over the central New South Wales coast. On these occasions falls of up to 380mm in 24 hours may occur. Very high monthly totals are occasionally recorded; for example, 670mm of rain were once recorded in April.

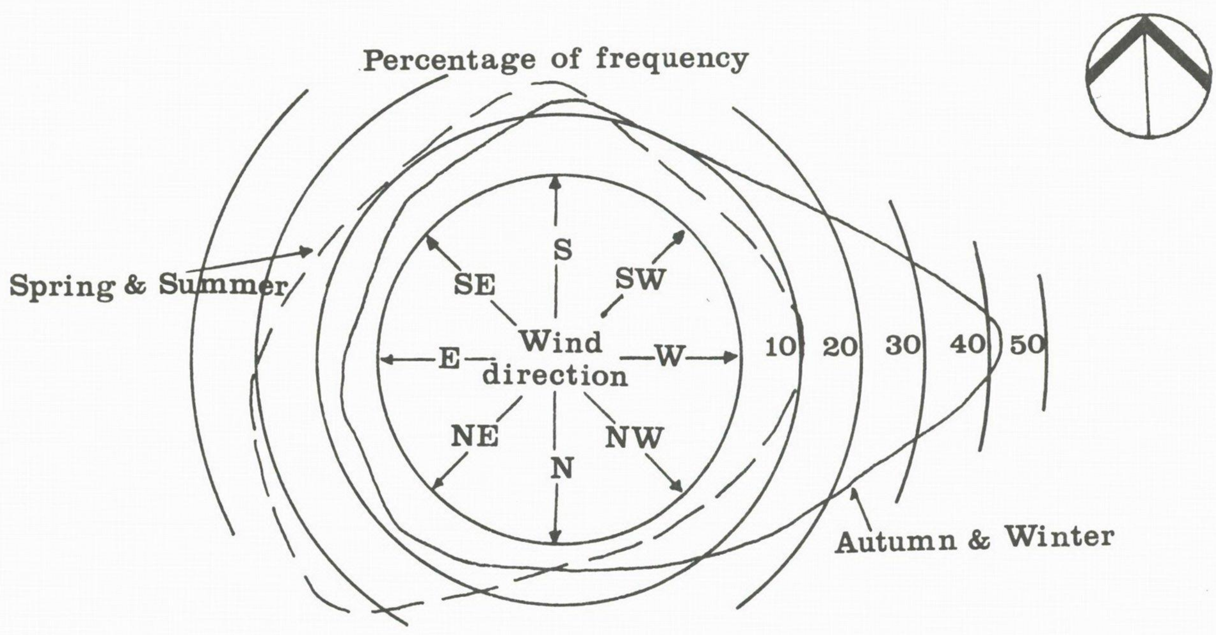


FIG 5.1 **Wind patteri at Gosford**

5.6.2 Temperature

The study area experiences an equable climate, with average temperature maxima ranging from about 27°C in summer to about 17°C in winter (Table 5.1). Average minima range from about 17°C in summer to 4°C in winter. Marked extremes of temperature tend to be rare compared with more inland areas. Thus the maximum temperature has only exceeded 40°C five times in the nine-year period 1965 to 1973 while temperatures below 0°C have been recorded 42 times over the same nine-year period.

5.6.3 Wind

The most frequent winds throughout the year are light Southerly to Southwesterly and Northeasterly up to 18.5 km/h. Westerly and Northwesterly winds occur periodically throughout the year but predominate in autumn and winter while on-shore winds varying South to Northeast generally predominate during spring and summer. There are occasional gale force (50km/h) East to Southeast winds in the summer months, in association with active depressions off the central New South Wales coast. Very strong wind gusts may occur from time to time in association with severe local storms. The seasonal wind pattern is shown in Figure 5.1.

Calm conditions are generally experienced for the six-hour period from 9.00pm to 3.00am on most nights, with light winds in the evening and early morning.

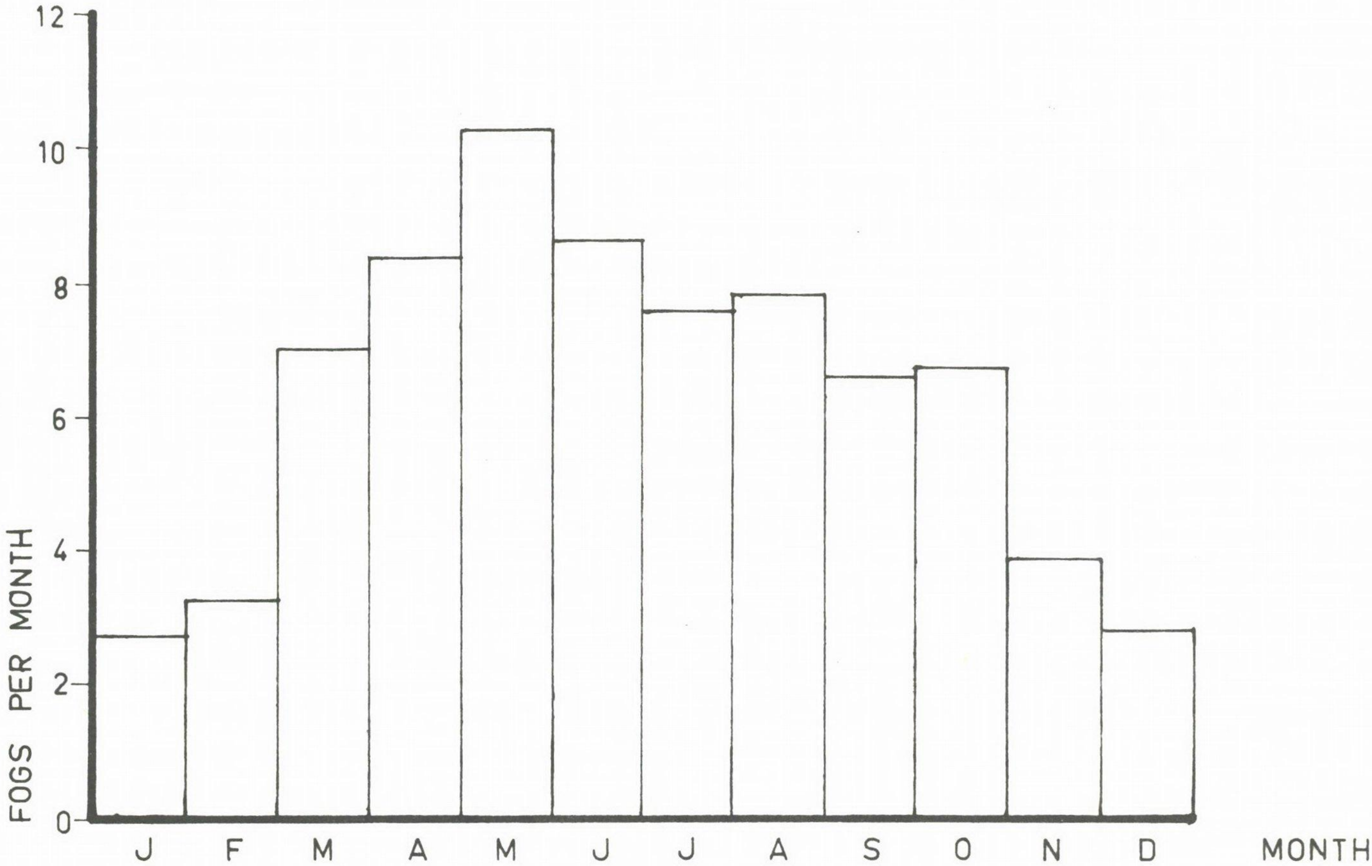


FIG 5.2 **Fogs**
AT RICHMOND

5.6.4 Fog

Under certain conditions clear night skies initiate a flow of moisture-laden marine air inland by way of the creek valleys. On cooling, the moisture in this air tends to condense out to form a fog. Records of conditions at Richmond show that fogs typically last from about 3am to 10am and that there are about 75 fogs per year at 7am (Richardson, 1972). The average number of fogs per month at Richmond is shown in Figure 5.2.

5.6.5 Drought

Prolonged severe dry spells are rare over the Hawkesbury valley, although sequences of below average rainfall have extended for periods of up to 10 years at some locations. During the years 1964 to 1968 the Hawkesbury valley, in common with much of New South Wales, experienced several periods of extremely low rainfall. The most critical periods were between November 1964 and September 1966 and again from November 1967 to November 1968. During these periods the Hawkesbury valley was proclaimed a drought area on three occasions - between January and October 1965, February and October 1966 and in April 1968.

Although droughts may be uncommon in the study area, it is essential that any constraints by the proposed freeway on the response of fauna within Brisbane Water National Park to drought conditions be considered.

5.7 Vegetation

The vegetation of the study area has developed in response to such factors as the physical substrate, climate and topography. It contains a high species diversity, with over 400 species having been recorded during a three-months survey by the National Herbarium (Benson, 1979). Despite the brevity of the collecting period this represents nearly half the number of species recorded for Ku-ring-gai Chase National Park (Rose, 1969), an area of similar vegetation South of the Hawkesbury River.

The detailed plant community map prepared by Benson (1979) is given in Map 5.6. Two of these communities (quarries and cleared land) result from extensive modification by man of the original vegetation. Brief descriptions of the other eleven, based on the text of Benson (1979), now follow.

i. Closed-forest

This community consisted of trees 10-30m high, with a dense foliage cover, and a moist understorey consisting of small trees, shrubs and ferns. It lined many of the creeks in the study area, favouring South to East running valleys. The dominant tree species were *Eucalyptus deanei*, *Angophora floribunda*, *Syncarpia glomulifera* with such "rain-forest species" as *Backhousia myrtifolia*, *Doryphora sassafras*, *Ceratopetalum apetalum* and *Acacia elata*.

MAP 5.6

Plant Communities

ii. Open forest with moist understorey

This community contained trees 10-30m in height with a mid-dense foliage cover and a moist understorey of varying density, consisting of small trees, shrubs, herbs and graminoids. It occurred on the Eastern or Southern slopes adjoining watercourses, often surrounding pockets of closed forest.

Two variants of this community were recognised. Type A was dominated by such tree species as *E. piperita, A. costata* with *E. pellita* or *E. umbra* and had a dense understorey. It was restricted to the Hawkesbury Sandstone in upper creek situations. Type B on the other hand was characterised by the trees *A. floribunda* and *Casuarina torulosa* and had a more open understorey. It favoured the Narrabeen Group geology and was most widespread in the forested areas to the North of the study area.

iii. Open forest with dry understorey

This community was represented by trees 10-30m high, with a mid-dense foliage cover and dry understorey consisting of tall shrubs, herbs and graminoids. It preferred slopes with "cooler" aspects (Eastern to Southern) although this varied. It also lined those creeks which extended into the plateau areas at higher elevations. The community preferred sandy soils derived from the Hawkesbury Sandstone. It was widespread in the study area and was characterised by the trees *E. piperita, E. gummifera, A. costata* often with *A. floribunda* and *S. glomulifera*.

iv. Low open-forest dominated by *Casuarina glauca*

This community was composed of small trees 5 to 8m high of mid-dense canopy cover and with a ground cover dominated by graminoids and herbs. It was restricted to the alluvial flats along watercourses, where it was occasionally subjected to inundation. Three stands occurred within the study area, one largely within corridor 2.

v. Low open-forest with dry, dense, tall understorey

This community was associated with a yellow earth soil found only at one locality, towards the Eastern end of corridor 1. A similar community was also found near Patonga in the far Southern section of Brisbane Waters National Park. It was characterised by trees 8-10m high with a mid-dense canopy cover. The understorey was dry, tall and dense and contained a scattering of herbs and graminoids. The community was characterised by the tree species *E. capitellata, E. gummifera, Banksia serrata* and *E. haemastoma*.

vi. Low open-forest to low woodland, with dry understorey

The most widespread community within the study area, this community occurred on ridges and ridge slopes usually on sandy soils in well drained, drier areas. The community was characterised by trees usually less than 10m high, with a mid-dense to open canopy cover. There was a mid-dense to open shrub layer, containing shrubs, herbs and graminoids. Species diversity was high. The main tree species present were *A. costata, E. gummifera, E. eximia, E. umbra, E. punctata* and *E. haemastoma*.

vii. Open-scrub (Mangrove)

Mangroves were most frequent between the Pacific Highway bridge across Mooney Mooney Creek and corridor 1 to the South, with few stands elsewhere in Mooney Mooney Creek. Two species of mangrove were present - *Avicennia marina* var. *australasica* and *Aegiceras corniculatum* - and the different heights of these two species (about 8m and 4m respectively) gave the community a distinctive appearance.

viii. Closed Heath

Dominated by such heathland shrubs as *B. ericifolia, Hakea* spp, *Grevillea punicea* and *Kunzea capitata,* this community formed a dense scrub up to 2m in height with a ground cover of graminoids. It was associated with moist, sandy, shallow soils overlying a hard sandstone base, and frequently occurred in shallow sloping shelves below ridges and above the main creek systems. Its distribution was often related to localities where shale lenses within the Hawkesbury Sandstone reach the surface (see 7.6.1).

ix. Rock outcrops with pockets of low scrub

Although a distinctive habitat for fauna, this community had a flora which varied from low open-woodland to closed-scrub. It was characterised by rock platforms generally with more than 50% rock surface exposed. The main tree species present were *E. haemastoma, E. gummifera, E. eximia* with *E. multicaulis* on the higher peaks.

x. Sedgeland

Typically this community was dominated by sedges (especially *Cyperaceae* and *Restionaceae*) and other graminoids. Trees

TABLE 5.2: Extent of plant communities

	Corridor 1 (ha)	Corridor 2 (ha)	Study area (ha)	%
1. Closed forest	8	<1	49	1.8
2. Open forest with moist understorey	48	8	357	13.2
3. Open forest with dry understorey	24	16	373	13.8
4. Low open-forest dominated by *Casuarina glauca*	0	4	16	0.6
5. Low open-forest with dry, dense tall understorey	16	0	24	0.9
6. Low open-forest/open woodland, with dry understorey	111	107	1095	40.5
7. Open scrub, mangrove	8	0	62	2.3
8. Closed heath	80	24	300	11.1
9. Rock outcrops with pockets of low scrub	16	0	70	2.6
10. Sedgeland	16	0	41	1.5
11. Reedland/Rushland	0	1	5	0.2
12. Cleared land	8	24	295	10.9
13. Quarries	<1	8	11	0.4

were absent and standing water was often present.

xi. Reedland/Rushland

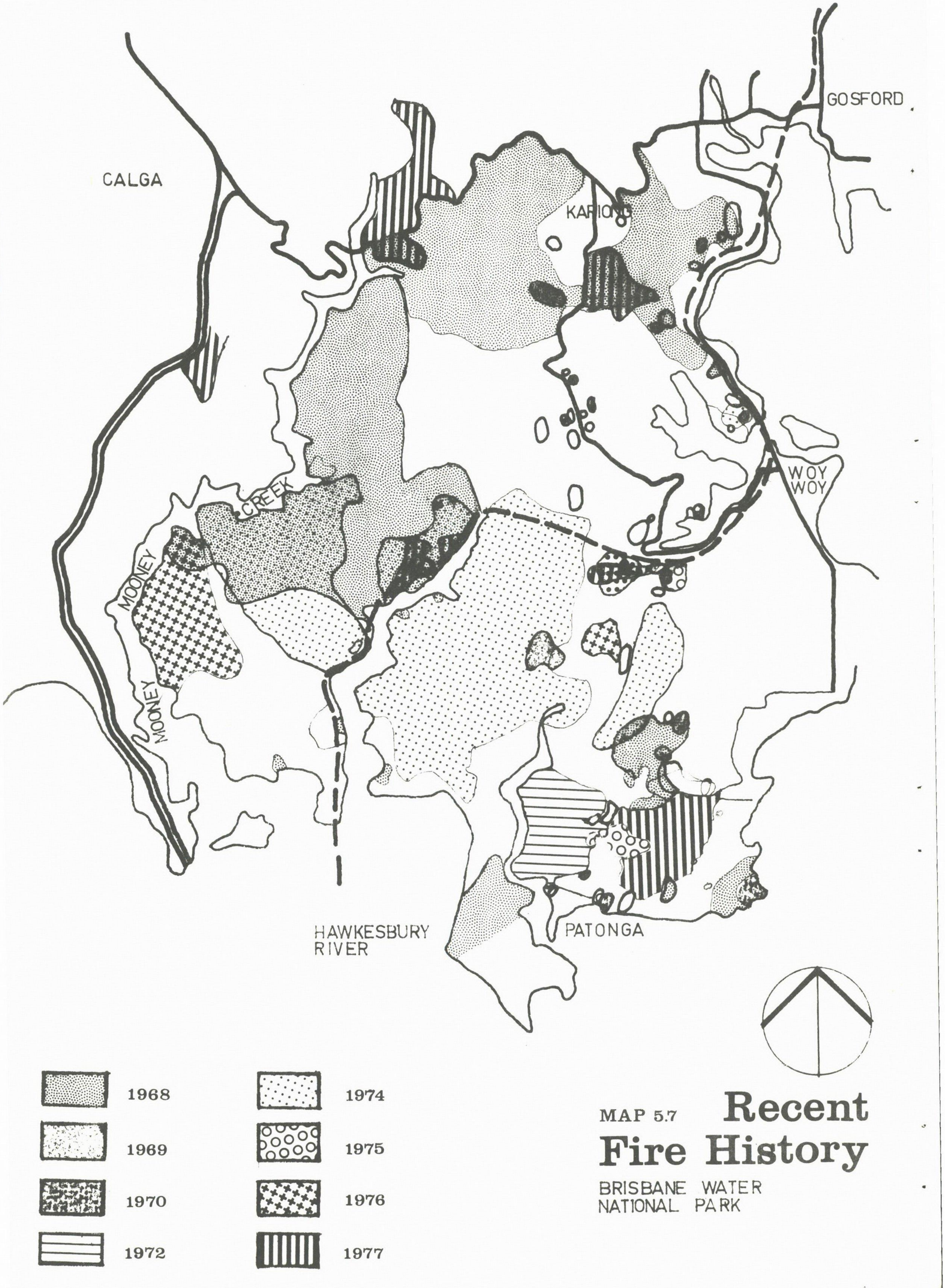
This community was composed mainly of members of the *Poaceae* (grasses) and *Juncaceae* (rushes). It occurred in depressions on the alluvial flats lining tidal watercourses and was subject to frequent tidal inundation. The two main species present were the reed *Phragmites australis* and the rush *Juncus kraussii.* This community was represented only at three places within the study area, one of which lay partly within corridor 2. The two Northerly examples of the community were dominated by *P. australis* and the third, more Southerly example, by *J. kraussii.*

The extents of all thirteen plant communities within each of the two corridors, and within the study area generally, are summarised in Table 5.2.

5.8 Fire

Map 5.7 gives the recent fire history of Brisbane Water National Park. Apart from an unsuccessful control burn during July 1978 in which site number 1.14 was part-burnt, none of the vegetation along corridor 1 has been burnt since the extensive spring-summer fires of 1968.

In contrast, corridor 2 has a more varied fire history, although inadequate documentation prevented its complete elucidation. Sites 2.1, 2.2 and, in part 2.5, were burnt in January 1977 while site 2.8 was burnt more recently still. Site 2.11 was burnt during the summer 1968 fires already noted while sites 2.3, 2.4, 2.6 and 2.9 were probably burnt more recently. Site 2.10



MAP 5.7 **Recent Fire History**

BRISBANE WATER NATIONAL PARK

in closed forest, had no recent fire history while the fire history for site 2.7 is not known. Sites 2.5 and 2.6 were burnt again in March, 1979.

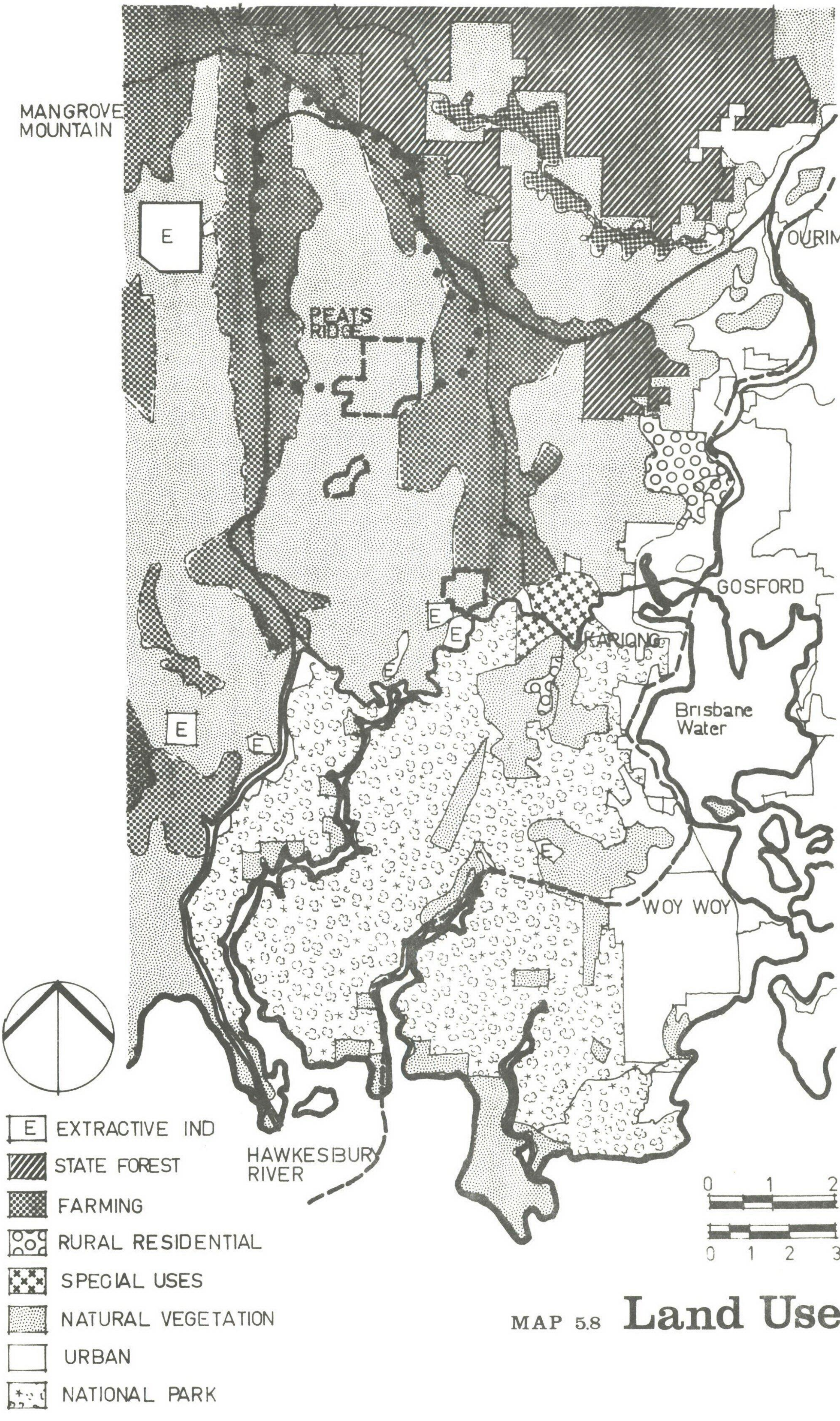
5.9 Land Use

Existing land use in the study and surrounding areas is shown in Map 5.8. To the South of the Pacific Highway most of the land has already been dedicated as Brisbane Water National Park. Much of the land fronting onto Brisbane Water itself, to the East of the Park, is zoned for urban use and is already extensively built upon. To the North-East is the township of Kariong - with lands designated Rural Residential - and the special uses area of Mount Penang Training School for Boys.

To the North of the National Park is a proposed National Park extension centred on the drainage system of Mooney Mooney Creek and an extensive area of farms (mainly citrus) on the Somersby Plateau. Several quarries for sandstone and road materials are located just North of the Pacific Highway (Map 5.6). To the North-West lies a second agricultural area, centred on Peats Ridge while the existing section of the Sydney-Newcastle freeway runs along the Western margin of the National Park.

The following points should be made in relation to existing land use:

(a) The proposed corridor 1 runs mainly through Brisbane Water National Park (6km).



MAP 5.8 **Land Use**

(b) The proposed corridor 2 runs in large part through the proposed Northern extension to Brisbane Water National Park (4km).

(c) Brisbane Water National Park is surrounded by land alienated from natural vegetation, whether for use as freeway, highway, agricultural land, rural or urban residential land.

5.10 Logging

Logging began in the Wyong-Ourimbah area in the 1840's. While the Hawkesbury Sandstone country has little silvicultural potential, saw logs were extracted from the better stands of timber beside the creeks through this country. Species particularly sought after were the Blue Gum *E. saligna*, Round-leaved Gum *E. deanei*, Turpentines *S. glomulifera* and the occasional Red Cedar *Toona australis*.

It is estimated that the banks of Piles and Mooney Mooney Creeks were lightly and selectively logged 40-50 years ago (G. Power, pers. comm.). The rather even-aged appearance of the stands at these sites is attributed to a particularly severe fire at about the same time rather than to the logging itself. These stands are not yet mature, a process which takes at least a century to complete.

6. FAUNAL STUDIES

6.1 Introduction

The primary concern of these studies was to identify the animal species and habitats most likely to be affected by the proposed freeway. This required:

(a) Detailed inventories of wildlife and habitat features, such as habitat types and their condition, animal community diversity, productivity and stability. These inventories are a prerequisite to accurate impact evaluations.

(b) A clear understanding of the agent of change, in this case the proposed freeway, and its impacts.

Since the abundance, diversity, productivity and physical condition of wildlife reflect the quality of their habitat, animal population inventories are normally used as indicators of habitat quality and value. Three approaches to obtaining this information are used: true censuses, sampling estimates and indices. True censuses seek to establish the actual populations of animals within a given area. They are best suited to localities in which the animals can be easily counted. Examples are the wintering areas for deer, elk and waterfowl, or breeding areas for colonial nesting birds. Such opportunities did not exist in the present study, so that direct censusing was not used.

Sampling estimates can provide a very satisfactory estimate of animal populations within a study area. Two examples of this approach will be given. The first requires the delineation of a set area - the sample plot - in which the numbers of individuals of each species under study are established. The second is the mark and recapture method, which is particularly suited to birds and small mammals. Individual animals are trapped, marked and released and then retrapped at a later date. An estimate of the total population can then be calculated from the ratio of marked to unmarked individuals obtained during the retrapping period. Although this method can give very precise estimates of population sizes, it is not only time-consuming to apply but would be over-precise for the present study.

The most widely used approach relies on the use of indices. Similar to many sampling plot methods, indices provide population trend information which can be used to determine annual variations as well as differences between habitats. This type of information is usually adequate for determining the major impacts of developments of the kind under consideration. Consequently the methods used in this study are of this kind.

While the faunal studies were concentrated within the two proposed freeway corridors, the provision of plant community information for the entire area between the two corridors and for some distance beyond each corridor meant that briefer studies in these additional areas could be meaningfully related to the core studies, and vice-versa (see 5.1).

6.2 Study sites

Accomplishment of the faunal studies was greatly helped by the mapping of plant communities within the study area (Benson, 1979). With this information it was possible to locate sites for the faunal studies along the two corridors so as to include not only all the major plant community types but also variations in aspect, slope, geology, etc. (Map 5.1).

As far as possible sites were located at 250m intervals along the centreline of each corridor, this interval being calculated to give a manageable number of sites for faunal study. In practice this procedure was sometimes modified to accommodate communities which did not fit into this sampling pattern, or to relocate sites which fell within an ecotone. Even in these cases, though, a standard approach - using predetermined distances between adjoining sites - was adopted.

It is a basic assumption of the faunal studies that the sampling plots closely reflect the diversity present within the study area as a whole.

After location, each study site was tagged. Twenty-eight such sites were selected along the two corridors.

6.3 Mammals

6.3.1 Summary

The mammal fauna of the study area was assessed by several methods. 255 captures of six species were made with small mammal traps during 2,000 trap-nights. Cage traps were used for larger mammals during 144 trap-nights, but without success. 62 hours of spotlighting yielded remarkably few sightings of nocturnal mammals - Sugar Gliders Petaurus breviceps, *Swamp Wallabies* Wallabia bicolor *and Ring-tailed Possums* Pseudocheirus peregrinus *being recorded. The analysis of over 250 individual scats from 73 sites yielded hairs of thirteen mammal species, the least expected of which was the Brown Hare* Lepus capensis. *A trial use of the hair-sampling tube method proved successful, while pit-trapping yielded 5 individuals of four species - including the Pygmy Possum* Cercatetus nanus, *Swainson's Marsupial Mouse* Antechinus swainsonii *and Common Marsupial Mouse* Sminthopsis murina. *In addition, sightings were*

made or evidence (e.g. tracks, burrows) found for the presence of ten mammal species.

Fourteen native and six feral species of mammals were recorded by these methods. A further eleven species have been recorded elsewhere in Brisbane Water National Park while another 8 could conceivably occur there. Most of these species may be present in the study area. A record of particular interest was that of the Fawn-footed Mosaic-tailed Rat Melomys cervinipes, *this being a Southerly extension in known range of about 45 km. The habitat preferences of the species recorded in the study area are discussed.*

6.3.2 Introduction

The studies described below have sought to establish the mammal fauna of the study area and, as far as time allowed, their habitat preferences and consequent distribution. To judge by the results of other work in Brisbane Water National Park it is most unlikely that a comprehensive listing of species has been obtained. The present study located 14 native mammal species out of 26 known to occur in the Park as a whole. The location of uncommon mammal species in a general survey is often a difficult and time-consuming process. For example, five species recorded in a recent survey of Myall Lakes were first located during the third year of study. For this reason, care has been taken to determine which species might occur within the study area, even though they were not recorded during the present survey.

6.3.3 Methods

Several different methods were used to survey the mammals of the study area. As any one method tends to favour the detection of some species in preference to others, the use of several methods should provide a better overall assessment of the species present.

6.3.3.1 Small mammal trapping

Elliott small mammal traps (measuring 33 x 10 x 10cm) were used to survey rats and small marsupials. One hundred traps were set at each sampling station. In the first trapping period lots of 25 traps were set 10m apart in square grids of 5 x 5 traps. This layout was replaced during later trapping periods with a trap line, in which the traps were placed at 10m intervals. This change was made partly to accommodate within-site variability of the vegetation more effectively (a trap line being longer than a grid) and partly because the shapes of some sites did not lend themselves to the grid format. The traps were baited with a mixture of peanut butter and rolled oats, to which a small amount of vanilla essence was added. The traps were operated over four consecutive days and checked daily for captures.

Although snap traps may be a more efficient means for sampling small mammals (Fox & Posamentier, 1976), they were not used in the present study as they kill animals unnecessarily.

6.3.3.2 Cage Trapping

Treadle-operated wire cage traps of two types were used, one measuring 20 x 20 x 55cm and the other 18 x 18 x 50cm. The peanut butter/rolled oats bait was used in some and commercial kangaroo meat in the others. The latter was preferred to the meat of domestic animals because it has a stronger odour and taste and is consequently considered more attractive to carnivorous animals. The traps were operated over four consecutive days and checked daily for captures.

6.3.3.3 Spot lighting

12V quartz-halogen spotlights were used for spotlighting, powered by either motor cycle batteries (spotlighting on foot) or a vehicle battery (spotlighting from vehicle). Lack of suitable trails meant that all spotlighting in the study area was done on foot, but was supplemented by spotlighting from a vehicle along nearby roads. Although spotlighting from vehicles tends to be more productive, smaller mammals are more readily located when spotlighting on foot.

6.3.3.4 Scat collection

The scats of carnivores (mostly feral cats and foxes) were collected from walking tracks in the study area. Hairs contained within the scats were identified, and prey species thus determined, by the method of Brunner and Coman (1975). This method required initial drying of the scats at 80^{o}C for 72 hours to kill parasite eggs. The scats were then washed, broken up and any bones present removed. The length, cross-sectional shape and size, cuticular scale pattern and colour of the primary guard hairs (usually the most species-specific hairs), and to a lesser extent other hairs, were then established. Identifications were made by reference to the photographs and text in Brunner and Coman (1975) and to standard hair specimens. Where possible bone (especially jaws, teeth and long bones) and claw fragments were also identified.

6.3.3.5 Hair-sampling tube

The hair-sampling tube method devised by Suckling (1978) was tested in plant community 6 near site 1.14. A 10cm length of 2.5cm internal diameter PVC tube was nailed through its centre to a tree. The nail retained a small amount of peanut butter/honey/oats bait wrapped in gauze in the middle of the tube. A length of double-sided tape (Permacel T3 from B.J. Mackie, Melbourne) was placed along the top inside of the tube. The principle of the method is that small arboreal mammals, having been attracted to the bait, enter the tube and in doing so leave hairs on the tape. These hairs can then be identified as described in the preceding section.

6.3.3.6 Pit-traps

Although this method primarily trapped reptiles and amphibia (see 6.5.3.2), it also proved useful in catching small mammals.

6.3.3.7 General observations

Casual observations on mammals were made from time-to-time during the study.

6.3.4 Results

The results obtained by the different methods were as follows:

6.3.4.1 Small mammal trapping

255 captures of six species were made during 2,000 trap-nights, as shown in Table 6.1

6.3.4.2 Cage trapping

Cage traps were operated for a total of 144 trap-nights in five major plant communities within the study area, as detailed in the following table.

TABLE 6.1: Results of small mammal trapping

Site No.	Plant Community	Species					
		Rattus fuscipes	*Rattus lutreolus*	*Melomys cervinipes*	*Antechinus stuarti*	*Antechinus swainsoni*	*Petaurus breviceps*
1.1	2	24					
1.2	1	3			3	2	
1.3	3	4			2		
1.4	1	9			1	2	
1.10	8						
-Aug.'78		4			1		
-Jan.'79		3					
1.11	3	30			6		
1.12	6				8		
1.16	5				1		
1.16 A	10	10	2		2		
2.1	8	7	1		1		
2.2	6	3			6		
2.4	6	7			8		
2.5	3	4			7		
2.6	2	6			24		2
Near 2.9	3	9			1	1	1
2.10	1	11		1	1		
2.11	6	20	2		1		
2.12	8	3	2		1		
2.13	8	5			2		
Total number of captures		162	8	1	76	5	3

Table 6.2: Details of cage trapping

Study site	Plant community	No. traps
1.13	3	4
Between 2.14/1.15	6/10	8
2.1	8	2
2.2	6	2
2.4	6	4
2.5	3	4
2.6	2	4
2.9	3	4
2.10	1	4

Despite evidence of possums and bandicoots in the study area, no large animals were caught.

6.3.4.3 Spotlighting

During 56 hours of spotlighting on foot, the following sightings were made:

Sugar Glider *Petaurus breviceps* :	Three individuals in plant communities 6 and 8 in the Camp Kariong/ Rifle Range area.
:	One individual in plant community 1 on the Girrakool walking trail.
Swamp Wallaby *Wallabia bicolor* :	Common in plant communities 2, 3, 6 and 8.

Two Ring-tail Possums *Pseudocheirus peregrinus* were observed in plant community 6 during six hours of spotlighting from a vehicle on Green Point Road.

6.3.4.4 Scat collection

Scats were collected in the following areas (See also Map 6.1):

A. 1-9 Girrakool-Patonga Beach walking track between Rat Gully and and corridor 1.

B. 1-8 Powerline service road across corridor 2, between Site 2.4 and Mooney Mooney Creek.

C. 1-8 Firebreak between Site 2.11 and Girrakool.

D. 1 Mooney Mooney Creek Road.

E. 1 Near Site 2.3

F. 1-13 Girrakool-Patonga track, from South of corridor 1 to saddle of Mt. Kariong.

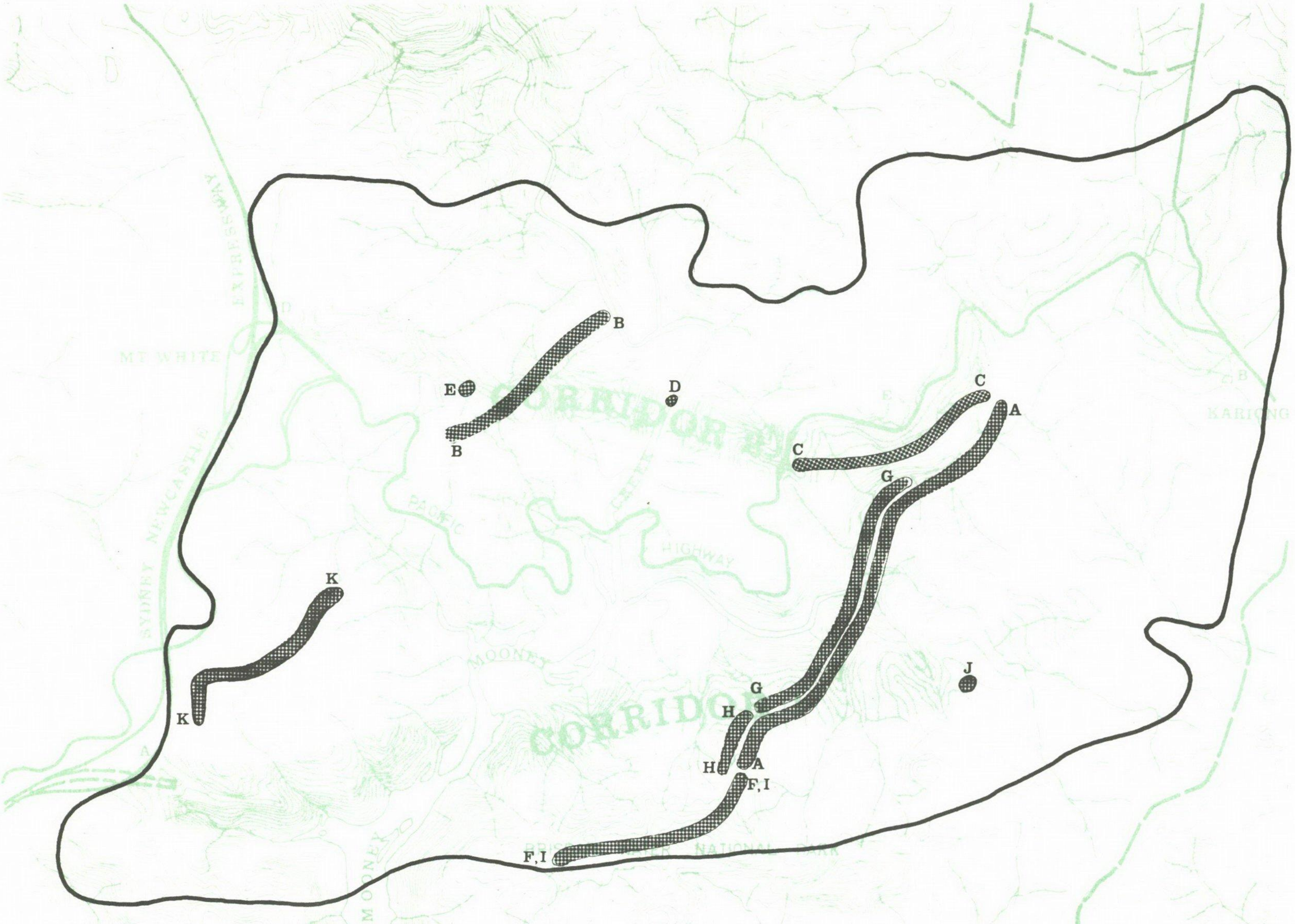
G. 1-5 Girrakool-Patonga track, from near Rat Gully to corridor 1.

H. 1-11 Corridor 1 near Girrakool track.

I. 1-8 As for F

J. 1-2 Near Site 1.14.

K. 1-7 Powerline service road North of Western end of corridor 1.



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MAP 6.1

Scat Collection Sites

TABLE 6.3: Scat analysis

Species	Recorded from Scat Group
Echidna *Tachyglossus aculeatus*	A1, A3, A7, H8
Wombat *Vombatus ursinus*	B1, I1
Long-nosed Bandicoot *Perameles nasuta*	A2, A4, A5, A6, A9, F7, F11, F14, F15, H1, H5, H10, I7, J2, K1
Brush-tailed Possum *Trichosurus vulpecula*	B5, C6
Ring-tailed Possum *Pseudocheirus peregrinus*	F3, G3
Pygmy Possum *Cercatetus nanus*	K1
Swamp Wallaby *Wallabia bicolor*	A8, C2, C3, C4, C7 C8, D1, E1, F2, F4, F5, F10, F12, F13, G1, G2, G4 H1, H3, H4, H7, H8, H9, I5, J1
Brown Marsupial Mouse *Antechinus stuartii*	F8, F12, I3
Southern Bush Rat *Rattus fuscipes*	A4, A7, B3, B4, B7, F1, F4, F13, F15, H1, H2, H4, H6, I4, K3
Swamp Rat *Rattus lutreolus*	C5
Murid (not *Rattus*, nearest to *Mastacomys* and *Pseudomys*	B8, C1
Brown Hare *Lepus capensis*	C3
Rabbit *Oryctolagus cuniculus*	K1
Macropod bones	B6
Small Dasyurid Jaw	I8
Birds	G5
Yabbie	A5, A6, H10, I2, I9
Nil identifiable	F9, H11, I6, K2, K5, K6, K7
Unidentified	B2

Samples A-E were collected in August, 1978, F-H in October, 1978, and I-K in January, 1979.

In all, 73 groups of scats, containing over 320 individual scats were examined. The results are given in Table 6.3.

6.3.4.5 Hair-sampling tube

Hairs of the Southern Bush Rat *R. fuscipes* and Sugar Glider *P. breviceps* were collected in the trial hair sampling tube.

6.3.4.6 Pit-trapping

The following table lists the small mammals collected by pit-trapping:

Table 6.4: Small mammals caught in pit traps

Site	Plant Community	Species
1.2	1	*Antechinus stuartii* (2 individuals)
1.10	8	*Cercatetus nanus*
1.16	5	*Antechinus swainsonii*
2.5	3	*Sminthopsis murina*

6.3.4.7 General observations

- To judge by the numbers of burrows and droppings, Wombats *Vombatus ursinus* were widespread in plant communities 3,5,6 and 9.

- Swamp Wallabies *Wallabia bicolor* were often seen in plant communities 2,3,5,6,8 and 10.

- An Echidna *Tachyglossus aculeatus* was seen in plant community 6 near site 2.3.

- A Long-nosed Bandicoot *Perameles nasuta* was seen in plant community 3 near site 1.13, while diggings of this species were frequent in plant communities 1,2,3,5,6,8 and 10.

- Goat *Capra hircus* tracks were seen on the powerline service road which crosses corridor 2, presumably of an animal escaped from the settlement beside Mooney Mooney Creek.

- Footprints of cats *Felis catus*, dogs *Canis familiaris*, foxes *Vulpes vulpes* were found on all tracks in the study area, while these species and pigs *Sus scrofa* were recorded at Camp Kariong.

- Cattle *Bos taurus* were observed near site 1.5, having presumably come from a property nearby.

- Soil disturbance caused by the rooting of pigs was widespread in the Lemon Tree Point and Kariong Brook areas of Brisbane Waters National Park.

- A fox, swamp wallaby and echidna were recorded as road kills on the expressway between the Hawkesbury River and Mount White.

6.3.5 Discussion

6.3.5.1 Status of species

The species of mammals recorded during this and earlier studies in Brisbane Water National Park are listed in Table 6.5, with a subjective assessment of their status in the study area. It should be noted that not all of the species observed by others in Brisbane Water National Park need necessarily occur within the study area, since their presence obviously depends on the presence of suitable habitat.

A species of particular interest in this listing is the Fawn-footed Mosaic-tailed Rat *Melomys cervinipes*. Until recently the southernmost locality known for this species was Dorrigo (Rose, 1976). Mahoney (pers. comm.) reports that its presence has now been established in Watagan State Forest by Mr. R. Williams, so that the present observation represents a Southerly extension in range of about 45km. As there is a possibility that the specific name is being applied to two different animals, tissue samples from the specimen collected were sent to Dr. P.R. Baverstock of the Institute for Medical and Veterinary Science, Adelaide for cytological and immunological examination.

Several other species may occur in the study area besides those already recorded. These include eleven species which have been recorded elsewhere in Brisbane Water National Park (Table 6.5) as well as the following species which, although not yet recorded in the park, could conceivably occur there: New Holland Mouse *Pseudomys novaehollandiae*, Water Rat *Hydromys chrysogaster*, Tuan *Phascogale tapoatafa*, Eastern Native Cat *Dasyurus viverinus*, Parma Wallaby *Macropus parma*, Rock Wallaby *Petrogale penicillata*, Red-shouldered Pademelon *Thylogale thetis and* Platypus *Ornithorhynchus anatinus*. Of these the New Holland Mouse and Water Rat have both been reported from Ku-ring-gai Chase National Park

TABLE 6.5: Mammals of the study area and Brisbane Water National Park

Species	Presence in Brisbane Water National Park according to:			Present Study	Status
	Mahoney & Posamentier (1975) (1)	Hodson (1976)	Rose (1978)	(2)	(3)
Order *Artiodactyla*					
Family *Bovidae*					
**Bos taurus* Cow				+	D
**Capra hircus* Goat				+	D
Family *Suidae*					
**Sus scrofa* Pig				+	R
Order *Carnivora*					
Family *Felidae*					
**Felis catus* Cat				+	A
Family *Canidae*					
**Canis familiaris* Dog				+	C
**Vulpes vulpes* Red Fox				+	C
Order *Lagamorpha*					
Family *Leporidae*					
**Lepus capensis* Brown Hare				+	U
**Oryctolagus cuniculus* Rabbit				+	U
Order *Rodentata*					
Family *Muridae*					
**Rattus rattus* Long-tailed Ship Rat	+		+		
R. fuscipes Southern Bush Rat	+	+	+	+	A
R. lutreolus Eastern Swamp Rat	+	+	+	+	C
Melomys cervinipes Fawn-footed Mosaic-tailed Rat				+	R
Pseudomys gracilicaudatus Eastern Chestnut Rat	+	+(4)	+	?	
**Mus musculus* House Mouse	+			?	
Order *Marsupialia*					
Family *Dasyuridae*					
Antechinus stuartii Brown Marsupial Mouse	+	+	+	+	A
A. swainsonii Swainson's Marsupial Mouse	+	+	+	+	C
Sminthopsis murina Common Marsupial Mouse	+	+	+	+	U
Dasyurus maculatus Tiger Cat		+(4)	+	?	
Family *Peramelidae*					
Perameles nasuta Long-nosed Bandicoot		+(4)		+	A
Isoodon macrourus Short-nosed Bandicoot			+	?	

TABLE 6.5: Mammals of the study area and Brisbane Waters National Park (Continued)

Species	Presence in Brisbane Waters National Park according to: Mahoney & Posamentier (1975)	Hodson (1976)	Rose (1978)	Present Study	Status
Family *Macropodidae*					
Wallabia bicolor Swamp Wallaby		+	+	+	A
Macropus giganteus Eastern Grey Kangaroo		+(4)			
M. robustus Wallaroo		+(4)			
M. rufogriseus Red-necked Wallaby		+(4)		?	
Potorous tridactylus Potoroo		+(4)	+	?	
Family *Vombatidae*					
Vombatus ursinus Common Wombat		+(4)		+	U
Family *Petauridae*					
Schoinobates volans Greater Glider		+		?	
Pseudocheirus peregrinus Ringtail Possum				+	U
Petaurus breviceps Sugar Glider		+	+	+	C
P. norfolcensis Squirrel Glider		+		?	
Family *Phalangeridae*					
Trichosurus vulpecula Brush-tailed Possum		+		+	U
T. caninus Mountain Possum		+		?	
Family *Phascolarctidae*					
Phascolarctos cinereus		+		?	
Family *Burramyidae*					
Cercatetus nanus Pygmy Possum		+(4)		+	
Acrobates pygmaeus Feathertail Glider		+	+	?	
Order *Monotremata*					
Family *Tachyglossidae*					
Tachyglossus aculeatus Echidna				+	C

Notes on table:

(1) Results from small mammal trapping only

(2) Species likely to occur in study area indicated with question mark

(3) Subjective assessment of status: A-Abundant; C-Common; U-Uncommon; R-Rare; D-Domestic (i.e. populations controlled by man)

(4) Species reported to Hodson from other sources

* Introduced Species - apart from *Rattus rattus* Hodson and Rose do not consider these species

(Anon. a; n.d.) while the Platypus is known from the headwaters of Mooney Mooney Creek (R. Oliver, National Parks & Wildlife Service, pers. comm.). Maynes (1977) considered that the Parma Wallaby may occur just to the North of the study area while this same author (pers. comm.) recorded Rock Wallabies from Olney, Watagan and Corrabare State Forests and Red-necked Pademelon from Ourimbah State Forest.

6.3.5.2 Habitat requirements

This section reviews the feeding and habitat needs of certain species found during the present study, and relates this information to the distribution of these species through the study area.

Several recent papers provide information on the feeding habits and habitat needs of Australian rats. Watts and Braithwaite (1978) found *Rattus fuscipes* to be an opportunistic feeder, choosing whatever food was seasonally available. In general insects, fruits and seeds were important components of the diet in summer while fungi became important in winter. Such catholicity in diet may help account for the wide distribution of the species in the study area - for it was found in all but two of the plots trapped. The habitat requirements of *R. fuscipes* also appear to vary widely between studies (c.f. Barnett et al., 1978) and this too may point to an ability to live in many different habitats.

Rattus lutreolus feeds largely on the basal stems of plants, chiefly monocotyledons (grasses, etc.) and its distribution is related to the availability of these food plants (Watts & Braithwaite, 1978; Braithwaite et al., 1978). The species was found in much lower numbers than *R. fuscipes* during the present study and seemed to prefer wetter vegetation with dense cover.

Melomys cervinipes is arboreal (Wood, 1971; Rose, 1976) and herbivorous. The single specimen taken during the present study was in open forest with a moist understorey, a habitat similar to that described for this species by others (Wood, 1971; Rose, 1976; Barnett et al., 1978).

Both *Antechinus* species are carnivores which feed mainly on insects. To the extent that *A. stuartii* is more of a generalist than *A. swainsonii,* it was found in a much wider range of habitats during the present study. It occurred in all seven plant community types trapped and in all but one study area, this latter being a site with a dense understorey which favoured *Rattus fuscipes*. *A. swainsonii* was found in plant communities 1 and 3 and may favour moister plant communities.

Sminthopsis murina is a largely insectivorous marsupial mouse which prefers drier locations. It is favoured by areas of young regrowth and is an early colonizer after fire; the two specimens caught in the present study were from an area which was burnt two years previously. This species probably occurs patchily through the study area in similar habitat.

Swamp Wallabies *Wallabia bicolor* are solitary browsing macropods which seem to prefer dense vegetation of a moist type. To judge from the abundance of diggings, the Long-nosed Bandicoot *Perameles nasuta* is common through the study area and, while perhaps favouring patches of dense vegetation, nevertheless feeds in many different plant communities.

The Sugar Glider *Petaurus breviceps,* primarily a nectar and sap-feeder which also takes insects, is known from a wide range of habitats (McKay, 1978). In view of its small size this species can use smaller nesting holes than the larger possums and was thus encountered in parts of the study area seemingly devoid of the latter.

The two larger possums *Trichosurus vulpecula* and *Pseudocheirus peregrinus* are generalist feeders, with *P. peregrinus* tending to be more vegetarian. Both species seem to be restricted to larger trees with suitable nesting hollows, and this factor may determine their pattern of distribution within the study area.

The incidence of Wombat burrows and droppings would suggest a low local population of this browsing animal. The number of burrows abandoned due to striking rock during excavation suggest that the availability of burrow sites may limit populations of this species within the study area.

6.4 Birds

6.4.1 Summary

109 bird species were observed in the study area, 96 along corridor 1 and 77 along corridor 2. The higher number of species along corridor 1 was attributed to greater habitat diversity. Another 30-odd species may also occur occasionally in the study area. Several of the species observed in the low priority sections of each corridor reflected man's modification of the natural vegetation - mainly through land clearance.

Six of the species observed are considered rare in the Sydney region - including the Collared Sparrowhawk, Glossy Black Cockatoo and Red-browed Treecreeper - while another six species were locally distributed in Brisbane Water National Park. Five of the latter occurred in closed forest and the sixth in closed heath.

Four major avifaunal habitats were recognised in the study area - closed forest; cool, moist open forest; warm, dry open forest; and low open forest/open woodland/closed heathland. It is suggested that plant community structure and aspect - both of which may primarily reflect moisture gradients - were the major determinants of bird distribution.

Species diversity analyses showed that the cool, moist open forest had a species richness about twice that of the other three major avifaunal habitats, while the closed forest supported the most distinctive avifauna.

About eleven species observed in the study area were total (latitudinal) migrants; they particularly favoured the cool, moist open forest and, to a lesser extent, the warm, dry open forest. Several other species also showed movements in or out of the study area at different times of the year, presumably in response to changes in food supply.

6.4.2 Introduction

Investigation of the avifauna of the study area sought to answer several questions. The prime concern was to determine which species occurred in the study area and their preferred habitats. The second aim was to establish the avifaunal significance of different plant communities, as indicated by species diversity. The final purpose of the study was to identify any migration or movement by the avifauna.

6.4.3 Methods

6.4.3.1 Field studies

Bird species observed during the study were checklisted separately for both high and low priority sections of each proposed freeway corridor and for the study area in general.

The habitat preferences of individual species and the species diversity of different plant communities were established by spot censusing at sites within each plant community (see 6.2). During censusing all birds observed within 40 metres of the study site centre point were recorded during a 30-minute observation period. In an endeavour to standardise the method, censusing was restricted to a certain time of day (between 0700 and 10.00hr Standard East Australian time) and to favourable weather conditions (no rain or strong winds). Calls as well as sightings were used to identify birds during the census period. Each study site was censused during the winter, spring and summer, to detect any changes in both the overall population and the occurrence of individual species with season. Censuses were done between the following dates:

Winter: 23-27th July; 11-13th and 26th August, 1978.
Spring: 21-27th September; 21-23rd October, 1978.
Summer: 7-19th January, 1979.

In addition to censusing, all species observed within each vegetation plot containing a census site were noted, thus providing listings for the different plant communities. In this way casual observations made during fieldwork could be included, thus providing fuller avifaunal 'profiles' for the different plant communities than the census results alone gave. This method suffers the drawback that it is neither quantitative nor standardised, so that any comparison of the data from different sites should be made with caution. Plant community listings were prepared for each season covered by the study, to further elucidate seasonal movements by species.

The avifauna of the low priority sections EC and BC were surveyed between 24/25th February, 1979.

6.4.3.2 Data analysis

Computer programmes from the taxon library of the CSIRO were used to analyse the spot census and plant community listing results.

At first MULCLAS and MULTBET were used. Both are agglomerative, in that they take individual attributes (bird species in the normal analysis, census sites in the inverse) and progressively fuse them by attribute similarity until the whole population is hierarchically arranged. This feature of the programmes proved unsatisfactory in the present study, because fusions were made (on the basis of inadequate data) between species which field experience showed to have distinct habitat needs.

The data were submitted instead to the divisive polythetic classificatory programme REMUL (Lance & Williams, 1975), in which the complete population is progressively divided (in practice always dichotomously) until the desired degree of sub-division is obtained. A desirable feature of the REMUL programme is a provision to reallocate individuals. This is applied after each division, when individuals may move between the groups just formed, as well as at the end of the analysis, when any migration is allowed. In this way consistency is ensured between all levels of analysis

6.4.4 Results and discussion

6.4.4.1 Species recorded

109 bird species were observed in the study area (Appendix 3). The numbers of species recorded in the low and high-priority sections of each corridor are given in Table 6.6.

Table 6.6: Numbers of bird species observed in each corridor

Freeway corridor	No. species observed
1. Section AB	92
Section BC	32
2. Section DE	68
Section EC	38

The disparity in species numbers between high and low-priority sections of each corridor is a reflection both of the much briefer surveys of the latter sections and their more uniform habitat (Map 5.6).

The combined totals for both sections of corridor 1 was 96 species and that for corridor 2 was 77 species. The considerably larger number of species observed along corridor 1 was attributed to the more diverse habitat in that corridor.

Comparison with the preliminary checklist of birds in Ku-ring-gai Chase National Park (Anon. b; n.d.) is instructive. Of the 163 species recorded in that list twelve are marine or littoral species, which are most unlikely to occur in the study area, while at least another eleven may be considered vagrant to Ku-ring-gai Chase. The remaining 140 species have been recorded in habitats similar to those represented in the study area. Another 30-odd species may thus occur in the study area, mostly as occasional visitors.

Whereas introduced species or species which favour disturbed habitat seldom occurred along the high-priority sections AB and DE, such species were frequent along the low-priority sections BC and EC. Among these species were the Spotted Turtle-dove, Peaceful Dove, Crested Pigeon, Eastern Rosella, Red-rumped Parrot, Willie Wagtail, Goldfinch, Starling and Magpie Lark. It seems clear that the original avifaunas of the low-priority sections of both proposed corridors have been much modified by human activity - mostly land clearance.

6.4.4.2 <u>Status of species</u>

Of the species recorded, six were considered rare or very local by Hindwood and McGill (1958) after their study of the birds of Sydney two decades ago. These are the Brown Quail, Collared Sparrowhawk, Glossy Black Cockatoo, Gang-gang Cockatoo, Red-browed Treecreeper and Bell Miner. Each of these species will now be considered in more detail.

The Brown Quail was recorded only from the closed heath community represented by site 1.10. Along with other quail, this species is shy and rarely seen, so that the full extent of its distribution through the study area would be difficult to establish. It prefers swampy areas and may well occur wherever such habitat exists within the study area.

The Collared Sparrowhawk closely resembles the Brown Goshawk *Accipiter fasciatus,* from which it can be distinguished in the field by size and tail shape. Accipiters were observed four times during the study, and on two occasions the bird was seen clearly enough to confirm its identity.

The occurrence of the Glossy Black Cockatoo is of particular interest, as this species was considered "extremely rare" in the Sydney region by Hindwood and McGill (1958) and is generally rare or uncommon throughout its range (Forshaw, 1969). It feeds mainly on the small seeds of the She-oak *(Casuarina)* and, except when on the move, is seldom seen far from groves of this tree. According to Forshaw (1969) preservation and management of extensive stands of She-oaks near suitable breeding areas are essential for the conservation of the species. Such stands are very restricted within the study area, mostly to the open forest with moist understorey (community 2, type B) which clothes the east-facing slopes of Mooney Mooney Creek. The retention of these stands may therefore be important to the conservation within the National Park of both this species and the Yellow-tailed Black Cockatoo, which also feeds extensively on She-oak seeds.

The Gang-gang Cockatoo is primarily a bird of the ranges, so that its rare occurrence in the Sydney region has little relevance to its overall status in this part of N.S.W. The Red-browed Treecreeper was recorded only near site 1.5 in Community 2 (community 2 type B), although it may well occur in this community elsewhere in the study area.

The Bell Miner has a very local distribution around Sydney, with a few small colonies reported by Hindwood and McGill (1958) mostly in localities bordering the Nepean River between Douglas Park and Yarramundi - that is to the SW and NW of the city. The small colony just South of Mooney Mooney Creek bridge may well be the nearest one to Sydney along this city's Northern approaches.

In addition, several species may be regarded as rare or restricted in distribution both in the study area and Brisbane Water National Park. Notable among these were the closed forest species - the Topknot Pigeon, Scaly Thrush, Large-billed Scrubwren, Yellow-throated Scrubwren and Brown Warbler. Another species with specific habitat requirements and small populations was the Tawny-crowned Honeyeater. This bird was recorded twice during the study, once from closed heathland near site 1.10 and again in similar habitat near site 1.17.

6.4.4.3 Avifaunal habitats (See Map 6.2)

The major patterns of bird distribution in the study area were determined by the classificatory computer programme REMUL (see 6.4.3.2). The community species listings from the entire study period (i.e. all three seasons) were used for this analysis as they were the most comprehensive results available although qualitative in nature. Normal and inverse analyses were made, to provide similarity groupings of study sites and bird species respectively.

The results from these analyses are presented as a two-way table (Table 6.7). The normal analysis classified the twenty-eight study sites into three major groups. Group 1 comprised five sites belonging to plant communities 2B (open forest with moist open understorey) and 3 (open forest with dry understorey). Group 2 was the most heterogeneous, containing the three community 1 sites (closed forest), both community 2A sites (open forest with moist dense understorey), the remaining community 3 sites and three low

MAP 6.2

Avifaunal Habitats

Table 6.7: REMUL Groupings of study sites and bird species

GROUP	SPECIES	SITE GROUPS AND NUMBERS: 1					2A			2B										3									
		1.3	1.5	1.6	2.5	2.6	1.2	1.4	2.10	1.1	1.7	1.8	1.9	1.11	1.13	1.16	2.7	2.8	2.9	1.10	1.12	1.14	1.15	1.17	2.1	2.2	2.3	2.4	2.11
A	Variegated Wren		+	+	+	+				+	+	+	+		+			+	+	+		+		+					+
	Yellow-faced Honeyeater		+	+	+	+					+		+	+			+	+		+					+	+		+	
	Pied Currawong		+	+	+	+							+	+				+	+			+		+		+		+	
B	Brown Thornbill	+	+	+	+	+	+	+	+	+			+		+	+	+	+	+				+				+		
	Grey Fantail	+	+	+			+	+		+			+	+	+	+							+	+					
	Golden Whistler	+	+	+		+	+	+	+	+	+	+		+	+	+	+												
	White-throated Tree - creeper	+	+	+	+	+		+		+	+	+	+	+	+	+		+	+					+					+
	Eastern Spinebill	+		+	+		+	+	+	+		+	+	+	+	+		+	+	+		+	+	+	+	+	+	+	+
	Eastern Yellow Robin		+	+		+	+	+		+	+			+	+	+	+	+	+				+	+	+		+	+	
C	Crimson Rosella	+	+	+	+	+	+	+			+	+	+	+	+			+			+	+			+	+	+	+	+
	Grey Shrike-Thrush	+	+	+	+			+			+				+			+			+	+					+	+	
	Spotted Pardalote	+	+	+	+	+	+			+	+	+		+			+				+	+		+		+	+	+	
	Silvereye	+	+	+	+	+				+			+		+	+					+	+		+			+	+	
	Noisy Friarbird				+	+								+			+	+			+	+			+	+	+	+	+
D	Rufous Whistler			+	+											+	+			+	+	+		+					
	White-eared honeyeater												+			+					+	+	+		+	+		+	
	New Holland honeyeater																			+	+	+	+	+	+				+
	White-cheeked honey- eater				+					+	+		+		+	+				+	+	+	+	+			+	+	
	Little Wattlebird	+			+										+							+	+	+	+	+	+		
E	King Parrot	+	+	+	+														+										
	Scarlet Robin	+	+		+	+																							
	Mistletoe Bird	+	+	+	+					+				+	+													+	
	Grey Butcherbird	+			+	+																					+		

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Table 6.7: REMUL Groupings of study sites and bird species (Continued)

GRP.	SPECIES	SITE GROUPS AND NUMBERS 1					2A			2B										3									
		1.3	1.5	1.6	2.5	2.6	1.2	1.4	2.10	1.1	1.7	1.8	1.9	1.11	1.13	1.16	2.7	2.8	2.9	1.10	1.12	1.14	1.15	1.17	2.1	2.2	2.3	2.4	2.11
	Australian Raven		+		+	+								+								+				+			
	Striated Thornbill	+	+		+	+				+								+						+					
	Satin Bower Bird	+		+																									
	Lewin's Honeyeater		+	+			+	+	+		+							+											
	White-browed Scrub Wren	+	+	+		+	+	+	+				+		+												+		
	Large-billed Scrub Wren								+																				
	Brown Warbler						+		+																				
	Topknot Pigeon						+																						
	Scaly Thrush						+	+																					
E	Chestnut-Rumped Hylacola																			+	+				+			+	
	Collared Sparrowhawk				+																		+						
(Con.)	Brown Quail																			+									
	Wonga Pigeon		+							+																			
	Yellow-tailed Black Cockatoo		+								+																		
	Glossy Black Cockatoo																	+											
	Gang-Gang Cockatoo																										+	+	
	Eastern Rosella																								+			+	
	Brush Cuckoo			+							+																		
	Fan-tailed Cuckoo		+	+		+				+					+			+		+									+
	Golden-bronze Cuckoo	+		+		+																+		+					
	Boobook Owl		+																										
	Tawny Frogmouth					+										+													
	White-throated Nightjar		+																										

Table 6.7: REMUL Groupings of study sites and bird species (Continued)

GRP.	SPECIES	SITE GROUPS AND NUMBERS																											
		1					2A			2B										3									
		1.3	1.5	1.6	2.5	2.6	1.2	1.4	2.10	1.1	1.7	1.8	1.9	1.11	1.13	1.16	2.7	2.8	2.9	1.10	1.12	1.14	1.15	1.17	2.1	2.2	2.3	2.4	2.11
	Laughing Kookaburra	+	+	+								+						+				+				+			
	Sacred Kingfisher			+		+								+															+
	Dollar Bird			+		+												+											
	Superb Lyrebird					+	+	+		+	+				+														
	Black-faced Cuckoo-Shrike	+		+	+	+									+	+						+				+		+	
	Cicada Bird				+													+	+										
	Superb Blue Wren			+													+	+											
	Southern Emu Wren																+	+											
	White-throated Warbler					+																							
E	Rock Warbler				+						+		+	+							+						+		
(Con.)	Leaden Flycatcher	+		+							+						+												
	Black-faced Monarch			+																									
	Orange-winged Sittella			+	+																								+
	Striated Pardalote																				+			+					
	Brown-headed Honeyeater																					+		+					
	Tawny-crowned Honeyeater																			+									
	Red-browed Firetail	+																											
	Olive-backed Oriole			+																									
	Eastern Whipbird		+				+		+	+	+			+	+			+						+	+	+			+
	Black-backed Magpie				+	+																+							+

open forest/open woodland sites. Group 3 comprised six of the seven community 6 sites (low open forest/open woodland) and all four community 8 sites (closed heath). For convenience in later discussion, Group 2 has been subdivided into closed forest (Group2A) and open forest (Group 2B) sites.

The inverse REMUL analysis classified the 66 bird species submitted into five major groups (Table 6.7), none of which was unique to any one site group. Group E was the largest and most heterogeneous, consisting mostly of less common species. Some of the species in this group have been subjectively assembled into subgroups, on the basis of similar patterns of distribution, these latter being indicated in Table 6.7 by dashed lines.

This two-way analysis permits an interpretation of the major patterns of bird distribution in the study area. The Group 1 sites were characterised by bird species Groups A, C and to a lesser extent B, although most of the species concerned also occurred widely in the two other major sites groups. Several species in bird species Group E appeared more specific to the Group 1 sites, notably the King Parrot, Scarlet Robin, Satin Bowerbird, Grey Butcherbird and possibly the Striated Thornbill, Mistletoe Bird and Australian Raven.

Group 2 sites as a whole had few if any characteristic species, being avifaunally intermediate between Group 1 and 3 sites. This was not true though of the Group 2A sites, which contained several species confined to closed forest (e.g. Topknot Pigeon, Scaly Thrush, Large-billed Scrubwren and Brown Warbler).

Group 3 sites were characterised both by the infrequent occurrence of most Group B species (including absence of the Golden Whistler) and the commonness of species in Bird Species Group D (i.e. Rufous Whistler, Little Wattlebird, White-eared Honeyeater, New Holland Honeyeater and White-cheeked Honeyeater).

To help relate these patterns of distribution to more basic parameters of the study area, physical and botanical attributes of each study site are given in Table 6.8. The Group 3 sites have several distinctive attributes in that they had a characteristic vegetation (as reflected by low canopy height (11m or less) and canopy cover (46% or less), occurred mainly at high elevations (130m or more), and mostly on the ridges (with shallow slopes of 10° or less).

Group 2A sites supported the botanically-distinctive closed forest (Benson, 1979). In contrast Site Groups 1 and 2B shared most attributes. The most striking difference between the two groups was in aspect - Group 1 sites mostly facing East or South (i.e. cool and moist) while Group 2B sites were primarily North or West facing (i.e. warm and dry).

Although sites 1.9 (community 6), 1.16 (community 5) and 2.7 (community 4) would have been expected - on community structure - to belong to Group 3 rather than Group 2, there are plausible reasons for their not doing so. Site 1.9, for instance, was near to a creek and this may have resulted in the development of a forest structure and water regime differing from those of the other community 6 sites, all of which were on ridges. This explanation receives some credence from the presence of *Angophora costata* as a dominant tree species, since this species is more characteristic of open forest (communities 2 and 3) (see Appendix 2). Site 1.16 represented a plant community (5) unique in the study area and unusual in structure (Benson, 1979). Site 2.7 represented a plant community which occurred only in small patches through the study area and may thus have lacked an avifauna of its own - instead supporting species from adjoining plant communities, in this case community 3.

This analysis suggests that bird distribution in the study area is related primarily to the floristic and/or structural composition of the vegetation and to aspect, these in turn probably reflecting moisture gradients through the study area.

TABLE 6.8: Site attributes

Attributes	SITE GROUPS																			SITE GROUPS								
	1					2														3								
						A			B																			
	1.3	1.5	1.6	2.5	2.6	1.2	1.4	2.10	1.1	1.7	1.8	1.9	1.11	1.13	1.16	2.7	2.8	2.9	1.10	1.12	1.14	1.15	1.17	2.1	2.2	2.3	2.4	2.11
Elevation (m)	120	60	50	80	30	70	70	40	100	60	20	80	80	130	170	5	20	90	130	130	150	170	165	180	200	170	160	140
Geology	HS	HS/NG	NG	HS	NG	HS	HS/NG	NG	HS	HS	HS	HS	HS	HS	HS	Al	NG	NG	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS
Geomorphology	S	S	S	S	S	C	C	C	S	S	S/C	S/C	C	C	R	F	S	S	R	RS	R	R	R	RS	R	RS	R	R
Aspect (°)	130	90	30	190	110	150	120	260	180	310	225	270	0	260	340	0	270	180	0	240	310	330	230	230	160	50	60	95
Slope (°)	8	22	23	14	23	24	14	22	18	23	20	11	23	18	2	0	23	25	3	7	3	2		10	8	7	9	8
Canopy height (m)	15	15	25	13	20	22	25	20	20	12	20	10	23	15	10	8	20	27	6	10	8	7			10	9	9	11
Canopy cover (%)	60	58	60	28	46	76	72	82	58	38	42	42	45	50	44	56	54	52	18	32	6	8			36	34	46	32

Geology: HS - Hawkesbury Sandstone

NG - Narrabeen Group

Al - Alluvial

Geomorphology: S - Slope of valley

R - Ridge

C - Creek

F - River flats

6.4.4.4 Species Diversity

Whittaker (1972) recognised two kinds of diversity relevant to the present study. Alpha-diversity describes an avian community's richness in terms of species numbers while beta-diversity describes the similarity between communities.

At its simplest, α- diversity can be based on the number of species per unit area - as determined by a standardised method This approach has limitations, particularly sampling errors incurred by irregularities in species distribution and differing success in finding rare species, but has been used here because of its simplicity. Table 6.9 gives the total numbers of species observed at each study site during the study, the sites being grouped according to the REMUL analysis described already (see 6.4.4.3).

It is clear that the cool, moist, open forest (Group 1) sites contained a much more diverse avifauna than those in the other three groups - all of which contained similar numbers of species. This is true whether the spot census or community listing results were used (see Table 6.9). The species richness of Group 1 sites was due, in part, to the preference shown for this habitat by the total summer migrants to the study area.

To establish β- diversity, composite community listings were prepared for each of the four major site groupings (see 6.4.4.3) and the percentage of shared species determined by pairwise comparisons of these listings. From the results given in Table 6.10 it is clear that the closed forest (Group 2A) sites are avifaunally the most distinct, sharing at most 31% of species with the Group 2B sites. The cool, moist and warm, dry open forests, which flank the major creeks, were predictably most alike - with 68% of species in common. Both of these communities shared about 50% of their species with the closed heath/low open forest/open woodland communities of the ridges.

TABLE 6.9: Bird species diversity of study sites

No. species/site

Site Group	Site Number	Spot census		Community listing	
		Individual	Average	Individual	Average
1	1.3	19	15	22	26
	1.5	13		26	
	1.6	17		31	
	2.5	9		27	
	2.6	16		26	
2A	1.2	8	7	14	12
	1.4	7		11	
	2.10	5		10	
2B	1.1	10	8	16	14
	1.7	10		18	
	1.8	3		7	
	1.9	10		13	
	1.11	9		15	
	1.13	12		18	
	1.16	10		12	
	2.7	6		11	
	2.8	7		20	
	2.9	4		9	
3	1.10	5	8	9	13
	1.12	6		12	
	1.14	6		19	
	1.15	7		9	
	1.17	15		18	
	2.1	9		11	
	2.2	7		12	
	2.3	6		13	
	2.4	12		18	
	2.11	5		13	

Table 6.10: Similarity of avifaunal habitats

Site Groups	Total No. species/site group pair			
	3	1	2B	2A
3		60	51	50
1	52		53	56
2B	53	68		45
2A	24	29	31	
	% shared species			

Table 6.11: Habitat preferences of latitudinal migrants

Species	Site Group			
	1	2A	2B	3
Brush Cuckoo	+		+	
Golden Bronze Cuckoo	+			+
Sacred Kingfisher	+		+	+
Dollar Bird	+		+	
Cicada Bird	+		+	
Rufous Whistler	+		+	+
Leaden Flycatcher	+		+	
Noisy Friarbird	+		+	+
Olive-backed Oriole	+			
White-throated Nightjar	+			

6.4.4.5 Migration and movement

6.4.4.5.1 Introduction

It has been estimated that more than half the 713 bird species recorded in Australia exhibit movements of some kind (Purchase, 1975). During studies beside the Murrumbidgee River near Canberra, Lamm & Calaby (1950) found that the populations of only 13 (16%) of the 83 species observed did not vary with season. Subsequently, Lamm & Wilson (1966) found that only 19 (30%) of 63 species observed in the Brindibella Range near Canberra were year-round residents. Predictably, the need of birds to move is a response to food supply - a subject well considered by Nix (1976).

Several types of bird movement have been recognised. The most striking of these is the regular South-North migration shown by about 8% of the Australian avifauna (Keast, 1959). In South-East Australia altitudinal migration is also important, the birds leaving the highlands for lower altitudes and the coastal plains in winter and returning again in summer.

The third major form of movement is nomadism, in which birds move particularly (but not exclusively) in response to abnormal climatic change and its associated effects on vegetation. Keast (1959) considered that perhaps 26% of Australian birds are nomadic. Although the more spectacular nomadic movements of birds occur in the arid interior, there are many nomadic species in the eucalypt forests of the coastal districts. Well-known examples are the 'blossom nomads' - the lorikeets and honeyeaters which move in response to the flowering of trees and shrubs.

The present study sought to establish any role that the study area might have in the movement of these birds.

6.4.4.5.2 Latitudinal Migrants

North-South migrants fall into two categories. Firstly there are those species which are essentially total migrants. The Spine-tailed Swift provides a most impressive example of this kind of migrant among the species recorded from the study area, for it breeds in the forests of Northern Asia and Japan, South of the tundra. More often migration is to Northern Australia and the islands further North. Several species observed in the study area show this pattern of movement, notably the Brush Cuckoo, Golden Bronze Cuckoo, Sacred Kingfisher, Dollar Bird, Cicada Bird, Rufous Whistler, Leaden Flycatcher, Noisy Friarbird, Olive-backed Oriole and probably the White-throated Nightjar. Individuals of the Golden Bronze Cuckoo, Rufous Whistler and Noisy Friarbird were observed during the winter study period, so that residual populations of these species apparently remain in the study area

With the exception of the Spine-tailed Swift the above species may be presumed to breed in the study area, although this was demonstrated only for the Noisy Friarbird. Information on the habitat preferences of these species within the study area is summarised in Table 6.11. The strong preference of most species for the open forest communities 1 and 2B is most evident, as also is the avoidance of closed forest by these species.

Five other total summer migrants were also recorded in the study area during the migration period, but apparently did not remain to breed. These were the Indian Koel, Black-faced Monarch, Rufous Fantail, White-throated Warbler and Dusky Woodswallow. The transitoriness of the Rufous Fantail and Black-faced Monarch is puzzling since suitable breeding habitat for these species would seem to exist in the study area. The White-throated Warbler was observed twice during the spring study period (24/25th September), but may well breed in the nearby Somersby area. Small flocks of Dusky Woodswallows were observed on 25/26th January, presumably during Northward migration.

The second group of regular South-North migrants are those species in which local populations are supplemented at certain times of the year by birds from further South. This pattern of movement is exemplified by the two honeyeaters - the Yellow-faced Honeyeater and the White-naped Honeyeater - and the Silvereye. The two honeyeater species show a marked South-North migration through the Sydney area in late April and early May (Keast, 1968), a time of year not covered by the present study. It was therefore not possible to assess any significance of the study area to these migrant species. While a presumably resident population of Yellow-faced Honeyeaters occurred in the study area, the White-naped Honeyeater suprisingly was not observed. The return movement in spring is less pronounced for either species, but individuals and small flocks drift South between August and October. No evidence of this Southerly movement was recorded from the study area.

A small flock of the Tasmanian race of the Silvereye was observed in open forest (plant community 2) beside Piles Creek on 25th August, 1978, presumably during migration southwards.

6.4.4.5.3 Other movements

Several other species showed marked changes in populations during the study, both in terms of the number of sites at which they were observed during each study period and the total number of observations during spot censusing (Table 6.12).

In some cases these population changes followed well-known patterns for the Sydney region. For example, the Topknot Pigeon is considered by Hindwood & McGill (1958) to occur irregularly around Sydney, usually between May and October. Three individuals of this species were observed in closed forest at site 1.2 on 24.9.78. The Scarlet Robin appears to be an altitudinal migrant, moving from the Blue Mountains West of Sydney onto the coastal plains during autumn and

TABLE 6.12: Changes in bird populations

Species	No. sites in which species observed during			Total no. observations during spot censusing in		
	Winter	Spring	Summer	Winter	Spring	Summer
Topknot Pigeon	0	1	0	0	3	0
Laughing Kookaburra	7	1	0	13	1	0
Scarlet Robin	3	1	0	2	0	0
Golden Whistler	5	8	1	16	16	1
Grey Fantail	6	7	3	12	14	5
Brown Thornbill	8	11	3	20	14	3
White-throated Treecreper	4	5	2	9	8	2
Yellow-faced Honeyeater	7	6	4	20	18	7
White-eared Honeyeater	6	5	4	12	13	6
New Holland Honeyeater	6	5	2	43	29	11
White-cheeked Honeyeater	5	3	3	13	16	5
Eastern Spinebill	14	8	4	30	12	5
Spotted Pardalote	10	6	3	15	10	3
Silvereye	4	4	0	28	22	0
Red-browed Firetail	0	0	1	0	0	5

winter (Hindwood & McGill, 1958). It was observed frequently during the winter study period in open forest communities 2B and 3. Two individuals were observed during the spring study period but none was recorded in summer.

The Red-browed Firetail showed a noticeable influx into the study area between the spring and summer study period. Until then it had been recorded only around settlements at Camp Kariong and beside Mooney Mooney Creek, where the birds were fed. It seems likely that the influx of this species, which is gramnivorous, was in response to the seeding of grasses.

There was a marked decline in the populations and distribution of several other species between the spring and summer study periods (Table 6.12). The total number of observations made during spot censusing reflected this decline, falling from 291 observations in winter and 304 in spring to 126 in summer. The decline may have been due, in part, to reduced activity by individuals following breeding, but probably also represented a movement of birds out of the study area. Such a movement may have occurred in response to the very hot and dry conditions which prevailed during January.

To summarise, several regular latitudinal migrants were recorded from the study area. These species appeared to favour particularly the open forest communities 2B and 3. Altitudinal migrants may also use the study area although the extent to which this occurred was not clear. Several species seemed to change in numbers and/or distribution during the study period. These movements were probably local in nature and made in response to changes in the availability of food. It is unfortunate that the study area was not surveyed between April and early August, when a large influx of blossom and nectar-feeding species (honeyeaters especially) into the study area may well occur (c.f. Hindwood, 1944; Keast,1968).

6.5 Reptiles and amphibia

6.5.1 Summary

The herpetofauna of the study area is rich and varied. Twelve species of frogs and twenty-eight of reptiles were recorded, these representing perhaps a half to two-thirds of the predicted herpetofauna. Notable observations included the Red-crowned Toadlet, which is restricted to the Hawkesbury Sandstone, and the Pink-tongued Lizard, which may reach its southernmost limit within Brisbane Water National Park.

Most species probably have large populations both within the study area and more generally in Brisbane Water National Park. Exceptions are those species with restricted habitat requirements or species with large territorial needs. The former include species restricted to creeks, rocky outcrops, the sand-mined areas beside Mooney Mooney Creek and the wetter vegetation types - especially closed forest. The latter include the Lace Monitor and perhaps some of the larger snakes.

6.5.2 Introduction

The herpetofauna of eastern New South Wales in general and the Sydney region in particular is a rich one. Some 40% of Australian frog species, for example, occur in eastern New South Wales (Moore, 1961).

The Gosford area itself has a diverse herpetofauna. Perhaps 30 species of frogs (about 20% of all Australian species and representing nine of the continent's 27 frog genera) and almost 50 species of reptiles (about 10% of all Australian species and representing about a third of the continent's reptile genera) occur in this area.

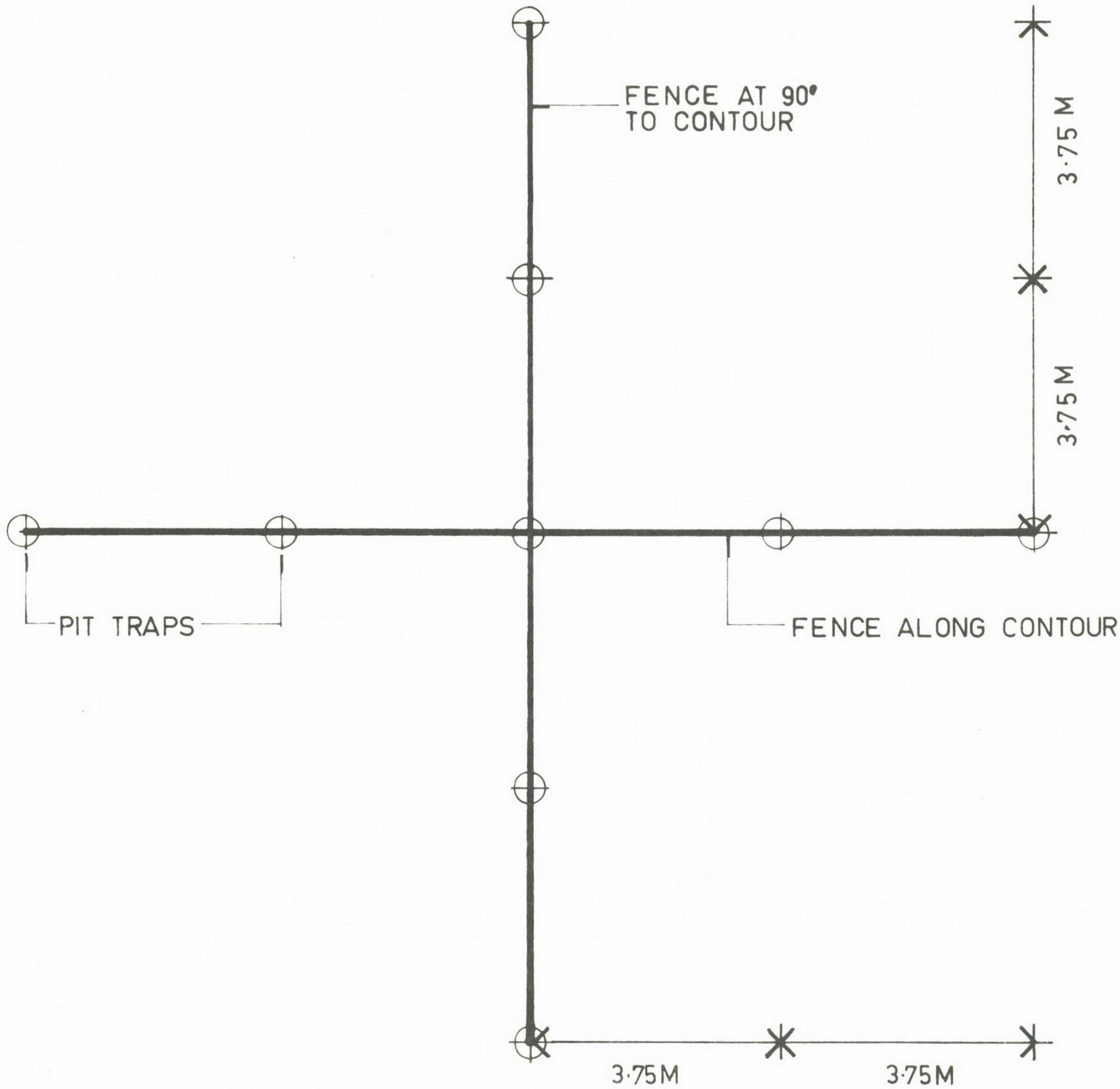


FIG 6.1 **Pit-traps**

PHOTOGRAPH 6.1: Detail of pit-traps

6.5.3 Methods

Search and capture methods were used throughout the study. In the later stages other methods were also used - pit-trapping, spot lighting and recorded frog calls (see Grigg & Barker, 1977). These methods are now described in more detail.

6.5.3.1 Search and capture

Specimens were sought under rocks, leaf litter, logs, etc. and collected. Where possible the specimens were identified immediately and released at the point of capture. Where field identification was not possible, specimens were preserved in 70% ethyl alcohol for later identification.

6.5.3.2 Pit-trapping

Seven pit-trap assemblages were installed in representative samples of each major plant community (i.e. plant communities 1, 2 3, 5, 6, 8 and 10). Each assemblage consisted of a plastic sheeting drift fence, 45cm high, in the shape of a cross with each arm 7.5m long. The pit-traps themselves consisted of plastic ice-cream buckets 24cm in diameter and 21cm deep, each containing 800ml of 10% formalin. The formalin was covered with a thin layer of peanut oil to prevent water loss through evaporation. Seven such pit-traps were used in each assemblage, one beneath the centrepoint of the drift fences and two under each arm. Details are shown in Figure 6.1 and Photograph 6.1.

The method worked by deflecting small animals which encountered the drift fence into one of the pits. The formalin preserved the specimens thus obtained, thereby eliminating the need to check the traps daily.

The pit-trap assemblages were installed between 9-16th January, 1979, and specimens were collected on the 24/25th January, 24/25th February and the 31st March/1st April, 1979.

6.5.3.3 Spotlighting

Spotlighting was used to locate nocturnal species, notably geckos and frogs.

6.5.3.4 Recording of frog calls

Frog species are for the most part readily distinguished by their calls. These latter were collected with a portable tape recorder and then identified by comparison with commercial tapes. This method has the significant advantage that the frogs themselves do not have to be found and captured, although this may still be helpful to confirm an identification.

6.5.3.5 Additional observations

Information was also provided by other observers in the study area. K. Paull provided information on the snakes of Camp Kariong while H. Fallding and J. Benson made several observations during their botanical survey of the area.

6.5.4 Results and discussion

6.5.4.1 Species recorded

Twelve amphibians and twenty-eight reptiles were recorded during the study (Table 6.13). These represent about 40% and 60% respectively of the potential faunas of the study area. Species which may also occur within the study area are listed in Table 6.14. It is hard to assess the likely occurrence of these latter species because their habitat needs are so little known. However, those which have been recorded from Ku-ring-gai Chase National Park (Table 6.14) may reasonably occur in the study area, since the two National Parks are vegetationally similar.

TABLE 6.13: Frogs and reptiles recorded in the study area

FROGS	[1,3]Green Tree Frog	*Litoria caerulea*
	[1,3]Dwarf Tree Frog	*L. fallax*
	[3]Leaf Green Tree Frog	*L. phyllochroa*
	[1]Broad-palmed Frog	*L. latopalmata*
	[1,2,3]Freycinet's Frog	*L. freycineti*
	[1]Rocket Frog	*L. nasuta*
	[1,2,3]Bleating Tree Frog	*L. dentata*
	[2,3]Brown Frog	*Limnodynastes peroni*
	[1,2,3]Giant Burrowing Frog	*Heleioporus australiacus*
	[1,2,3]Red-crowned Toadlet	*Pseudophryne australis*
	[1,2,3]Common Eastern Froglet	*Ranidella signifera*
	[1,2,3]Gray's Toadlet	*Uperoleia marmorata*
REPTILES	[1]Lesueur's Velvet Gecko	*Oedura lesueurii*
	[1,2]Southern Leaf-tailed Gecko	*Phyllurus platurus*
	[1]Burton's Snake Lizard	*Lialis burtonis*
	[1]Common Scaly-foot	*Pygopus lepidopodus*
	[4]Bearded Dragon	*Amphibolurus barbatus*
	[1,2]Mountain Dragon	*A. diemensis*
	[4]Eastern Water Dragon	*Physignathus lesueurii*
	[4]Lace Monitor	*Varanus varius*
	[2]Bouton's Snake-eyed Skink	*Cryptoblepharus boutonii*
	[1,2]Copper-tailed Skink	*Ctenotus taeniolatus*
	[1]Cunningham's Skink	*Egernia cunninghami*
	[1,2]White's Skink	*E. whitii*
	[2]Fence Skink	*Lampropholis delicata*
	[2]Weasel Skink	*Lampropholis mustelina*
	[1,2]Red-throated Skink	*Leiolopisma platynota*
	[1,2]Three-toed Skink	*Saiphos equalis*
	[1]Eastern Water Skink	*Sphenomorphus quoyi*
	[1,2]Barred-sided Skink	*S. tenuis*
	[2]Pink-tongued Lizard	*Tiliqua gerrardii*
	[4]Blue-tongued Lizard	*T. scincoides*
	[5]Diamond Python	*Morelia spilotes*
	[4]Common Tree Snake	*Dendrelaphis punctulatus*
	[1]Common Death Adder	*Acanthophis antarcticus*
	[4]Yellow-faced Whip Snake	*Demansia psammophis*
	[4]Red-naped Snake	*Furina diadema*
	[5]Eastern Tiger Snake	*Notechis scutatus*
	[4]Red-bellied Black Snake	*Pseudechis porphyriacus*
	Eastern Brown Snake	*Pseudonaja textilis*
	Black-bellied Swamp Snake	*Hemiaspis signata*

[1]Hand collection

[2]Pit-trapping

[3]Call

[4]Observation

[5]Photograph

TABLE 6.14: Frogs and reptiles which may occur in study area

FROGS

*Perons Tree Frog *Litoria peronii*

North Coast Green Tree Frog *L. chloris*

Dainty Green Tree Frog *L. gracilenta*

*Green and Golden Bell Frog *L. aurea*

Green-thighed Frog *L. brevipalmata*

*Blue Mountains Tree Frog *L. citropa*

Verreaux's Tree Frog *L. verreauxi*

*Jervis Bay Tree Frog *L. jervisiensis*

*Brown Tree Frog *L. ewingii*

Lesueur's Frog *L. lesueurii*

Tusked Frog *Adelotus brevis*

Haswell's Froglet *Crinia haswelli*

*Brown Toadlet *Pseudophryne bibronii*

Lowland Great Barred Frog *Mixophyes fasciolatus*

Mountain Great Barred Frog *M. balbus*

Fletcher's Frog *Lechriodus fletcheri*

*Banjo Frog *Limnodynastes dumerilli*

*Ornate Burrowing Frog *L. ornatus*

Spotted Marsh Frog *L. tasmaniensis*

REPTILES

* Wood Gecko *Diplodactylus vittatus*

* Barking Gecko *Underwoodsaurus milii*

Four-fingered Snake-eyed Skink *Carlia burnetti*

* Sand Goanna *Varanus gouldii*

* Jacky Lizard *Amphibolurus muricatus*

Oak Skink *Tiliqua casuarinae*

* Striped Skink *Ctenotus robustus*

* Grass Skink *Leiolopisma guichenoti*

* Tree-lined Skink *L. trilineata*

Limbless Skink *Anomalopus* sp

* Eastern Blind Snake *Typhlina nigrescens*

* Brown Tree Snake *Boiga irregularis*

Stephen's Banded Snake *Hoplocephalus stephensi*

Broad-headed Snake *H. bungaroides*

Montane Yellow-naped Snake *Drysdalia mastersi*

White-lipped Snake *D. coronoides*

* Small-eyed Snake *Cryptophis nigrescens*

* Bandy Bandy *Vermicella annulata*

* Golden-crowned Snake *Cacophis squamulosus*

6.5.4.2 Habitat requirements

No detailed assessment of the habitat needs of each species recorded was attempted. However, the pit-trap results (Table 6.15) provide useful ecological information and this latter has been integrated with field observations to give an account of the habitat needs of each species (Appendix 6). The more important information in this account is summarised below.

The more habitat-specific herpetofauna collected during the survey have been classified into five major groupings (Table 6.16) according to habitat preference. It is clear that most species preferred the drier habitats and were thus widely distributed through the study area. However some species had more specific habitat needs and were consequently of more limited distribution.

The most limited habitat within the study area was the swampy areas which have developed alongside Mooney Mooney Creek as a result of sand mining. Large populations of seven different frog species were observed in this locality, which was the only discovered location within the study area for two of the species - Dwarf Tree Frog and Gray's Toadlet. Another restricted habitat was the rocky outcrops, especially those associated with Leochares Peak and Mount Kariong. These places were favoured by several skink and gecko species. As with birds (see 6.4.4.3), the moister habitats - particularly the closed forests of the gullies - contained a small but distinctive herpetofauna. This latter may include several frog species not detected during the present study - for example the North Coast Green Tree Frog and the Barred Frogs. The creeks through the study area also supported a distinctive herpetofauna, particularly the Eastern Water Skink and the Eastern Water Dragon but probably several frog species also.

Although little is known of the territorial requirements of reptiles and amphibia, it may be predicted that most species within

TABLE 6.15: Herpetofauna caught in pit-traps

Site No.	No. individuals/site						
	1.2	1.10	1.16	1.16A	2.4	2.5	2.6
Plant Community type / Species	1	8	5	10	6	3	2
Litoria freycineti							
24/25.1.79							1
L. dentata							
24/25.1.79					2	3	1
Limnodynastes peroni							
24/25.1.79						1	2
Heleioporus australiacus							
24/25.1.79		3					
Pseudophryne australis							
24/25.1.79		7	1		3	1	
24/25.2.79			1		1	4	1
Ranidella signifera							
24/25.1.79		3	7	23	4	21	76
24/25.2.79		4	8	3	4	78	57
Uperoleia marmorata							
24/25.1.79						3	
Unidentified Frog							
24/25.1.79						1	
Phyllurus platurus							
24/25.1.79							1
Amphibolurus diemensis							
24/25.2.79			1				
Cryptoblepharus boutonii							
24/25.1.79					1		
24/25.2.79					2		
Ctenotus taeniolatus							
24/25.1.79					2	1	
24/25.2.79		1		1	1	3	
Egernia whitii							
24/25.2.79				1			
Lampropholis delicata							
24/25.1.79		2	4	3			1
24/25.2.79		3		1	1	1	2
L. mustelina							
24/25.1.79	2						1
24/25.2.79	1						
Leiolopisma platynota							
24/25.2.79						1	
Saiphos equalis							
24/25.1.79	1						2
24/25.2.79	2						
Sphenomorphus tenuis							
24/25.1.79	4						
24/25.2.79	1						
Tiliqua gerrardi							
24/25.2.79	1						

TABLE 6.16: Habitat preferences of more habitat-specific herpetofauna

Creeks	Sand-mined area	Moist habitat (Closed forest; Open forest with moist understorey)	Dry habitat (Open forest with dry understorey; Low open forest/open woodland; closed heath)	Rocky outcrops
Litoria phyllochroa *Physignathus lesueurii* *Spenomorphus quoyi*	*Litoria fallax* *Uperoleia marmorata*	*Lampropholis mustelina* *Saiphos equalis* *Sphenomorphus tenuis* *Tiliqua gerrardii*	*Heleioporus australiacus* *Pseudophryne australis* *Pygopus lepidopodus* *Amphibolurus diemensis* *Ctenotus taeniolatus* *Leiolopisma platynota* *Tiliqua scincoides*	*Oedura lesuerii* *Ctenotus taeniolatus* *Egernia cunninghami* *E. whitii*

the study area do not have large spatial requirements and consequently are represented by large populations within both the study area and Brisbane Water National Park. Notable exceptions to this general prediction are likely to be the Lace Monitor and some of the larger snakes.

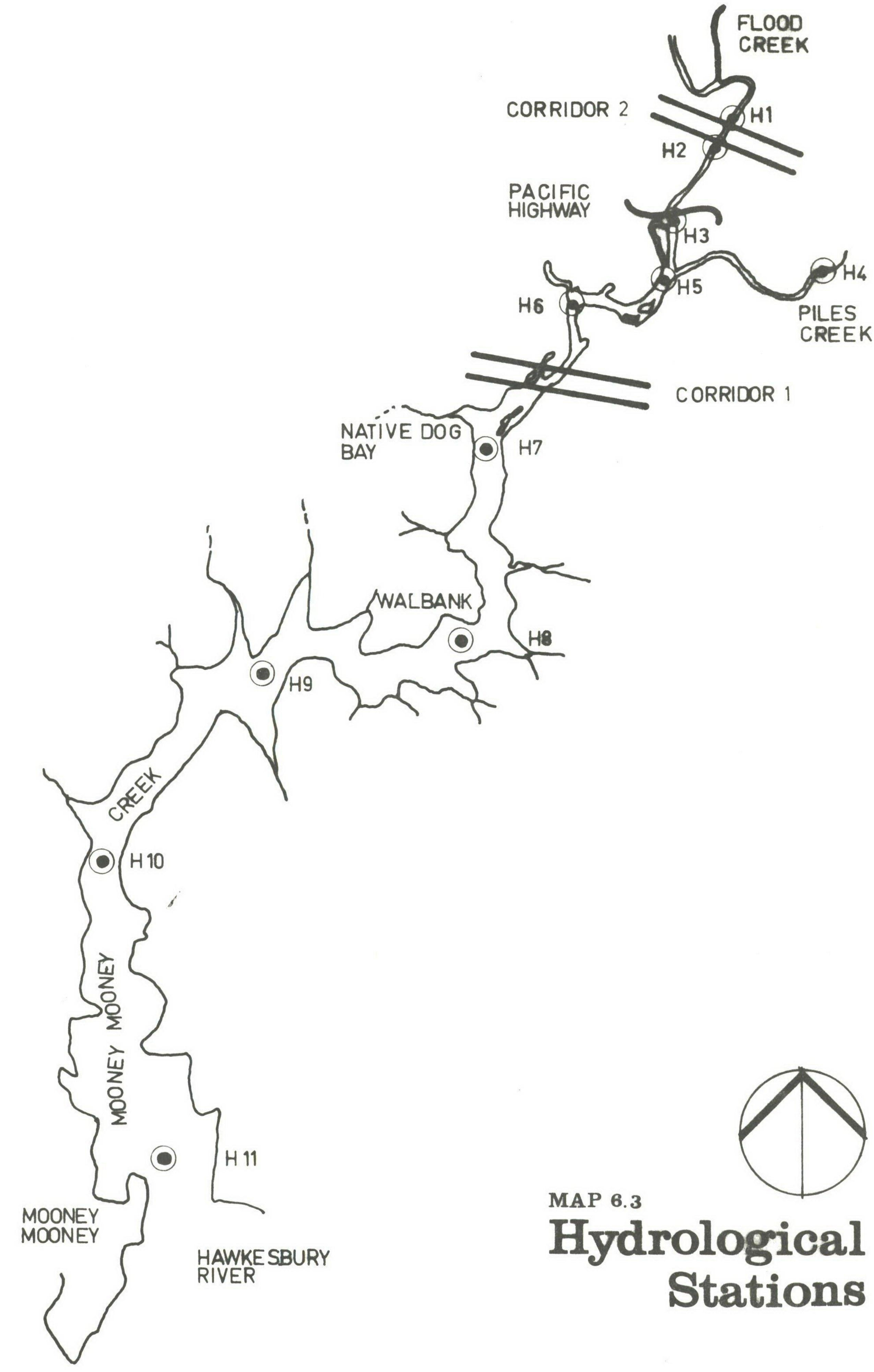
6.6 Fishes

6.6.1 Summary

It seems clear from this survey that the major impact of freeway construction on the ecology of Mooney Mooney and Piles Creeks will be through increased sedimentation caused by erosion during construction.

The impact will be similar for both proposed routes. Should corridor 1 be chosen, sedimentation is likely to occur at first in Piles Creek, but will be flushed eventually into the wider reaches of Mooney Mooney creek downstream from Piles Creek. If corridor 2 is chosen sedimentation is likely to occur initially in both Mooney Mooney and Piles Creeks above their confluence. Some may remain in these areas but most of the material will once again be transported during flooding to the wider reaches of Mooney Mooney Creek.

Sedimentation from construction of the proposed freeway should be minimised if the already severe impacts of existing agricultural, quarrying and freeway construction activities on the fish fauna of Mooney Mooney Creek are not to be further aggravated.



MAP 6.3

Hydrological Stations

6.6.2 Introduction

The main purpose of this study was to survey the fish faunas of Mooney Mooney and Piles Creeks, and thus establish possible impacts of the proposed freeway on these creeks. To assist interpretation of the survey findings, the hydrological and sedimentary regimes of both creeks were also briefly investigated.

6.6.3 Methods

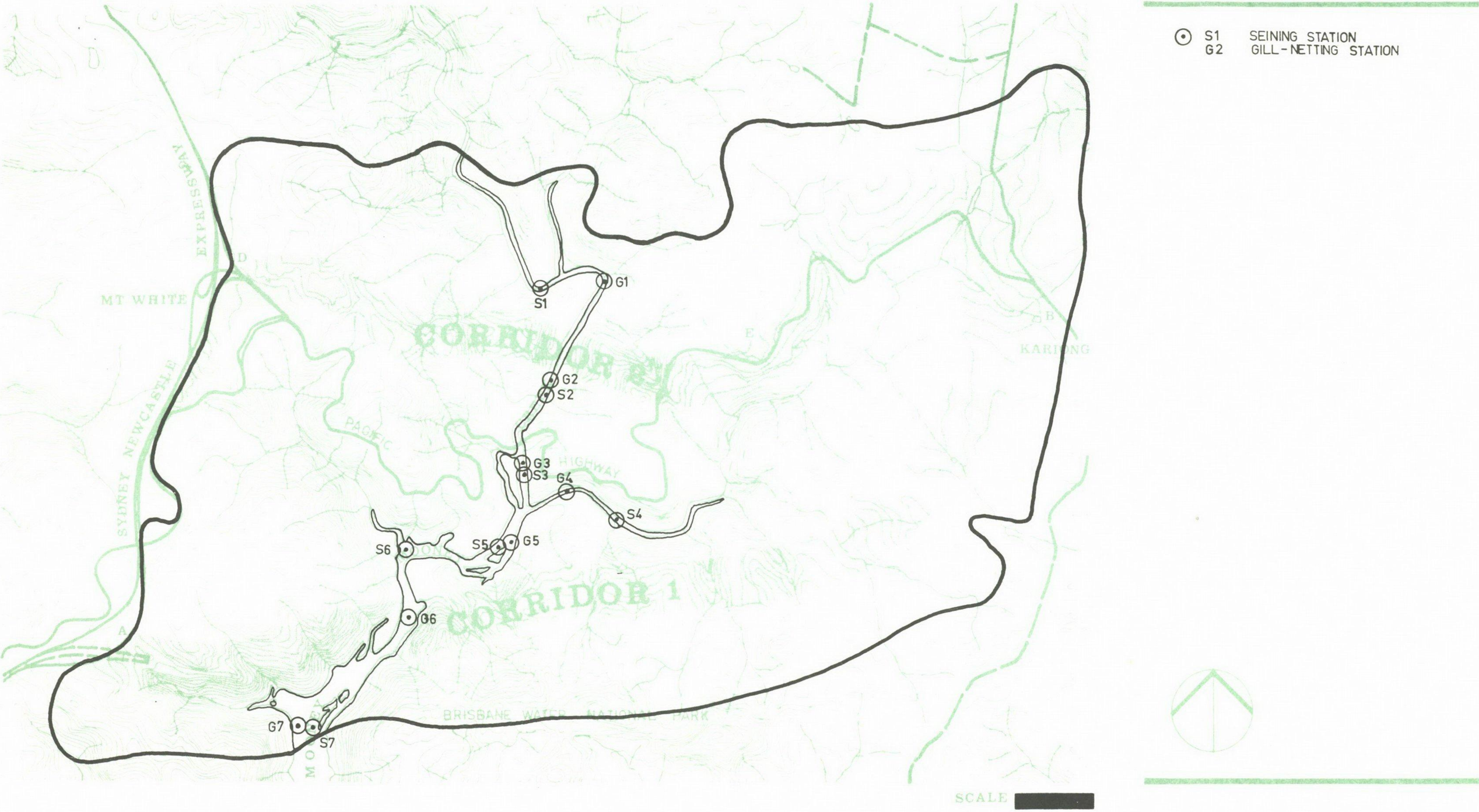
6.6.3.1 Hydrological studies

Salinity, water temperatures and dissolved oxygen readings were taken at several stations (Map 6.3). Salinity and water temperature readings were taken with an Autolab S-T meter with probe, while dissolved oxygen concentrations were measured with a portable Townson and Mercer dissolved oxygen meter.

6.6.3.2 Fish studies

Two surveys were made, between 21/22nd September and 9/10th November respectively. These dates were chosen to precede and follow the breeding season of most estuarine fish species, in case there were significant changes in the fish fauna related to breeding.

The fish were sampled by two methods. First, a Seine net (measuring 60m long, 3m deep with a wing mesh of 30mm (stretched mesh) and funnel mesh of 13mm (stretched mesh)) was laid in suitable parts of the creek and either pulled ashore or, if this was not possible, aboard an anchored boat. The latter method was less efficient but the lack of snag-free banks made its use necessary in most cases.



MAP 6.4
Fishing Stations

Several gill nets,with mesh sizes between 80 and 120 mm (stretched mesh), were also used. These were set at stations in deeper water where the movement of fish was anticipated. The stations at which one or both net types were set are given in Map 6.4. The full grid references of both the fish survey and hydrological stations are given in Appendix 7.

6.6.4 Results and discussion

6.6.4.1 Hydrological studies

Salinity profiles for Mooney Mooney Creek and one station in Piles Creek are given in Figure 6.2. The first survey covered the immediate study area while the second included the whole of Mooney Mooney Creek between Flood Creek and the Hawkesbury River.

Mooney Mooney Creek showed a moderate salinity stratification in September. Salinity ranged from 8‰ near Flood Creek (Station H1) to 20.8‰ at Native Dog Bay (Station H6). In comparison seawater has a salinity of 35‰. While salinities in Piles Creek were depressed by light rains, this had little effect on the salinity of Mooney Mooney Creek.

Salinity levels were similar in November, although recent rain had depressed the level near Flood Creek to 3‰. Salinity progressively increased downstream towards the junction of Mooney Mooney Creek with the Hawkesbury River, where the deepwater salinity was 26‰. Horizontal stratification was more evident downstream.

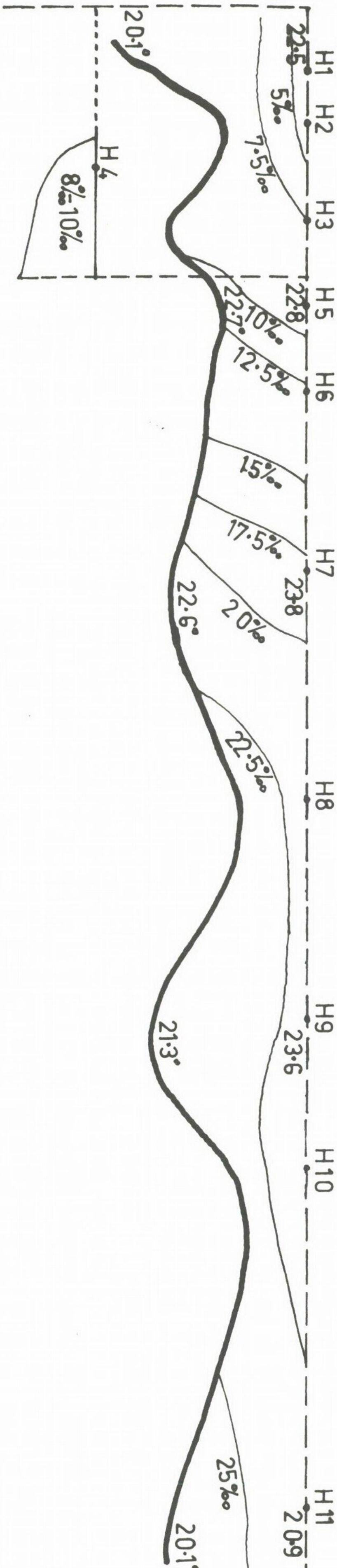


FIGURE 2
SURVEY 9·11·78

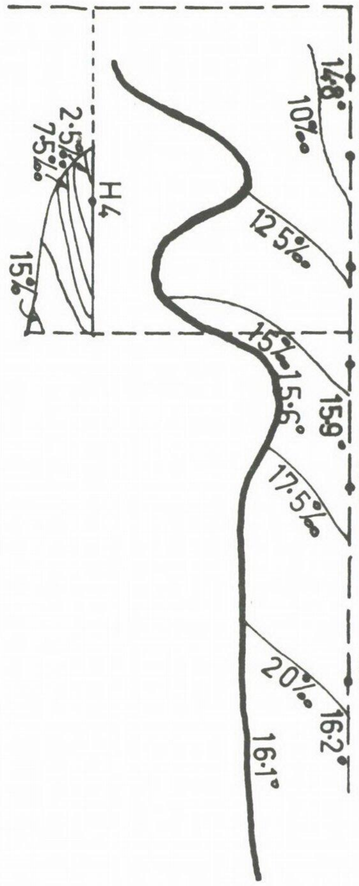


FIGURE 1
SURVEY 20·9·78

FIG 6.2 **Salinity Profiles**

The results from both surveys show a very marked decline in salinity upstream of the extensive sand flats near Native Dog Bay. It appears that the shallow nature of Mooney Mooney Creek at and above this point restricts the upstream movement of more saline water.

The mean water temperature rose from 15.7°C in September to 22.3°C in November in response to the advent of warmer summer weather. Dissolved oxygen levels were measured only during the September survey. They ranged from 78% to 90% of saturation, the lower value being near Flood Creek (Station H1). They suggest that under normal conditions dissolved oxygen levels in the creek are not ecologically limiting, although it is possible that the bottom layers of the deeper waters above the Pacific Highway Bridge may deoxygenate after rainfall through a combination of hydrological and biological features; tidal flow and turbulence should produce rapid vertical mixing and render such conditions transient.

6.6.4.2 Fish surveys

Twenty-three species of fish were captured during the surveys (Table 6.17). Apart from three commercial species and some small gobies, most species were captured only in small numbers (Appendix 8). The catches of the three commercial species Flat-tailed Mullet *L. argentea,* Sea Mullet *M. cephalus* and River Garfish *H. ardelio* are given in Table 6.18.

Although the study area was not extensively sampled, these catch levels are unexpectedly low when compared to the results from similar studies elsewhere. For example, catches in gill nets of more than 100 mullets in 3 hours were common during surveys made by the Centre for Environmental Studies in the generally similar estuaries of Lane Cove and Hacking Rivers between 1976 and 1978. Similar catches could be expected from a Seine net pulled over seagrass beds.

TABLE 6.17: Fish species captured in Mooney Mooney Creek

Long-finned Eel *Anguilla reinhardti*

Goby *Arenogobius bifrenatus*

Goby *A. frenatus*

Fortescue *Centropogon australis*

Snapper *Chrysophrus auratus*

Anchovy *Engraulis australis*

Goby *Favonigobius exquisitus*

Goby *F. tamarensis*

Silver Biddy *Gerres ovatus*

River Garfish *Hemirhamphus ardelio*

Jewfish *Johni antarctica*

Flat-tailed Mullet *Liza argentea*

Sea Mullet *Mugil cephalus*

Black Bream *Mylio australis*

Sand Mullet *Myxus elongatus*

Bullrout *Notesthes robusta*

Estuary Perch *Percalates colonorum*

Dusky Flathead *Platycephalus fuscus*

Tailor *Pomatomus saltator*

Goby *Redigobius macrostoma*

Tarwhine *Rhabdosargus sarba*

Sand Whiting *Sillago ciliata*

Trumpeter Whiting *S. maculata*

Glassy Perch *Velambassis jacksonensis*

TABLE 6.18: Catches of three commercial fishes

A. SEINE NETTING

Date	Station / Species	S1	S2	S3	S4	S5	S6	S7
September, 1978	*L. argentea*							
	M. cephalus				18[J]			9
	H. ardelio	1			8	34	21	90
November, 1978	*L. argentea*							
	M. cephalus	1						77[o]
	H. ardelio	1			28			11[o]

B. GILL NETTING

Date	Station / Species	G1	G2	G3	G4	G5	G6	G7
September, 1978	*L. argentea*	5	31*		4			14
	M. cephalus		29*		15		1	7
	H. ardelio							
November, 1978	*L. argentea*						2	
	M. cephalus			4*			6	27*
	H. ardelio							

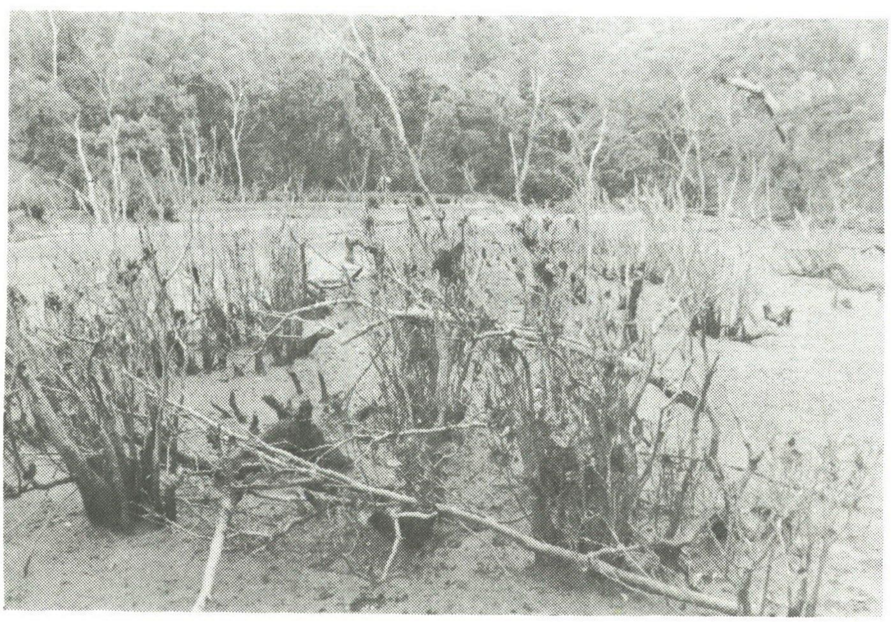
[J]Less than one year class [o]1-2 year class *Net set overnight (10hr)

Since the creek appears to be hydrologically healthy, reasons for the low fish populations must be sought elsewhere. A significant observation in this context was the conspicuous absence of seagrass beds in the study area. These beds are a favoured and productive habitat of many fish species. It is characteristic of the drowned valley estuaries in Sydney sandstone areas that small tributary creeks form sand-bars across their mouths, parallel to the main channel, and seagrass beds may develop on the outer slopes of these bars. Where turbidity and stability permit, seagrass beds may also occur on midstream sand and mud banks. However an examination of aerial photographs taken in 1975 failed to show any large seagrass beds in the study area. Small patches were noted on the outer sediment slopes of Native Dog Bay, on banks opposite and 300m North of this bay, and on the sand flats near Piles Creek. Of these beds only that near Piles Creek was recorded during the present study.

Further, it became evident during the study that Mooney Mooney Creek below the mouth of Piles Creek was exceptionally shallow, being almost impassible to a motor boat at low tide. This was due to extensive deposits of mobile, barren sand of apparently recent origin. Further downstream the deposits in the main channel tended to be muddier but still relatively mobile.

An examination of aerial photographs showed that sedimentation is light in Mooney Mooney Creek upstream of the Pacific Highway bridge, whereas Piles Creek itself is heavily silted. It appears then that most of the recent sediment in Mooney Mooney Creek has been contributed by way of Piles Creek. The sand may have originated from roadside erosion along the Pacific Highway between Mooney Mooney Creek and Kariong, during the development of Kariong and Old Sydney Town, from agricultural activities on the Somersby Plateau and from sandstone quarrying near Kariong. In contrast Mooney Mooney Creek above Piles Creek is protected by a less-developed catchment and, importantly, by two dams - the Gosford Water Supply Dam and a minor dam about 2km further downstream - which act as sediment traps. Sand-mining

PHOTOGRAPHS 6.2/6.3: Healthy and sediment-affected mangroves
(Native Dog Bay)



along the Western bank of Mooney Mooney Creek for some distance upstream of the Pacific Highway bridge may be expected to have contributed mainly fine sediments to the creek.

From these observations it is suggested that heavy deposition of sands in recent times may have largely destroyed the bottom conditions necessary for the survival of some fish species. It is relevant, then, that bottom-dwelling species were not well represented in the catches, even though they should have been adequately sampled with the Seine net.

Examination of the mouths of tributaries to Mooney Mooney Creek downstream from the study area disclosed a further pattern of sedimentation. Whereas extensive and recent deposition of sandy material had occurred at the mouths of those tributaries on the Western side of Mooney Mooney Creek, this was not apparent for the tributaries on the Eastern side. Once again agricultural activities and particularly construction of the existing freeway were the most likely sources of this sediment. In that sedimentation of the western tributaries was associated in places with areas of dead mangroves, considerable impact had already occurred (Photographs 6.2 and 6.3).

Since seagrasses cannot readily colonise mobile sand and mud, continuing sedimentation will effectively prevent their re-establishment and the consequent recovery of certain fish populations.

7. FAUNAL IMPACTS OF PROPOSED CORRIDORS

7.1 Loss/alteration of habitat

As all construction activities (e.g. borrow pits, spoil dumps, machinery parks, campsites etc.) will be contained within the road reserve (Department of Main Roads letter F.3/184.1614 of 18.8.78), the extent of this impact will be limited to the immediate corridor. Some 330 hectares of habitat will be lost or greatly modified between Mount White and Somersby if corridor 1 is adopted (of which about 130 ha will be in Brisbane Water National Park) while 190 will be lost or greatly modified between Calga and Somersby if corridor 2 is chosen (of which about 120 ha will be in the proposed Park extension). In respect of corridor 1, this represents a loss of wildlife habitat amounting to 1.7% of the National Park.

As faunal distribution is related to habitat, it should be possible to identify those areas along the two proposed corridors that will be most affected by construction of the freeway. From the faunal studies just described these faunally more important areas have been identified as:

7.1.1 Closed forest

Closed forest is very restricted in extent within the study area (Map 5.6), occurring mostly in creek gullies with a Southerly or Easterly aspect. Within the study area it accounts for some 2% of the total habitat available to wildlife (Table 5.2).

Despite its limited occurrence, closed forest was found to support a distinctive vertebrate fauna. Bird species confined to this habitat were the Brown Warbler *Gerygone mouki*, Yellow-throated Scrubwren *Sericornis citreogularis*, Large-billed Scrubwren *S. magnirostris*, Topknot Pigeon *Lopholaimus antarcticus*, and Scaly Thrush *Zoothera dauma*. In addition, Lewin's Honeyeater *Meliphaga lewinii* was particularly common in closed forest. Among the reptiles the Pink-tongued Lizard *Tiliqua gerrardii* was confined to closed forest while the Three-toed Skink *Saiphos equalis* and Weasel Skink *Leiolopisma mustelina* preferred moist habitats, including closed forest. Among the mammals, the Fawn-footed Mosaic-tailed Rat *Melomys cervinipes*, which reaches its southernmost known limit of distribution in the study area, was restricted to closed forest, while Swainson's Marsupial Mouse *Antechinus swainsonii* preferred this habitat.

The closed forest fauna is probably the most distinctive and restricted faunal assemblage within the study area. It would be extensively affected by freeway construction along corridor 1, marginally so along corridor 2. Although none of the above species is rare or endangered in terms of their overall occurrence, this must be considered a major impact within the context of Brisbane Water National Park.

7.1.2 Cool, moist open forest

The cool moist open forests of the study area supported an exceptionally rich avifauna (see 6.4.4.4) and were the preferred habitat of most latitudinal bird migrants observed in the study area (see 6.4.4.5).

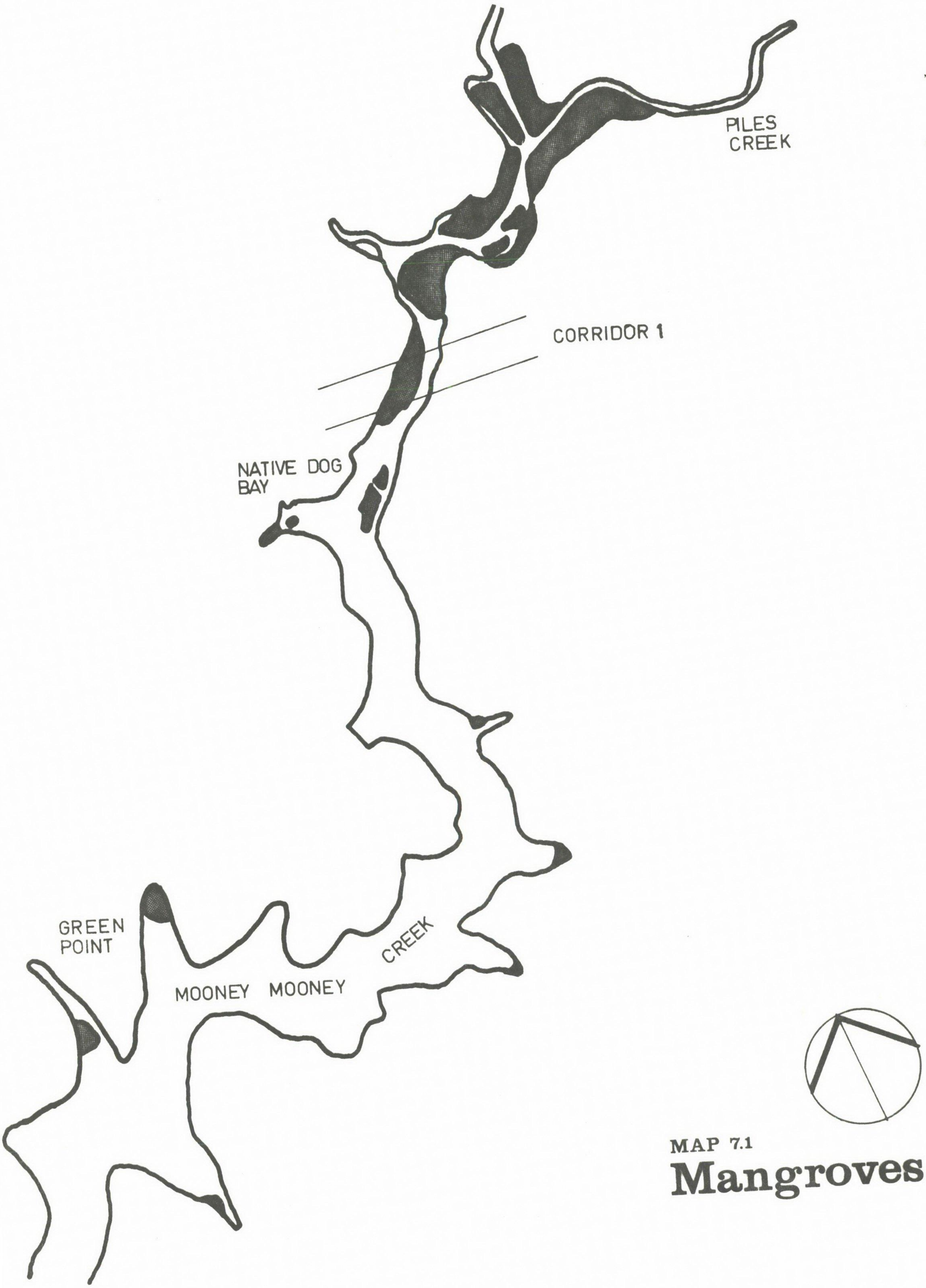
More specifically, plant community 2B was found to provide a major food source, in the nuts of the She Oak *Casuarina torulosa*, for the Glossy Black and Yellow-tailed Black Cockatoos. The former species is considered 'extremely rare' in the Sydney region (Hindwood & McGill, 1958) and is generally rare or uncommon throughout its range (Forshaw, 1969). The sole observation of the uncommon Red-browed Treecreeper *Climacteris erythrops* within the study area was also made in open forest of Plant Community 2B.

Similar areas of this habitat are affected by both corridors (Map 6.2) although the higher bridge crossing of Mooney Mooney Creek on corridor 2 may lessen the impact of that route.

7.1.3 Mangroves

Although the present study did not show any vertebrate fauna to be restricted to mangroves, this plant community plays an essential role in the estuarine ecosystems of Mooney Mooney and Piles Creeks. Its overall significance is in the movement and transformation of matter and energy, utilizing imported inorganic matter to manufacture organic matter which ultimately, as plant debris, supports inshore food chains. Overseas studies have shown that in some coastal waters 80% of fish caught commercially are linked to food chains ultimately dependent on mangroves (Lear & Turner, 1977). Mangroves can support many consumers because of their exceptional productivity. Dunstan (1973) for example recorded that the production of organic matter from mangrove leaves in New South Wales amounts to some 4 tons/acre/year. This matter decomposes slowly, forming organic detritus with its associated fungi, bacteria, protozoa and micro-algae. Because of this gradual but continuous decomposition the decaying leaves form a constant supply of food for marine organisms, including crabs, prawns and some fish. The best oyster leases are always close to mangroves and it is thought that they harbour the micro-organisms essential as food for oysters.

In terms of direct impact on this plant community, corridor 1 straddles a large island of mangroves, so that care would be needed to avoid any damage to this stand. Corridor 2 on the other hand would at most affect the narrow strip of mangroves which grows along Mooney Mooney Creek at this point. Indirectly, however, sedimentation from freeway construction along either corridor may have a much greater impact on the mangroves and aquatic fauna of both Mooney Mooney and Piles Creeks (see 6.6). It should be noted that the mangrove stands in the study area constitute about 95% of the total extent of mangroves in Mooney Mooney Creek (Map 7.1) and probably play a key role in the biological productivity of the creek in general and the oyster beds downstream in particular.



MAP 7.1
Mangroves

7.1.4 Closed heath

Two bird species of particular interest occurred in this community, the Brown Quail *Coturnix australis* and Tawny-crowned Honeyeater *Phylidonyris melanops* (see 6.4.4.2). The former was observed only near study site 1.10, although it may be presumed to occur in similar habitat elsewhere in the study area, while the latter was observed both at this site and near site 1.17 (see also Part 2 of this report).

The Brown Quail is regarded as rare in the Sydney Region (Hindwood & McGill, 1958). It ranges widely through the coastal lowlands of North, East and South-west Australia but, being sensitive to habitat disturbance, is decreasing in numbers. In view of these considerations, further destruction of its habitat must be regarded as undesirable. The Tawny-crowned Honeyeater is a bird of quite specific habitats - coastal heathlands and mallee - but is widely distributed in suitable localities. Loss of habitat for this species is probably undesirable within the context of Brisbane Water National Park but is not critical in terms of its overall status.

7.1.5 Other plant communities

The sand-mined areas beside Mooney Mooney Creek, near the proposed crossing point for corridor 2, are faunally significant in that they support large populations of at least seven different frog species.

Studies on other plant communities in the study area did not provide evidence of much faunal significance. Although communities 4 (Low open-forest dominated by *Casuarina glauca*), 5 (Low open-forest with dry, tall dense understorey), 10 (sedgeland) and 11 (reedland/rushland) may be of botanical interest, probably due to their very restricted occurrence within the study area they did not support distinctive vertebrate fauna. Their significance to invertebrates is, however, unknown.

Although several vertebrate species occurred particularly in plant community 6 (Low open-forest/low woodland with a dry understorey) this community was the most widely represented within the study area (40% of total habitat) so that any impacts of the proposed freeway on this community should be relatively less important.

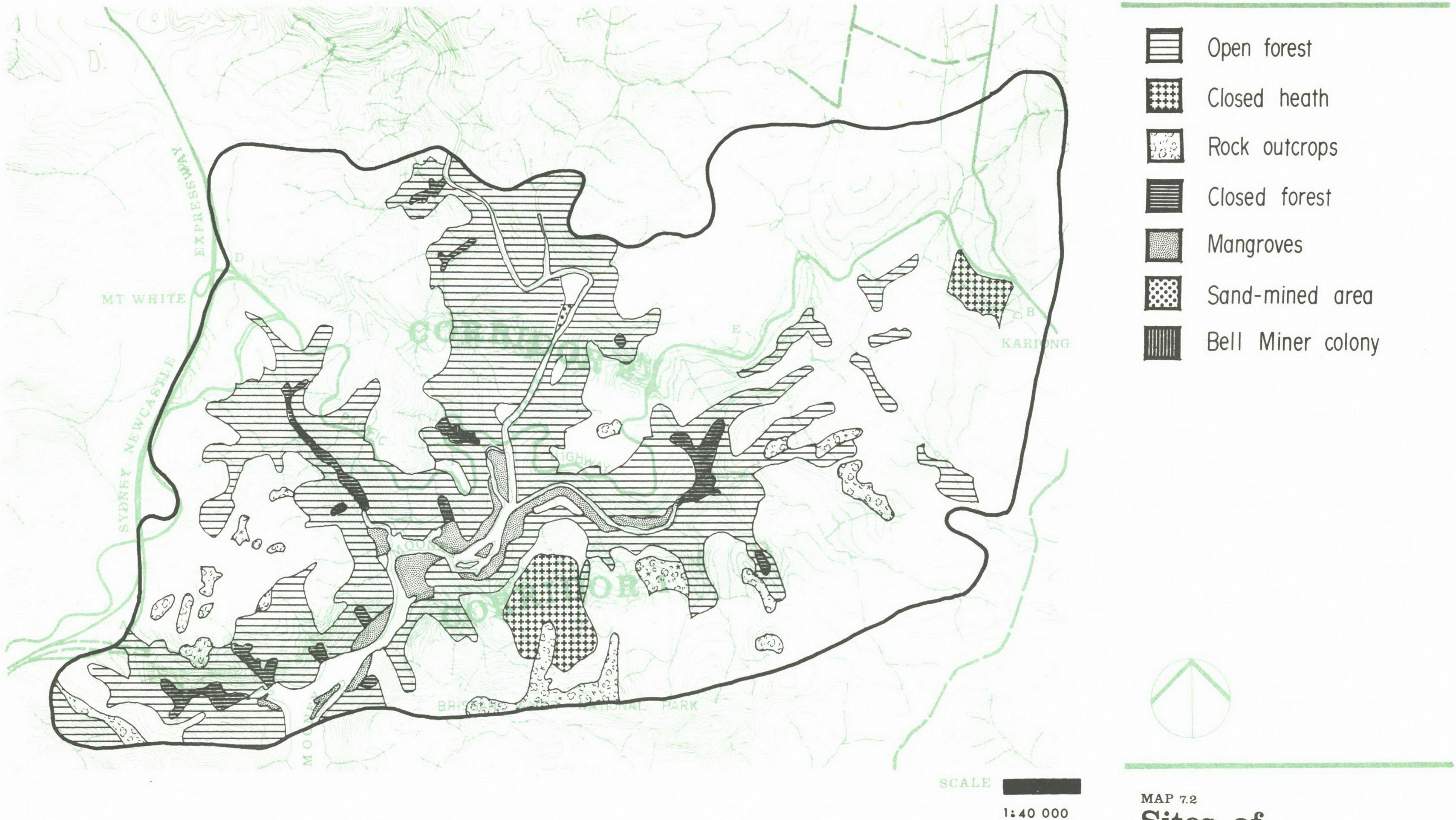
The sites of faunal significance are shown on Map 7.2. It can be seen that the impact of freeway construction along corridor 1 will be substantially greater than along corridor 2, in terms of loss or alteration of habitat for vertebrate fauna.

7.2 Fragmentation of habitat

Further fragmentation of natural habitat in the Brisbane Water National Park area may well be the most significant impact of the proposed freeway. The concepts of minimum viable numbers and spatial needs for such a population have already been described at length (see 4.3.2). When these considerations are applied to Brisbane Water National Park the impact that the proposed freeway may have on the viability of the Park's mammal fauna becomes evident.

The Park is already largely isolated from other areas of natural vegetation in the region through urban development, agricultural land, the waterways of Mooney Mooney Creek and the Hawkesbury River, the existing freeway and - to a lesser extent - the Pacific Highway (see 5.9). The remaining sizable areas of natural vegetation lie to the West, North and North-East of the Park but, of these, the area to the West is already effectively isolated by the existing freeway.

It is to the North that an extension is proposed to the existing Park (Map 5.8). This extension may well be vital to the survival of the larger or rarer mammals present in the existing Park (e.g. Wombat *Vombatus ursinus*, Swamp Wallaby *Wallabia bicolor*, Eastern Grey Kangaroo *Macropus giganteus*, Wallaroo *M. robustus*, Red-necked Wallaby *M. rufogriseus*, Potoroo *Potorous tridactylus*, Koala *Phascolarctos cine-*



MAP 7.2
Sites of Faunal Significance

reus, Tiger Cat *Dasyurus maculatus* and Echidna *Tachyglossus aculeatus*), by enlarging the area of the Park. The present Park occupies an area of 7,825 hectares and the proposed extension an area of some 3,500 hectares, a total of about 11,300 hectares.

Corridor 1, if adopted, would effectively reduce the size of Brisbane Water National Park from about 7,800 hectares to 6,800 hectares (by 12%). It would also largely nullify the advantages of the proposed extension for larger mammals. Corridor 2, although not affecting the existing Park, would separate it from the proposed extention. Both proposed routes, therefore, may have a major adverse impact on the mammal fauna of the Park through fragmentation of habitat.

7.3 Wildlife mortality

The impact of a highway on animal populations through wildlife vehicle collisions is poorly known, although the phenomenon itself is well documented (see 4.5). There are however two general comments worth making in the present context.

First, it is likely that larger animals will be most adversely affected, because they are less likely to consider roads impassable (see 4.3.2) and because their populations are generally small but with large spatial needs. For example B. Allen, (Green Point resident; pers. comm.) noted that 18 Swamp Wallabies were killed on the existing expressway near Mount White within the first three weeks of operation.

Secondly, the impact could be severe in the case of isolated populations. It has been mentioned already (see 5.9) that

Brisbane Water National Park is isolated from other areas of natural vegetation, and hence sources of faunal replenishment. An analogous situation seems to exist in Ku-ring-gai Chase National Park, where Swamp Wallaby populations have apparently declined drastically since the upgrading of West Head Road (A.B. Rose, pers. comm.).

Construction of the freeway along either proposed route could have an important impact on the populations of larger mammals because of road kills.

7.4 Erosion and sedimentation

7.4.1 Introduction

Erosion, and concomitant sedimentation in associated waterways, will increase rapidly during construction of the proposed freeway unless controlled. Sedimentation will decline again once construction has ceased, although it may be several years before loadings reach pre-construction levels (Dawdy, 1967). There are many variables (e.g. extent of soil disturbance, nature of weather, soil type topography) which determine the final extent of erosion.

Erosion associated with construction of the freeway will first affect minor creeks. Seven moderate-sized creeks are crossed by corridor 1 between points AB, and two such creeks are crossed by corridor 2 between points CB. This difference arises because corridor 2 largely follows the ridge tops whereas corridor 1 crosses the lower slopes of Leochares Peak and Mount Kariong. Although the resulting damage to these creeks may not be economically significant, it could greatly affect their role in the overall ecology of the area.

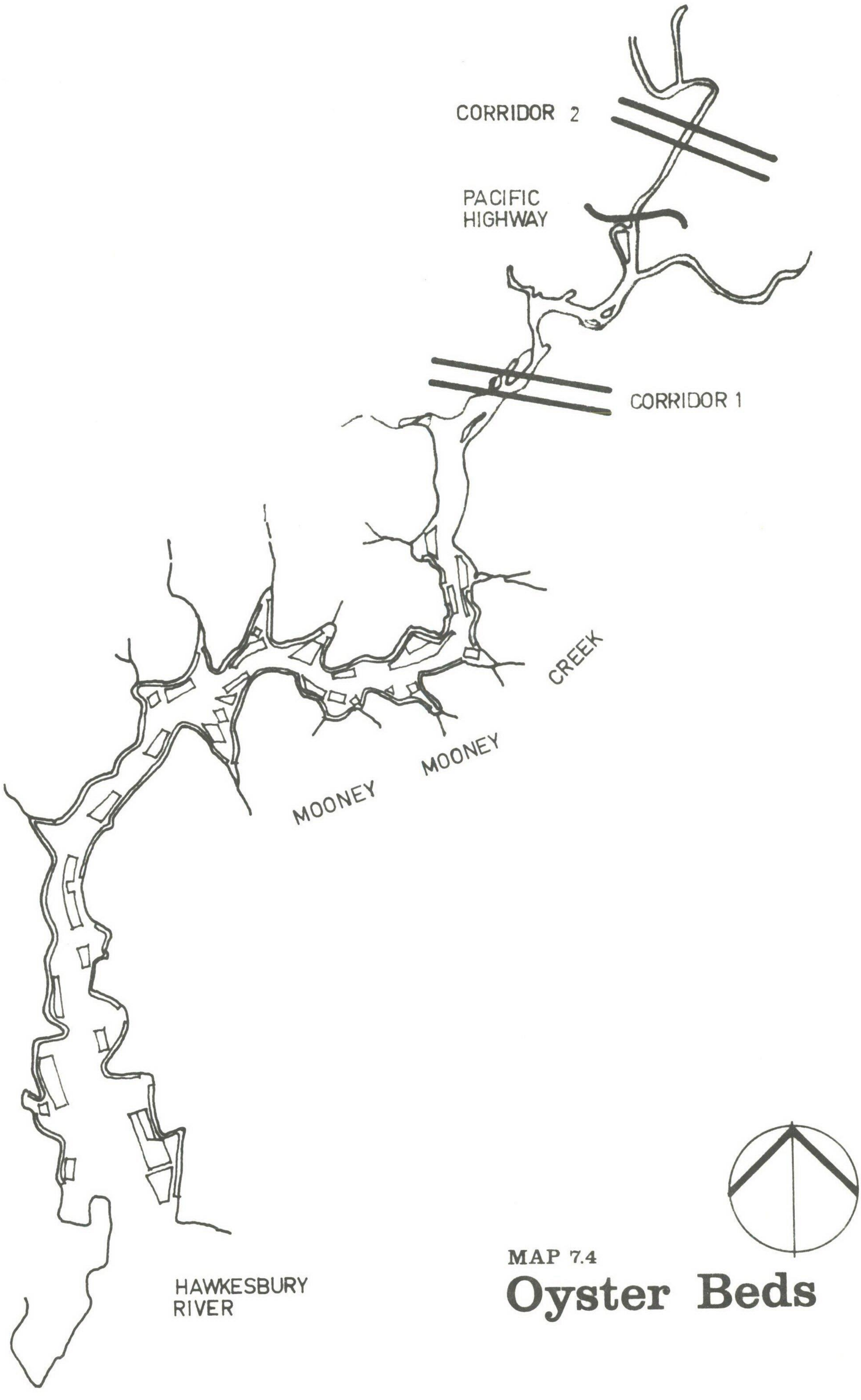
Uncontrolled erosion from construction of the freeway is not only most undesirable because of its impact on the minor creeks in the study area, but more particularly because of its potential impact on Piles and Mooney Mooney Creeks. The latter is estuarine where the two proposed corridors cross and here, to quote Dunstan (1973): "ocean waters are diluted with water from land runoff and thus is formed an oasis of great fertility - the estuary, which includes not only the water itself up to the limit of tidal influence but the mud flats, salt marshes, mangrove swamps and other intertidal zones".

In New South Wales about 60% of the commercial catch by weight and around 55% of the major commercial species of fish and prawns are estuarine-dependent (i.e. the majority of these species inhabit an estuarine environment during at least a portion of their life cycle) (Dunstan, 1976). The most economically important fishery in the State, the oyster industry, is completely estuarine dependent. Increased turbidity, whether through dredging or construction activities, may reach a point where the additional energy required by oysters to cleanse themselves will impede growth and may cause death. Turbidities of the order of 0.1g per litre reduce the pumping rate of oysters by 50 per cent (Dunstan, 1973).

7.4.2 Impact of proposed freeway

Both proposed routes for the freeway could have considerable impacts on the estuarine ecosystems of Mooney Mooney Creek unless erosion during and after construction is contained.

It is clear from Map 7.1 that the stands of mangroves in Mooney Mooney Creek are centred on the mouth of Piles Creek, so that



MAP 7.4

Oyster Beds

uncontrolled erosion from either freeway corridor could extensively damage these stands. While mangroves can tolerate considerable rates of sedimentation, it is clear from those in Native Dog Bay that excessive amounts of sediment will cause their destruction. Here, erosion of the earthworks at the Western end of corrodor 1 has caused the death of some mangrove stands (Photographs 6.2 and 6.3).

Mooney Mooney Creek downstream of where both proposed freeway corridors cross supports a small oyster industry (Map 7.4). This industry is thought to have already been adversely affected by sedimentation from various land activities in Mooney Mooney catchment, so that further sedimentation from freeway construction would be most undesirable.

Adequate protection of these creek systems from erosion during freeway construction is even more desirable because of similar impacts likely from other proposed construction activities in the area (e.g. gas and oil pipelines, Somersby industrial estate). In addition Piles Creek performs an important function as a representative example of creekside flora and fauna for visitors to the Brisbane Water National Park Centre at Girrakool

7.5 Vehicle-derived pollutants

7.5.1 Introduction

During 1976 the existing Sydney-Newcastle freeway carried an estimated annual average daily total (AADT) of 18,700 vehicles just north of the Hawkesbury River bridge (Department of Main Roads, 1976). Straight-line projections indicate an AADT in the order of 28,000 vehicles by 1986 at Mount White (Department of Main Roads estimates).

7.5.2 Impact of proposed freeway

These traffic flow rates are high enough to cause increased lead levels in roadside fauna and flora (Smith, 1976), to provide a significant risk of environmental damage from accidental spillage of hazardous chemicals and to cause increased pollutant levels in runoff waters from the freeway. Laxen & Harrison (1977), using a variety of information sources, estimated that lead concentrations in highway runoff are 10^3-10^4 times general background levels in surface waters.

Although the environmental effects of highway-related pollutants are still little understood, any deleterious effects which may occur are likely to be aggravated both with time and with the predicted increase in traffic flows.

7.6 Hydrology

7.6.1 Impact of proposed freeway

Although a detailed assessment of the hydrological impacts of freeway construction on the fauna is beyond the scope of this report, there follow two examples of such impacts.

Map 7.3 shows the extent of the catchment areas which will be crossed by the two proposed corridors. It may be predicted that construction of the freeway will modify at least groundwater flow to those parts of these catchments downslope from the freeway, with consequent changes to their vegetation and associated fauna.

MAP 7.3

Creeks & Catchments

Another impact relates to the shale beds interbedded with sandstone in the Hawkesbury Formation. The biological significance of these beds was recognised by Holland (1974), during his study of hanging valleys in the Blue Mountains. Holland found that valley-side swamps often occurred below points at which a bed of clay (presumably weathered claystone) occurred at a break of surface slope. Swamp (heath) vegetation with a wet ground surface occurred below this point while above it the vegetation changed abruptly to forest with a dry ground surface.

Holland suggested that water percolating through sandstone would, on reaching the sandstone/clay interface, move along this interface due to the aquicludal nature of the clay bed. That there is considerable water flow along this interface is evident from the shale beds exposed along the existing freeway (see photographs 5.1 and 5.2). Holland further noted that 82% of the 54 swamps he studied were on east-facing slopes. This strongly suggested that the original dip of the geological study was effective in directing the water which emerges at the claystone exposures.

It is clear that the freeway cuttings could, by dispersing ground water flow along shale beds, have a considerable impact on the vegetation downhill from the cuttings (Figure 7.1) - an impact that would extend to the fauna.

The swamplands also serve as a means of purifying and oxygenating the water supply, as collection basins for groundwater recharge areas, and as reservoirs to prevent stream flooding. Their loss or modification consequently may have a considerable impact on the local ecology of an area.

Two shale bed-related swamplands are likely to be affected by construction of the freeway along corridor 1. Firstly, there is the extensive heathland surrounding study site 1.10 (Map 5.1). While the main impact of freeway construction on this site will be loss

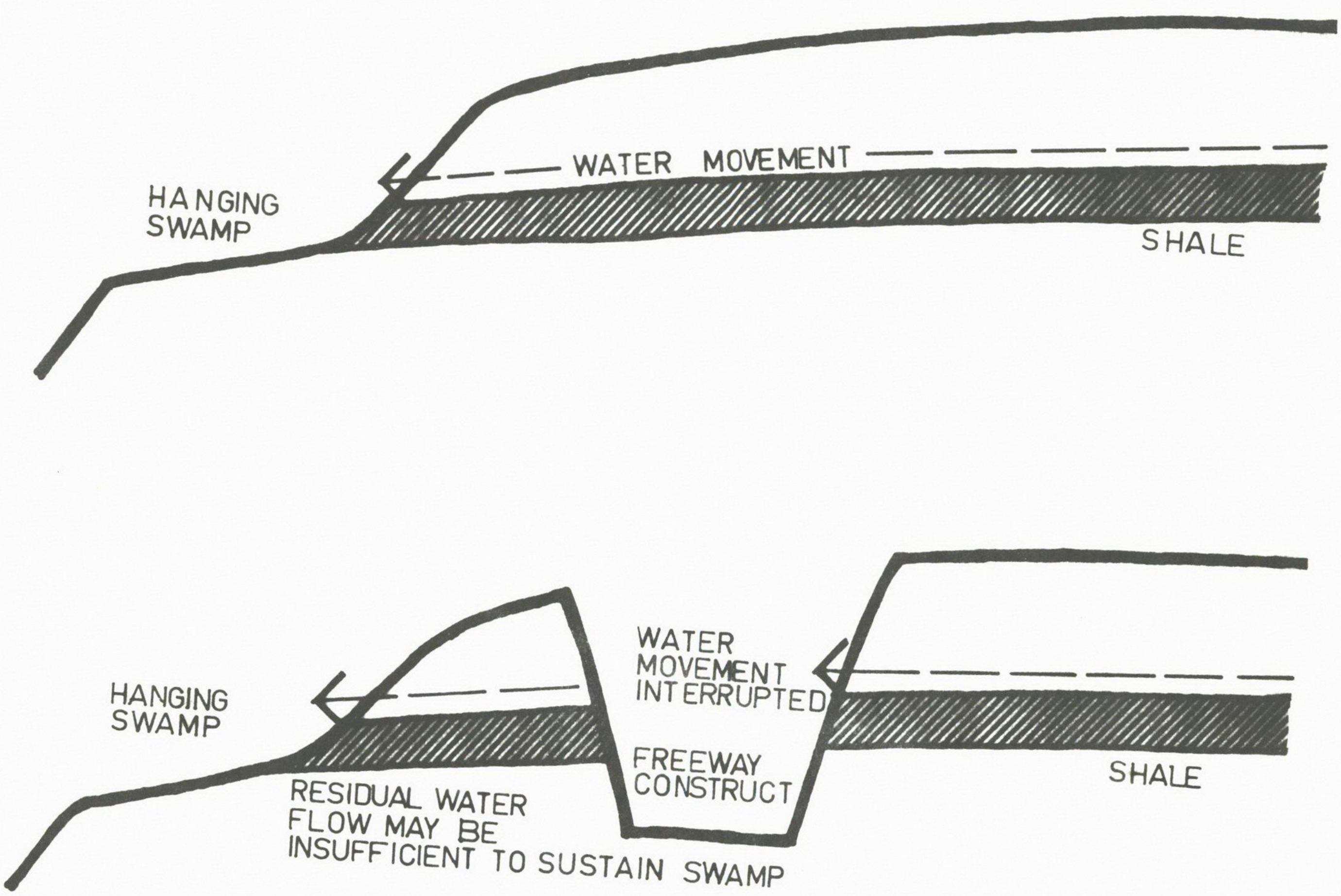


FIG 7.1 **Waterflow over Shale**

of habitat, amounting to perhaps half of the heathland area, it is possible that the water supply to the remaining heathland downhill from the freeway will also be greatly modified by construction. The second is an area of heathland South-West of the existing junction of the Wiseman's Ferry road with the Pacific Highway. Here the proposed freeway route may cut off the flow of water from this area and above through tributary creeks into Piles Creek.

The construction of the freeway along corridor 2 is also likely to affect two heathland areas. In both cases a classical shale swamp has developed and in both cases the proposed freeway is likely to cut off water supply to the swampland areas with consequent desiccation and change in vegetation towards woodland.

7.7 Fire

7.7.1 Introduction

Fire is an integral part of the Australian environment. Even today, when so many fires are started by man, it is estimated that up to a quarter of the fires in coastal areas are attributable to lightning (Anon., 1976).

It is not surprising then that the Australian flora and fauna have adapted to cope with fire. For example, all but fifteen of Australia's 660-odd eucalypt species have large, partly or completely buried, woody structures which sprout new stems if the original stem is killed by fire (Anon., 1976). Many plants have a thick bark, which protects dormant buds from fire - these buds being the point of regrowth after burning (Gill, 1975).

Some plants even require fire to complete their reproductive cycles. Some grass-trees (*Xanthorrhoea* spp), for example, seldom flower unless fired (Gill & Ingwersen, 1976), while some Banksias and She-oaks (*Casuarina* spp) release little seed without fire (Gill, 1975). Fire also greatly assists the germination of seed in many species of wattle (*Acacia* spp) (Gill, 1975).

The adaptive responses of the Australian fauna to fire are less understood but may be equally diverse. Most animals survive low to moderate intensity fires. Snakes, lizards and echidnas can burrow into the soil or damp litter (Luke & McArthur, 1978) while many species (e.g. marsupial mice, rats, wombats) may seek refuge in existing underground holes or burrows. Others are know to take cover along streams where the fire is often less severe or absent (Recher, Lunney & Posamentier, 1975). Unburnt patches may provide a refuge for some species during and after fire. C. Smithers (Australian Museum) for example, caught 17 brown marsupial mice *Antechinus stuartii* in an unburnt patch of about $20m^2$. More mobile species - such as kangaroos and wallabies - negotiate their way through fires to move beyond the fire edge or back into already burnt areas. Tree dwellers probably escape all but the most severe bushfires by taking refuge in nesting hollows.

Recher et al. (1975) observed various recovery mechanisms by animals after fire. The Swamp Rat, for example, became abundant in forest - a habitat little used before the fire - while Bush Rats began breeding earlier than usual and many small birds (fantails, warblers, wrens) raised several broods of young. Newsome, McIlroy & Catling (1975) found that dingoes changed from a diet based on small mammals before a fire to one comprised mainly of large herbivores (wallabies, kangaroos) after a fire - a response to changes in availability of food sources brought about by the fire. B. Fox (pers. comm.) found a complex response of small mammals to fire at Myall Lakes, the size and composition of populations changing in response to the regrowth after fire. Fox found that a patchwork of burnt areas of different ages was important to the survival of small mammals.

Despite this ability of much of the Australian flora and fauna to survive fire, it is important to recognise that their response is to certain fire regimes as well as to fire itself. In other words, the too-frequent or severe burning of an area may cause local extinctions of plant and animal species. Many plant species, for example, take several years to reach maturity and produce seed again. Successive fires may thus break this cycle before new seed is produced (Burrell, 1968; Specht et al., 1958). At the macro-level, Jackson (1968) considered that repeated burning in Tasmania has reduced the extent of rainforests to 53% of the area they might once have occupied.

Once again the picture is less clear for animals. Severe bush-fires may have a catastrophic effect on local populations, particularly in areas isolated from sources of recolonisation. In one Victorian example 90% of a marsupial mouse population was lost after an intense bushfire, not only through the direct effects of the fire but also through the impact on the survivors of starvation and exposure to predators (Luke & McArthur, 1978). In this particular case both vegetation and small mammal populations returned to their pre-fire condition within two years. The timing of fires in relation to breeding cycles of the animals may also be critical. Recher, Lunney & Posamentier (1975), for instance, speculated that a fierce wildfire in winter could cause local extinctions of marsupial mice. These animals breed in winter and, since the male lives for barely a year, annual breeding is essential to their survival. Too frequent firing may also cause the extinction of species ill-adapted to fire or of species which cannot adequately replenish their populations between fires (e.g. wallabies and kangaroos).

Fire may also have more subtle influences on the flora and fauna. For example, severe erosion can often follow bushfires, through destruction of the protective layer of vegetation over the soil (e.g. Good, 1973). An example of this process occurred in Wallace's Creek, within the Tumut River catchment. It was calculated that this creek carried about 116,000 tons of sediment a day some seven months after a very severe fire (Anon. 1972). The resultant changes in soil structure, depth, etc., could render recolonisation by the original vegetation impossible for a very long period of time.

7.7.2 Impact of proposed freeway

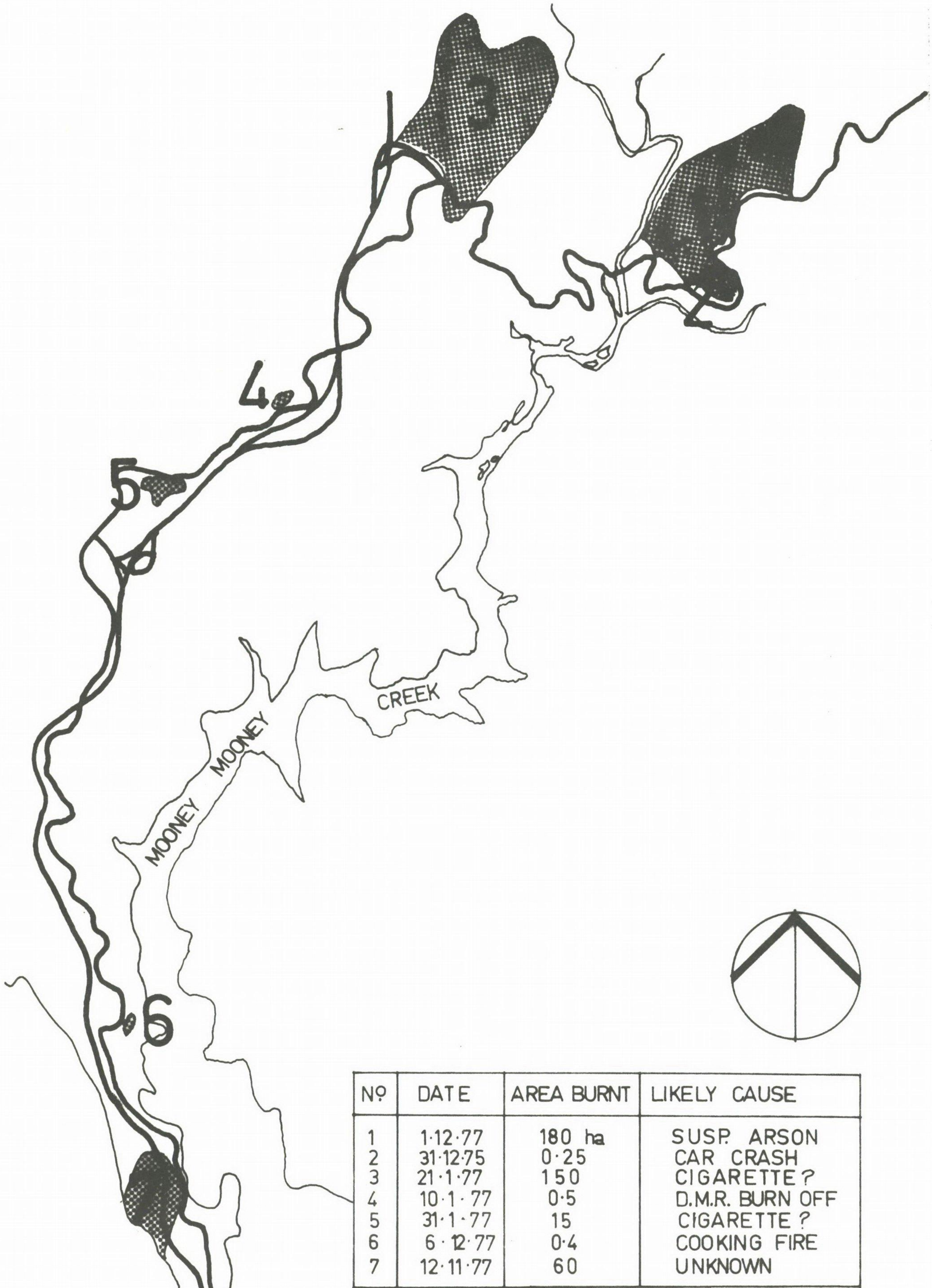
The proposed freeway may affect the interaction between fire and fauna in two ways. First, roads are likely to increase the incidence of fire in an area once less accessible to man. Highways especially are a frequent source of fire, freeways less so (Map 7.5). Construction of the proposed freeway along corridor 1 could increase the likelihood of road-related fires in a previously unroaded area. Construction of the freeway along corridor 2 on the other hand could, especially if the Pacific Highway between Calga and Kariong was closed to general traffic on completion of the freeway (see also 8.4), actually lessen the likelihood of road-related fires in this area. The island nature of Brisbane Water National Park (see 5.9) makes its fauna particularly vulnerable to the impact of fire, since there are no substantial continuous areas of natural vegetation from which recolonization can readily take place.

Secondly, the proposed freeway may affect the interaction between fire and fauna by denying fauna access to fire refuge areas. It is known that Brisbane Water National Park and its proposed extension to the North of the planned freeway routes are vegetationally distinct (Benson, 1979). Whether this difference is significant in terms of fire refuge areas, thus requiring the movement of animals across the proposed freeway corridors during major fires, is not known. It may be surmised, though, that the extensive areas of moist forest in the upper catchment area of Mooney Mooney Creek may be an important refuge for wildlife in times of severe fire.

7.8 Drought

7.8.1 Introduction

Although droughts are generally considered a feature of inland Australia, the much more widespread droughts of 1964/68 emphasise the need to consider any impacts of freeway construction on the drought responses of fauna within Brisbane Water National Park. Our knowledge of the responses of flora and fauna to drought is even more fragmentary than that of their responses to fire.



Nº	DATE	AREA BURNT	LIKELY CAUSE
1	1·12·77	180 ha	SUSP. ARSON
2	31·12·75	0·25	CAR CRASH
3	21·1·77	150	CIGARETTE ?
4	10·1·77	0·5	D.M.R. BURN OFF
5	31·1·77	15	CIGARETTE ?
6	6·12·77	0·4	COOKING FIRE
7	12·11·77	60	UNKNOWN

MAP 7.5 **Road-related Fires**

Two studies have been made into the effects of drought on Australian woodland. Pook, Costin & Moore (1966) followed the effects of an exceptional drought in the mid-1960's on natural vegetation in parts of the Australian Capital Territory and the Monaro Region. They found that the communities most severely affected were dry sclerophyll forests, especially those on shallow, stoney soils with Northerly and Westerly aspects. Communities which grew on relatively stone-free and heavy-textured soils with good water-holding capacity on the lower slopes and flats did not appear to suffer from water stress. It has been estimated that these latter soils may store up to ten times more water than the former (Pook, 1967). River Oaks *Casuarina cunninghamiana* along the Murrumbidgee River also showed severe water stress, presumably because the water-table had fallen to such an extent that supply to plants on shallow soils along the lower valley slopes was cut off.

Ashton, Bond & Morris (1975) made a similar study on the vegetation of Mount Towrang in South-central Victoria during the 1967/68 drought. They also found that drought damage was most evident on the exposed Westerly slopes and in areas marginal to creeks and dry gullies. Although the vegetation in these latter areas occurred on deeper soil, its evident water-stress was attributed to a lowering of the water table below the roots. Surprisingly, perhaps, Ashton et al. only occasionally found damage to the vegetation on the ridge tops. They surmised that in this case the low soil moisture levels were compensated for by the effect of mists and fogs which occurred most frequently at the higher altitudes.

Animals respond to drought in at least three ways. First they cease or curtail reproduction. Kirkpatrick & McEvoy (1966), for instance, found that Grey Kangaroos in Southern Queensland virtually ceased breeding after 8 months of drought, at which stage the pouched young began to die. There are several examples in the literature of birds failing to breed or producing reduced clutch sizes in response to drought (Berney, 1906; Berney, 1928; McGilp, 1924). Keast (1959) described the impact of the 1957 spring drought in the Sydney area as follows:

> 'Breeding was widespread and heavy during the first part of the season. The drought effects showed in (i) a delay of almost a fortnight in the ovulation date of many species, (ii) an early tapering off in the nesting and failure to rear second broods. The returning migrants (that normally start [nesting] in late October) were severely affected. Thus the majority of pairs of the warbler *Gerygone olivacea* and whistler *Pachycephala rufiventris* attempted to nest but were forced either to abandon efforts or else lost young (apparently from heat) in the nest. The Cicada-bird *Edoliisoma tenuirostris* did not nest at all'.

Secondly, animals tend to concentrate in areas favourable to their survival, referred to as 'refuge areas' by Myers & Parker (1975a). Thus Myers & Parker (1975b) found that the survival of rabbits during drought was, irrespective of habitat, clearly related to the drainage pattern and hence probably to the availability of water, either as free rainwater or, more likely, as causing repeated germinations of ephemeral plants and boosting the growth of perennials. They noted that such areas were also the focal points for other forms of wildlife and the predators which accompany them. Pearse (1972) similarly described the movement of wombats from the ridges down into the valleys during drought conditions, while a similar phenomenon has been observed with emus in Western Australia (Anon., 1975a).

In the case of birds this response may entail considerable movement. Brereton (1973), for instance, noted that budgerigars *Melopsittacus undulatus* may move in good seasons as far south as South Australia but that intense widespread drought reduces their range back to their outbreak centre ('refuge area') in the Mitchell grass plains of central Western Queensland.

Despite both of these adaptations to drought, there may sometimes be dramatic losses of life caused by drought. Such was the impact of drought on rabbits in Western New South Wales at the turn of the century that by 1903 the population had virtually disappeared (Heathcote, 1967). This same drought almost "wiped out" bird life over a large part of central Queensland (Barnard, 1917; 1927), it taking years for populations to return to their former levels.

7.8.2 Impact of proposed freeway

Any assessment of the impacts of freeway construction on the drought responses of fauna within Brisbane Water National Park is hindered by lack of information, and so must be largely conjectural. The role of water is obviously crucial in respect of both the flora and fauna, so that a concentration of fauna remaining in the Park in better-watered areas would seem likely. Recalling the vegetation studies of Pook, Costin & Moore (1966) and Ashton, Bond & Morris (1975) it is likely that such refuge areas occur on the Easterly and Southerly-facing slopes of the valleys and along the lower slopes of the ridges. In addition, refuge areas may also occur where shale lenses reach the surface and provide an outlet for water permeating through the sandstone rock mass (see 7.6.1).

It is also possible that the fauna might, in extreme drought conditions, move towards the headwaters of Mooney Mooney Creek. Not only are these waters fresh, in contrast to the brackish waters of the study area, but the stands of moist forest are more extensive there.

Should these predictions be correct, the impact of the proposed freeway on the drought responses of fauna within Brisbane Water National Park will be expressed in two ways. The first is through the loss of drought refuges through clearance for freeway construction. Secondly, the freeway may have an impact through denying access of fauna from the Park to possible refuge areas in the proposed extension.

7.9 Other impacts

7.9.1 Channelization

The proposed use of fills to carry the freeway across valleys (see 1) will require the channelization of the affected creeks through culverts under the freeway. Channelization may alter or destroy aquatic ecosystems by changing water temperature and quality, stream velocity and channel characteristics and the prevalence of plant, insect and microbial life (see also 4.2.4).

In that seven moderate-sized creeks would be affected by channelization between points AC on corridor 1 and only two such creeks along section DC of corridor 2, this faunal impact will be greater along the former corridor.

7.9.2 Dust generation

The effects of dust on the photosynthetic abilities of vegetation have been considered already (see 4.4.4). This impact is probably minor, transient in nature, and may be expected to be of similar importance along both proposed freeway corridors.

7.9.3 Disposal of construction wastes

It is normal practice to incorporate construction wastes into the road bed as construction progresses (Department of Main Roads, letter F.3/184.1614 of 18.8.78). There is not likely to be an adverse environmental impact from this practice unless substances toxic to vegetation and wildlife reach flowing water after burial and thus enter the natural environment.

7.9.4 Introduced species

Highways are well-known as routes by which animals can invade areas not previously accessible to them (see 8.3). In the present context this is likely to be most important with birds and mammals. It was found with birds (see 6.4.4.1) that the larger areas of natural vegetation (sections AB and DE) have been scarcely, if at all, invaded either by introduced species or by species associated with cleared areas. However, more disturbed areas of natural vegetation, such as those surveyed along sections BC and EC of the two freeway corridors have avifaunas which contain several introduced or open land species. It is possible that extensive disturbance or replacement of natural vegetation with exotic species (especially grasses) during highway construction will permit invasion of the study area by such species as the Peaceful Dove, Spotted Turtledove, Eastern Rosella, Red-rumped Parrot, Willie Wagtail, Goldfinch, Starling, Magpie Lark.

8. MITIGATION OF IMPACTS

8.1 Introduction

Concern with environmental matters during the planning, design and construction phases can do much to mitigate the adverse impacts of highway construction. This chapter describes specific measures to mitigate the impacts identified in the preceding chapter. To avoid needless repetition, the ameliorative measures have been grouped under different headings from those used in identifying the impacts.

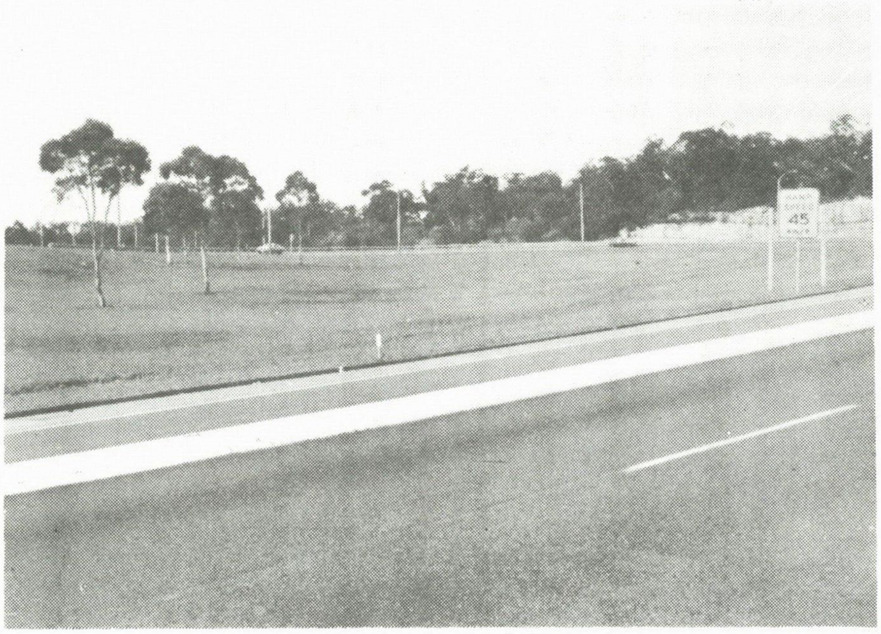
Two practical points should be made. The first is that the mitigation procedures adopted should be discussed and explained to staff and contractors at pre-construction briefings, so that the reasons behind the proposed measures are clear. Secondly, it is important that the mitigation procedures adopted be monitored during and after construction by their designers, so that their effectiveness can be assessed and any remedial action necessary can be promptly taken.

8.2 Route modification

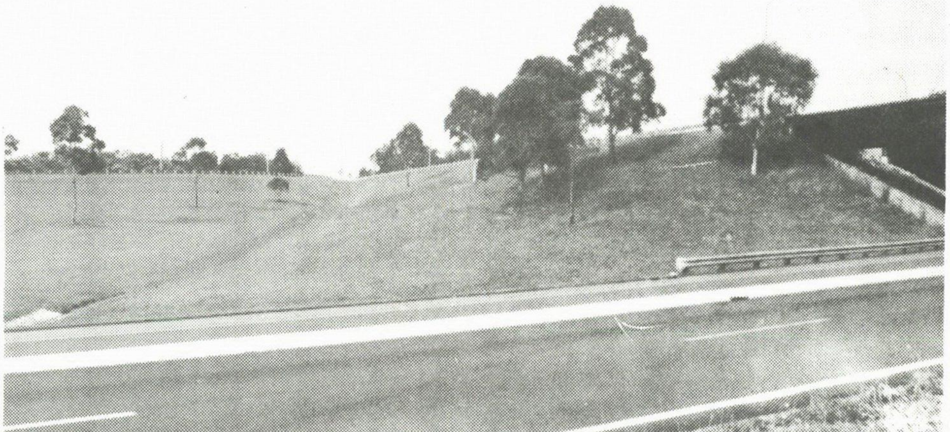
Taking the faunal studies together with the floral studies of Benson (1979), it is clear that, of the two proposed freeway corridors, corridor 1 will have by far the greater impact on natural communities in the study area.

Partial mitigation of these impacts may be possible by a generally more Southern relocation of the corridor, to the South of Native Dog Bay and higher up the slopes of Leochares Peak and Mount Kariong. Such relocation would however considerably worsen the visual impacts of the freeway.

Location of the freeway in corridor 2 should, in contrast, have a minimal impact on the more significant floral and faunal communities of the study area. It is important though that the Mooney Mooney Creek bridge be designed and constructed in such a way as to minimise impacts on the open forest communities and the sand-mined area beneath it. It is also important that construction does not impact the small closed forest community on the Northern boundary of this corridor; this may require minor modifications of the route.



PHOTOGRAPHS 8.1/8.2: Biologically-impoverished mown areas at freeway interchange



8.3 Native vegetation

The impact of highway construction on fauna can be lessened both by keeping clearance of vegetation before construction to an essential minimum, thus maintaining the integrity of the vegetation as far as possible, and by replanting cleared areas with local plant species when construction is complete. Specifications to contractors should clearly stipulate the need to retain as much of the natural vegetation along the right-of-way as possible.

Adoption of these practices will minimise the loss of natural habitat and discourage invasion by fauna alien to the area. It will also greatly lessen or obviate the use of herbicides and fertilisers, both of which can be detrimental to natural ecosystems. Most importantly, replanting with native rather than exotic vegetation will greatly lessen if not eliminate the need for mowing (Photographs 8.1 and 8.2). This concept is proving increasingly attractive to highway authorities overseas not only because it cuts maintenance costs but also because it renders biologically impoverished areas (e.g. mown grass) more diverse florally and hence faunally (Cassel & Oetting, 1970; Way, 1977).

Indeed the use of native vegetation along rights-of-way enhances a most vital and yet consistently under-recognised concept of the right-of-way - as a wildlife refuge. According to Way (1970):

> "The ecological significance of this linear habitat is considerable. It stems from the characteristic of the motorways themselves (as a communication web traversing the physical and climatic features of the land but mainly keeping to the lowlands), from the protected nature of the verges, and from the fact that the whole area is managed under the overall direction of a single organisation, the Ministry of Transport. If we accept the ecological significance of motorway verges, then we ought also to accept their potential for conservation of wildlife, especially as no other nationally important function has been proposed for them..."

But see p.179 ¶168

> "The conservation value of these long continuous areas of grass and some trees lies principally in their potential as reservoirs of populations of wild plants, invertebrates and small vertebrates....".

In Australia, roadside vegetation has been shown to play a vital role in the survival of a small marsupial, the Sugar Glider, in parts of Victoria (Byrne, 1978). Roadside strips of forest have been found to act as corridors between fragments of forest isolated by clearance for agricultural purposes.

It is true that some wildlife mortality may be expected through wildlife-vehicle collisions, but these losses will usually be replaced each year by animals seeking unclaimed territories. Surviving generations will adapt to the highway environment and stabilization of animal populations will then occur (McClure, 1951). This may not be true, however, in areas too small to sustain highway losses relative to the replacement rates of two wildlife populations (see 4.5 and 7.3).

The right-of-way can play a significant role as a wildlife refuge, because of its extent. Way (1977), for example, estimated that the roadsides of England and Wales alone contained 178,200 hectares of habitat. As long ago as 1942, Miller & Powell estimated that public highways in the United States occupied 17,787,000 acres or 0.7% of the total land area excluding Alaska and Hawaii. Damback in 1951, pointed out that Ohio's roadsides - then totalling some 250,000 acres - constituted an area greater than the State's forest.

Highway construction can also create new habitat. In the United States, for example, several authors (Emlen, 1954; Dobson & Peake, 1967; Alsop, 1970; Wallace, 1970) have reported cliff swallows *Petrochelidon pyrrhonota* nesting under bridges in various parts of the country. In the case of Alsop's observation, it represented the first nesting record of this species in Knox County, Tennessee. The Barn Swallow *Hirundo rustica* also frequently nests under highway bridges. Denton (1967) for example found Barn Swallows' nests on the flanges of several I-beams of a highway bridge in Georgia. Similar observations have been made in Australia. Reilly & Garrett (1973) recorded the nesting of Fairy Martins *Cecropis ariel* in both tubular and box-type culverts under roads in the Myall Lakes area. In the present study nests of the Welcome Swallow *Hirundo neoxena* were found under bridges along the existing section of the Sydney-Newcastle freeway.

Not only birds use bridge structures. Davis & Cockrum (1963) in Arizona, for example, reported the use of bridges by bats as day roosts. Bridge designers could well incorporate features into their designs which would encourage the use of bridges as nesting or roosting sites by fauna.

Development of highway rights-of-way for fauna must obviously be subsidiary to the needs of the highway engineer both to provide uncluttered sight-lines for motorists and to minimise the risks of vehicle-wildlife collisions. These needs can be satisfied without resorting to the biologically impoverished mown grass areas which characterise our highways today. In the United States, for example, the U.S. Forest Service is determining the food preferences of deer - a major cause of highway collisions - so that plantings along the right-of-way are of species unpalatable to these animals (Solomon, 1974). It should be possible to adopt a similar approach in Australia to discourage kangaroos and wallabies from using the right-of-way adjacent to highways.

Advocacy of the maximum retention and replanting of native vegetation in the freeway rights-of-way may seem at variance with the expressed desirability of retaining the sand-mined (i.e. disturbed) areas beside Mooney Mooney Creek for their significance to amphibia (see 7.1.5). The two concerns are distinct however. The use of exotic vegetation in the freeway rights-of-way will encourage invasion by fauna alien to the National Park. In contrast, the sand-mined areas beside Mooney Mooney Creek provide exceptionally favourable habitat for frog species which are, or can reasonably be presumed to be, a normal component of the National Park fauna.

8.4 Wildlife movement

Modern highways present a most hazardous and sometimes impassable obstacle to the movement of wildlife (see 4.5). Yet the need particularly for larger species of mammals, perhaps even reptiles, to cross the proposed freeway safely has been stressed already (see 7.2). This is necessary both to maintain population sizes and gene flows in the animals, and perhaps also to permit their movement in response to fire and drought (see 7.7 and 7.8).

The needs of wildlife to cross highways are well-recognised by highway authorities in some countries and much research has gone into finding safe crossing structures. This is especially true in the United States, where several species of deer exhibit traditional migrations between winter and summer feeding areas.

Underpasses have been found to reduce animal-vehicle accidents, by providing a means for deer and other animals to safely cross the highway. Reed, Woodward & Pojar (1975), for example, assessed the behavioural response of mule deer to, and the effectiveness of, a 3 x 3 x 30.5m long underpass under Interstate 70 in west Central Colorado for four years after its completion in 1970. They found that the underpass allowed about 61% of the local deer population to migrate safely under the highway but noted, by video time-lapse surveillance, that many of the animals were reluctant to use a structure of this size and character. They recommended, for future use, underpasses with widths and heights of at least 4.3 metres and minimal lengths, with dirt floors and no skylights or artificial lighting. Considerable use is being made by white-tailed deer of a bridge underpass, much larger than that just described, on Interstate 70 west of Baltimore, Maryland (Leedy, 1975). Deer have also been found to use unconfined wooden bridges with little or no hesitation (Wood & Smith, 1976).

It is difficult to assess the relevance of such findings to the Australian fauna, because deer on one hand and the larger Australian mammals on the other have very different behavioural patterns. The former often have well-established, traditional migratory routes, so that the appropriate locations for crossing structures are clear. Whether the large mammals of Australia similarly follow set routes when moving through the countryside is less clear.

Both proposed freeway routes have substantial bridges over Mooney Mooney Creek, and it would seem that these could provide a means for wildlife to safely cross the freeway corridor. For this to be effective, though, it is essential that as much as possible of the existing natural vegetation beneath the bridge be retained. In other words, bridge design should minimize the hindrance to wildlife movement by structural members of the bridge while access roads, materials dumps, machinery parks etc. should not be located beneath or near to the bridge. Any disturbed areas should be promptly revegetated.

To the extent that the bridge proposed for corridor 2 is 40 metres higher above the creek than that proposed for corridor 1 (see 1), it should be possible to retain more natural vegetation beneath it and its construction is consequently to be preferred.

At the same time, serious consideration should be given to freeway-crossing structures elsewhere along the section of freeway within Brisbane Water National Park or its proposed Northern extension. Fills proposed for this section could be replaced by either bridges or box culverts of substantial dimensions (i.e. not less than 4.3m high and wide). Preference should be given to siting the bridges in deeper valleys, so that bridge clearance is maximised. This will permit the penetration of

PHOTOGRAPHS 8.3/8.4: Continuous vegetation canopy beneath freeway bridge

enough light to maintain a continuous canopy of vegetation beneath the bridge (Photographs 8.3 and 8.4). It is also essential that the North and South-bound lanes of the freeway be separated at these crossing points by a band of natural vegetation wide enough to act as a temporary refuge for crossing animals. This will not only minimize the width of either the bridge or culvert crossing, considered essential by Reed et al. (1975), but may also permit gliding animals to move between vegetation on either side of the narrower carriageway. The proposed crossing structures should be monitored after installation to determine their use by different species.

Construction of bridges across the deeper valleys is desirable also in that it minimizes the impact of the freeway both on the creeks (see 7.9.1) and on the associated vegetation (Benson, 1979).

Consideration should also be given to the closure of the Pacific Highway between Calga and Kariong except for use as access to properties along Mooney Mooney Creek and for fire-fighting purposes. Such a measure would do much to render this road safe to wildlife.

8.5 Protection of watercourses

8.5.1 During construction

Uncontrolled erosion, especially during construction is likely to cause considerable damage to the already heavily impacted aquatic ecosystems of the lower Mooney Mooney Creek catchment (see 6.6.3.1). Components affected include the mangrove stands centred on the mouth of Piles Creek, the fish fauna of Mooney Mooney and Piles Creeks, the oyster farms downstream from the study area and the aquatic ecosystems of the tributaries of Piles and Mooney Mooney Creeks.

Adequate erosion controls are most important during the construction phase as this is when erosion is greatest (see 7.4.1). Failure to implement appropriate controls often results in costly stabilization programmes later. Many authors have provided good summaries of the many erosion controls available to highway engineers (Briggs, 1969; Khanna, 1973; Nebauer & Good, 1973; AASHTO, 1976; Quilty, Hunt & Hicks, 1979), the more important of which are:

- specifications to contractors should clearly require that clearance of vegetation be kept to an absolute minimum, both to reduce erosion and to assist in conservation of plant and animal communities (see 8.2);

- if the cut and fill method of construction must be used regardless of faunal considerations (see 4.2.3 and 8.4), cut or fill batters which are constructed through/with soil/decomposing rock, should be stabilized as soon as they reach their final form. Stabilization may be done by mulching and seeding with plants native to the area. At least some of the vegetation cleared prior to construction can be chipped for mulching purposes;

- temporary erosion controls should be introduced for all areas that are likely to be exposed for long periods before they are finally formed. Contractors should slope their earthworks in such a way that rainwater can runoff with minimal erosion, while protective mulching, plastic covering or temporary seeding should be used where necessary;

- a most important erosion control device, for use both during construction and for some time afterwards, is the sediment detention basin. All runoff from road-works within a particular catchment should be directed into such a basin before release from the construction area. Ward, Haan & Barfield (1977) and Quilty, Hunt and Hicks (1979) describe the different factors to be considered in designing an appropriate structure;

- all drains, temporary or permanent, should be stabilised immediately after construction and, if steep, provided with energy dissipators. Stabilization can be done by seeding with native plants, followed by mulching, or - on steeper grades - through the use of jute mesh and bitumen. It is essential that all drains have enough capacity to contain predicted runoff, since overtopping may cause serious erosion;

- every effort should be made to retain as much of the vegetation alongside the creeks as possible. This vegetation acts as a temperature control during warm summer months when water temperatures may otherwise exceed those tolerable by aquatic organisms. It also provides an important habitat for aquatic and terrestrial insects;

- frequent fording of live streams with construction equipment should be avoided and, where necessary, temporary bridges or other structures should be used;

- Disused borrow or waste pits should be finished and stabilised so that they do not erode;

- catch drains should be constructed above the proposed sites for cut batters, to prevent run off from beyond each batter reaching the exposed surface. These drains should be constructed as near to the top edge of the proposed cuts as possible to ensure maximum control of extraneous runoff;

- fill batters should be protected from gullying, caused by uncontrolled runoff during construction, by retaining an earth bank along the top edge of the fill to direct runoff to a safe outlet;

- culverts, if installed, should be wide enough to carry their flow at low velocities. Their outlets should be suitably designed to prevent gully erosion;

- adequate sanitation facilities should be provided for construction workers.

8.5.2 After construction

Several precautions should still be taken to control erosion from the freeway after construction. Apart from the continued use of sediment control basins until disturbed areas have stabilised, the following measures may be adopted:

- after construction is complete a windrow or earth bank should be formed on the top of fill batters to direct road runoff to drainage channels which will carry water to safe disposal areas;

- to quote Nebauer & Good (1973):

  "It is essential that the important role played by vegetation in the stabilization of the road batters, drains and culvert outlets and inlets be recognized by all authorities and workers involved with road maintenance".

  Regular surveillance of the roadway should be made for evidence of erosion. This is especially important if unfinished earthworks remain in anticipation of future construction (see 7.4.2). Spot reseeding of eroding areas may be necessary

8.5.3 Hydrological impacts

The hydrological impacts described in section 7.6 could be lessened by more judicious use of the cut and fill method of road construction, especially in faunally significant areas. Bridges rather than fills should be used to cross waterways wherever possible. If fills are unavoidable, they should be well-provided with pipes beneath the freeway so that existing patterns of water movement are modified as little as possible.

P. Swine, p. 6
A drainage mat.

8.6 Localised dispersal of runoff

The desirability of the current practice of directing most runoff waters from the highway into nearby watercourses is questioned. Ideally the water regimes of these watercourses should be unaltered by highway construction. In practice the additional volumes of water from highway runoff can cause scouring of the creek beds and erosion of their banks. In addition, highway runoff introduces vehicle-related pollutants and accidentally-spilled materials into the creek ecosystem and, through them, into aquatic ecosystems in general (see 4.2.5). Although the impacts of these pollutants on the natural environment are still unknown (e.g. Solomon, 1974); Hopkins, 1976), they will most likely be adverse.

It may be preferable, then, to disperse runoff waters at stable locations alongside the highway where it can filter into the soil. Suitable structures for this purpose, incorporating energy dissipators at their lower end, are already in use on the existing freeway (Photographs 8.5 and 8.6).

A novel approach to the problem of highway runoff is 'ecological paving' (Grover, Hoiberg, Haigh & Thelen, 1972; Anon, 1974). This paving consists of a relatively thin layer of gap-graded ashphalt over a deep base of permeable material that allows water to pass through to the subgrade. By permitting water to percolate directly into the soil, the porous system reduces the amount of curbing and drains necessary, reduces pollution and allows more normal recharge of the water table. The application of this concept to highways could prove a most innovative step.

8.7 Fire

Mitigation of the impact of the freeway on the interaction between wildlife and fire in Brisbane Water National Park may be achieved

PHOTOGRAPHS 8.5/8.6: Water runoff/energy dissipator structures installed beside existing freeway

in several ways. The increasingly isolated nature of the Park has necessitated the need to actively manage the effects of fire and, for this reason, the National Parks and Wildlife Service has prepared a fire management plan for the Park (B. Vile, pers. comm.). Clearly the success of this plan requires the prompt control of fires originating from both the existing Pacific Highway and the proposed freeway, whichever route is adopted.

An almost identical situation exists along the western boundary of Ku-ring-gai Chase National Park, which adjoins extensive urban areas, roads and a railway. The development of a controlled burning fire policy for this boundary has provided an effective barrier to unplanned fires emanating from outside the Park (Weir, 1978). Clearly a policy of controlled burning along both the existing and planned freeway sections is most desirable and should be developed in conjunction with the National Parks and Wildlife Service.

Secondly, the opportunity should exist for wildlife to move between Brisbane Water National Park and the proposed northern extension in response to both fire and drought. The suggestions for wildlife crossing points along the proposed freeway outlined in section 8.3 in respect of population viability should meet this need.

Thirdly, in the event of the freeway being constructed along corridor 2, careful consideration should be given to closing the Pacific Highway between Calga and Kariong to general traffic (see also 8.4). This move should considerably lessen the incidence of road-related fires in that area (see 7.7.2).

Finally, traffic authorities should be prepared to close the freeway should severe fires force wildlife onto the freeway. A precedent for this kind of action was created in West Germany in 1975, when an expressway in Bavaria was closed for about eight hours while thousands of toads crossed safely to their breeding grounds (Anon., 1975b).

8.8 Dust control

The control of dust during construction is desirable both for environmental reasons (see 4.4.4) and for the comfort of construction staff. Regular sprinkling with water in dusty areas during dry periods should adequately control this problem.

8.9 Disposal of construction wastes

Construction activities usually involve quantities of fuels and materials toxic to both wildlife and plants. Appropriate recognition of these dangers should be established through project specifications, regulations, permits or otherwise to safeguard against undesirable spillage.

Construction wastes should be placed in areas where there is no likelihood of transportation by groundwater away from the disposal site.

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APPENDIX 1: Study sites: map references

The map references below refer to the Central Mapping Authority of New South Wales maps:

GUNDERMAN: 9131-111-S First Edition 1:25000 series N.S.W. (Gun.).
GOSFORD : 9131-11-S First Edition 1:25000 series N.S.W. (Gos.).

Site Number	AMG Map Reference
1.1	Gun: 34709677
1.2	Gun: 34739660
1.3	Gun: 34989680
1.4	Gun: 35189684
1.5	Gun: 35969706
1.6	Gun: 36109743
1.7	Gun: 36449710
1.8	Gun: 36779716
1.9	Gun: 37109722
1.10	Gos: 37509733
1.11	Gos: 38689742
1.12	Gos: 38979746
1.13	Gos: 39279745
1.14	Gos: 39509756
1.15	Gos: 40149805
1.16	Gos: 40669929
1.16A	Gos: 40909944
1.17	Gos: 40979965
2.1	Gun: 35549953
2.2	Gun: 35889946
2.3	Gun: 36249943
2.4	Gun: 36649936
2.5	Gun: 37109930
2.6	Gos: 37469932
2.7	Gos: 37619920
2.8	Gos: 37749920

2.9	Gos: 38089940
2.10	Gos: 38109930
2.11	Gos: 38449906
2.12	Gos: 38589893
2.13	Gos: 38639889

APPENDIX 2: Study sites: physical and botanical attributes (after Benson, 1979)

Community Structure	Study Site	Elev. (m)	Geol	Geom	Aspect	Slope	Soil	% Rock, Stone or Bare	Canopy Height m	Canopy Cover %	Shrub Cover	Dominant Tree Species	Dominant Understorey Species
1. CLOSED-FOREST	1.2	70	HSs.	C.	150°(SSE)	24°	Dy: mS over a S.C.	-	22	76	Mid-dense	*E. deanii, A. floribunda* with *C. torulosa* and *Backhousia myrtifolia*	*Trochocarpa laurina, Ceratopetalum apetalum, Blechnum cartilaginum, Culcita dubia*
	1.4	70	HSs N.G.	C.	120°(ESE)	14°	Dy: mS over S.C.	-	25	72	Open	*E. deanii, A. floribunda, Syncarpia glomulifera* and *Backhousia myrtifolia*	*Trochocarpa laurina, Themeda australis*
	2.10	40	N.G.	C.	260°(W)	22°	Dy: L.S. over S.C.	-	20	82	Open	*Doryphora sassafrass, Syzygium coolminianum, Ceratopetalum apetalum*	*Synoum glandulosum, Doryphora sassafrass, Blechnum cartilaginum*
2. OPEN-FOREST, moist understorey, Type A	1.1	100	HSs	S	180°(S)	18°	Dy: mS over S.C.	10	20	58	Dense	*E. piperita, A. costata* with *E. pellita*	*Grevillea linearifolia, Pultenaea flexilis, Leptospermum flavescens, Xanthorrhoea arborea, Lasiopetalum ferrugineum*
	1.8	20	H.Ss	S to C.	225°	20°	LS	-	20	42	Mid-Dense	*E. piperita, A. costata* with *E. umbra*	*Tristania laurina, Ceratopetalum gummiferum, Culcita dubia, Phyllota phylicoides, Schizomeria ovata*
Type B	1.5	60	HSs	S	90°(E)	22°	mSL.	25	15	58	Open	*A. floribunda, C. torulosa*	*Cissus hypoglauca, Culcita dubia, Themeda australis, Ficus rubiginosa*
	1.6	50	N.G. with Hss blocks	S	30°(NNE)	23°	Dy: S.L. & mC	-	25	60	Open	*A. floribunda, C. torulosa*	*Imperata cylindrica, Pteridium esculatum, Hibbertia scandens, Doodia aspera*
	2.6	30	N.G. Hss. blocks	S	110°(ESE)	23°	Dy: mS over C	-	20	46	Open	*A. floribunda, C. torulosa* with *E. deanii*	*Tristania laurina, Culcita dubia, Themeda australis*
3. OPEN FOREST, dry understorey	1.3	120	HSs.	S.	130°(SE)	8°	mS	30	15	60	Dense	*A. costata, E. gummifera Syncarpia glomulifera*	*Phyllota phyllicoides, Dillwynia floribunda, Xanthorrhoea arborea*
	1.7	60	HSs	S	310°(NW)	23°	mS	40	12	38	Open	*E. piperita, E. punctata* with *E. gummifera*	*Pultenaea flexilis, Entolasia stricta, Pteridium esculentum*
	1.11	80	HSs	C	0°(N)	23° sides of creek	Dy. mS over SC	15	23	46	Mid-dense	*E. piperita* on creek side, *Tristania nurifolia* and *Ceratopetalum apetalum in creek*	*Acacia oxycedrus, Sticherus flabellatus, Gleichenia rupestris*

APPENDIX 2: Study sites: physical and botanical attributes (after Benson, 1979) (Continued)

Community Structure	Study Site	Elev. (m)	Geol	Geom	Aspect	Slope	Soil	% Rock, Stone or Bare	Canopy Height m	Canopy Cover %	Shrub Cover	Dominant Tree Species	Dominant Understorey Species
7. CLOSED HEATH *Banksia ericifolia/ Hakea* spp.	1.10	130	HSs	R	0^{o}(N)	3^{o}	mS skeletal	-	6	18	Dense	*E. haemastoma/E. gummifera*	*Banksia ericifolia, Hakea* spp. *Restio dimorphus*
	1.15	170	HSs	R	330^{o}(NNW)	2^{o}	Wet OS	30	7	8	Open	*E. haemastoma*	*Hakea teretifolia, Banksia ericifolia, Schoenus* spp.
	1.17	165	HSs	R	220^{o}								
	2.1	180	HSs	RS	230^{o}(SW)	10^{o}	mS skeletal	15	-	-	Mid-dense	-	*Banksia ericifolia, Leptospermum attenuatum, Leptocarpus tenax*
	2.12	130	HSs	R	90^{o}(E)	4	mS skeletal	15	-	-	Dense	-	*Banksia ericifolia, Hakea teretifolia, Restio fastigiatus, Kunzea capitata*
8. ROCK OUTCROPS with pockets of low scrub	-	-	HSs	R	-	-	skeletal mS	Usually < 50%		-	Variable usually dense in hollows	-	*Baeckea brevifolia, Darwinia* spp., *Restio* spp., *Grevillea* spp. with *Epacrids*
9. SEDGELAND	1.16A	160	HSs	S	20^{o}(NNE)	4	OS	-	-	-	Open	-	Dominated by a number of sedges and graminoids including *Restio fastigiatus, Schoenus brevifolius, Empodisma minus, Gymnoschoenus sphaerocephalus*

Key:

Community Structure - based on Specht (1970)

Elev. (m) - Elevation (meters)

Geol. - Geology
- HSs - Hawkesbury Sandstone
- N.G. - Narrabeen Group
- A - Alluvium

Geom. - Geomorphology
- R - Ridge
- S - Slope of Valley
- C - Creek
- F - River flats

Soil:
- D - duplex
- Y - yellow
- l - light
- m - medium
- S - Sand
- C - Clay
- L - Loam
- A - Alluvium
- O - Organic

Canopy Height - Height in meters of dominant canopy cover.

Canopy Cover - Projected foliage cover as per centage.

- E - *Eucalyptus*
- A - *Angophora*
- C - *Casuarina*

APPENDIX 2: Study sites: physical and botanical attributes (after Benson, 1979) (Continued)

Community Structure	Study Site	Elev. (m)	Geol	Geom	Aspect	Slope	Soil	% Rock, Stone or Bare	Canopy Height m	Canopy Cover %	Shrub Cover	Dominant Tree Species	Dominant Understorey Species
3. OPEN-FOREST dry understorey (Continued)	1.13	130	HSs	East bank of Creek C	260^{o}(W)	18^{o}	Dy. mS-ISC	5	15	50	Mid-dense to dense	*E. piperita, Angophora costata*	*Leptospermum flavescens, Bauera rubioides, Gleichenia dicarpa, Lepyrodia scariosa*
	2.5	80	HSs	S near C	190^{o}(S)	14^{o}	Dy mS-LSC	-	13	28	Mid-dense	*E. piperita, Banksia serrata* and *Syncarpia glomulifera*	*Phyllota phyllicoides, Xanthorrhoea arborea, Leptospermum flavescens, Imperata cylindrica*
	2.8	20	NG	S near base	270^{o}(W)	23^{o}	Dy:mS over SC	15	20	54	Open	*A. floribunda, C. torulosa*	*Themeda australis, Dodonaea triquetra, Kennedia rubicunda*
	2.9	90	NG	S	180^{o}(S)	25^{o}	Dy. mS over SC	10	27	52	Open	*A. floribunda, E. piperita C. torulosa*	*Culcita dubia, Pultenaea flexilis, Pteridium esculentum*
4 LOW OPEN-FOREST *Casuarina glauca*	2.7	5	A	F	-	-	AS	-	8	56	Sparse	*C. glauca, Melaleuca styphelioides*	*Juncus* spp., *Baumea juncea, Agrostis avenaceus, Viola hederacea*
5. LOW OPEN-FOREST dry, tall, dense understorey	1.16	170	HSs	R	340^{o}(N)	2^{o}	Yellow earth mS-LCS	-	10	44	Dense	*E. capitellata, E. gummifera, Banksia serrata* with *E. haemastoma*	*Leptospermum attenuatum, Petrophile pulchella, Lepyrodia scariosa*
6. LOW OPEN-FOREST/LOW WOODLAND dry understorey	1.9	80	HSs	SC	270^{o}(W)	11^{o}	mS skeletal	50	10	42	Open	*A. costata, E. umbra* with *E. eximia, E. gummifera*	*Banksia serrata, Xanthorrhoea media*
	1.12	130	HSs	RS	240^{o}(WSW)	7^{o}	mS skeletal	15	10	32	Mid-dense	*E. gummifera, E. haemastoma* with *E. umbra*	*Leptospermum attenuatum, Dillwynia floribunda, Lepyrodia scariosa*
	1.14	150	HSs	R	310^{o}(NW)	3^{o}	mS skeletal	25	8	6	Open	*E. haemastoma* with *Banksia serrata*	*A. hispidula, Xanthorrhoea media, Xyris gracilis, Lepyrodia scariosa*
	2.2	200	HSs	R	160^{o}(S)	8^{o}	mS skeletal	20	10	36		*Banksia serrata, E. gummifera, E. piperita*	*Anisopogon avenaceus, Lomandra* spp.
	2.3	170	HSs	RS	50^{o}(NE)	7^{o}	mS skeletal	35	9	34	Mid-dense	*E. umbra, E. gummifera*	*Banksia ericifolia, Hakea teretifolia* with various graminoids
	2.4	160	HSs	R	60^{o}(ENE)	9^{o}	Dy mS-ISC	10	9	46	Dense	*E. gummifera, E. umbra Banksia serrata*	*Dillwynia retorta, Xanthorrhoea media, Lepyrodia scariosa*
	2.11	140	HSs	R	95^{o}(E)	8^{o}	mS skeletal	10	11	32	Dense	*E. punctata, E. umbra, E. eximia*	*Dillwynia floribunda, Hakea teretifolia, Entolasia stricta, Acacia oxycedrus*

APPENDIX 3: Bird species checklist

NOTE: Species observed in study area but not within corridors are simply listed

	Corridor 1		Corridor 2	
	AB	BC	DE	EC
Little Pied Cormorant *Phalacrocorax melanoleucos*	X		X	
Black Cormorant *P. carbo*	X			
Little Black Cormorant *P. sulcirostris*	X			
White-necked Heron *Ardea pacifica*	X			
White-faced Heron *A. novaehollandiae*	X		X	
Nankeen Night Heron *Nycticorax caledonicus*	X			
Mangrove Heron *Butorides striatus*				
Black Duck *Anas superciliosa*	X			X
*Wood Duck *Chenonetta jubata*				
Whistling Kite *Haliastur sphenurus*	X			
Collared Sparrowhawk *Accipiter cirrhocephalus*	X		X	
White-breasted Sea Eagle *Haliaetus leucogaster*	X		X	
Brown Quail *Coturnix australis*	X			
Painted Button Quail *Turnix varia*				
Spur-winged Plover *Vanellus miles novaehollandiae*	X			
Silver Gull *Larus novaehollandiae*				
Topknot Pigeon *Lopholaimus antarcticus*	X			
Spotted Turtledove *Streptopelia chinensis*	X			X
Peaceful Dove *Geopelia striata*	X			X
Common Bronzewing *Phaps chalcoptera*	X		X	X
Crested Pigeon *Ocyphaps lophotes*		X		
Wonga Pigeon *Leucosarcia melanoleuca*	X			
Glossy Black Cockatoo *Calyptorhynchus lathami*	X		X	
Yellow-tailed Black Cockatoo *C. funereus*	X		X	
Gang-gang Cockatoo *Callocephalon fimbriatum*	X*		X	
Sulphur-crested Cockatoo *Cacatua galerita*	X		X	
Rainbow Lorikeet *Trichoglossus haematodus*				X
King Parrot *Alisterus scapularis*	X		X	
Crimson Rosella *Platycercus elegans*	X		X	
Eastern Rosella *P. eximius*	X	X	X	X
Red-rumped Parrot *Psephotus haematonotus*		X		
Brush Cuckoo *Cuculus variolosus*	X		X	
Fan-tailed Cuckoo *C. pyrrhophanus*	X		X	X
Golden Bronze Cuckoo *Chrysococcyx lucidus plagosus*	X		X	
Indian Koel *Eudynamys scolopacea*				
Pheasant Coucal *Centropus phasianinus*	X			
Boobook Owl *Ninox novaeseelandiae*	X		X	
Tawny Frogmouth *Podargus strigoides*	X		X	
Owlet Nightjar *Aegatheles cristatus*	X			
White-throated Nightjar *Caprimulgus mystacalis*	X		X	
Spine-tailed Swift *Hirundapus caudacutus*	X			X
Azure Kingfisher *Ceyx azureus*	X		X	
Laughing Kookaburra *Dacelo gigas*	X	X	X	X
Sacred Kingfisher *Halcyon sancta*	X	X	X	X
Dollar Bird *Eurystomus orientalis*	X		X	
Superb Lyrebird *Menura novaehollandiae*	X		X	
Welcome Swallow *Hirundo neoxena*	X	X	X	X

APPENDIX 3: Bird species checklist (Continued)

Species	Corridor 1 AB	Corridor 1 BC	Corridor 2 DE	Corridor 2 EC
Richard's Pipit *Anthus novaeseelandiae*	x			
Black-faced Cuckoo-shrike *Coracina novaehollandiae*	x	x	x	
Cicada Bird *Coracina tenuirostris*	x		x	
Scaly Thrush *Zoothera dauma*	x			
Scarlet Robin *Petroica multicolor*	x		x	
Eastern Yellow Robin *Eopsaltria australis*	x		x	x
Jacky Winter *Microeca leucophaea*	x			
Rufous Whistler *Pachycephala rufiventris*	x	x	x	x
Golden Whistler *P. pectoralis*	x		x	
Grey Shrike-thrush *Colluricincla harmonica*	x	x	x	x
Black-faced Monarch *Monarcha melanopsis*	x			
Leaden Flycatcher *Myiagra rubecula*	x		x	
*Rufous Fantail *Rhipidura rufifrons*				
Grey Fantail *R. fuliginosa*	x	x	x	x
Willie Wagtail *R. leucophrys*		x		
Eastern Whipbird *Psophodes olivaceus*	x		x	x
*Spotted Quail-thrush *Cinclosoma punctatum*	x			
Superb Blue Wren *Malurus cyaneus*	x	x	x	x
Variegated Wren *M. lamberti*	x	x	x	x
Southern Emu Wren *Stipiturus malachurus*	x	x	x	
Rock Warbler *Origma solitaria*	x		x	
Large-billed Scrubwren *Sericornis magnirostris*			x	
Yellow-throated Scrubwren *S. citreogularis*				
White-browed Scrubwren *S. frontalis*	x		x	
Chestnut-rumped Hylacola *S. pyrrhopygius*	x		x	x
Brown Thornbill *Acanthiza pusilla*	x		x	
Buff-rumped Thornbill *A. reguloides*			x	x
Striated Thornbill *A. lineata*	x	x	x	
Yellow-rumped Thornbill *A. chrysorrhoa*				x
Brown Warbler *Gerygone mouki*	x		x	
White-throated Warbler *G. olivacea*	x	x	x	
Orange-winged Sitella *Daphoenositta chrysoptera*	x		x	
White-throated Treecreeper *Climacteris leucophaea*	x		x	x
Red-browed Treecreeper *C. erythrops*	x			
Little Wattlebird *Anthochaera chrysoptera*	x	x	x	x
Noisy Friarbird *Philemon corniculatus*	x		x	
Bell Miner *Manorina melanophrys*				
Lewin's Honeyeater *Meliphaga lewinii*	x		x	
Yellow-faced Honeyeater *Lichenostomus chrysops*	x	x	x	x
White-eared Honeyeater *L. leucotis*	x	x	x	
Brown-headed Honeyeater *Melithreptus brevirostris*	x	x	x	
New Holland Honeyeater *Phylidonyris novaehollandiae*	x	x	x	x
White-cheeked Honeyeater *P. nigra*	x	x	x	x
Tawny-crowned Honeyeater *P. melanops*	x			
Eastern Spinebill *Acanthorhynchus tenuirostris*	x	x	x	x
*Scarlet Honeyeater *Myzomela sanguinolenta*				
Mistletoe Bird *Dicaeum hirundinaceum*	x		x	
Spotted Pardalote *Pardalotus punctatus*	x		x	x

APPENDIX 3: Bird species checklist (Continued)

Species	Corridor 1 AB	Corridor 1 BC	Corridor 2 DE	Corridor 2 EC
Striated Pardalote *Pardalotus striatus*	x	x		
Silvereye *Zosterops lateralis*	x	x	x	x
European Goldfinch *Carduelis carduelis*	x	x		
Red-browed Firetail *Emblema temporalis*	x	x	x	x
Double-barred Finch *Poephila bichenovii*	x	x		x
Common Starling *Sturnus vulgaris*	x	x		
Olive-backed Oriole *Oriolus sagittatus*	x		x	
Satin Bowerbird *Ptilonorhynchus violaceus*	x		x	
Australian Magpie Lark *Grallina cyanoleuca*		x	x	x
Dusky Woodswallow *Artamus cyanopterus*	x			x
Grey Butcherbird *Cracticus torquatus*	x		x	x
Australian Magpie *Gymnorhina tibicen*	x	x	x	x
Pied Currawong *Strepera graculina*	x		x	x
Australian Raven *Corvus coronoides*	x	x	x	x

* Observations provided by K. Paull

APPENDIX 4: Bird Spot Census Results

A. WINTER RESULTS

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Yellow-tailed Black Cockatoo					4																							
Crimson Rosella		2					1																					
Eastern Rosella																		2										
Fan-tailed Cuckoo	1																											
Laughing Kookaburra						1								1				2	1		3	3	2					
Black-faced Cuckoo -Shrike			1																									
Superb Blue Wren																								1				
Brown Warbler		4																									2	
Striated Thornbill			3														3											
Brown Thornbill			3	2		3			2				2										3	4			1	
White-browed Scrub-wren			2										2															
Scarlet Robin			1																				1					
Eastern Yellow Robin	1	2		4		1																						
Grey Fantail		5	1			2	1															1					1	
Golden Whistler	3	6	3													1											3	
Grey Shrike-Thrush			1																									
Eastern Whipbird																	1											
White-throated Treecreeper	3		2								2												2					
																									NO BIRDS OBSERVED	NO BIRDS OBSERVED		NOT CENSUSED

A. WINTER RESULTS (Continued)

SITE NUMBER

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17
Mistletoe Bird			1								1						
Spotted Pardalote	2	1			2	1	1	1				3					
Silvereye	18								6							2	2
Lewin's Honeyeater		5		1	1												
Yellow-faced Honeyeater						2	7		3	2							
White-eared Honeyeater									1						4	2	
Brown-headed Honeyeater																	2
Eastern Spinebill	5		2			1		3	3	2			2	1	1	3	
New Holland Honeyeater										3		2		1	5		30
White-cheeked Honeyeater										5			3		3	1	
Little Wattlebird															1		
Noisy Friarbird																	
Grey Butcherbird			1														
Black-backed Magpie																	
Satin Bower-bird			1														
Australian Raven														1			

SPECIES	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Mistletoe Bird								NO BIRDS OBSERVED	NO BIRDS OBSERVED		NOT CENSUSED
Spotted Pardalote		2		1		1					
Silvereye											
Lewin's Honeyeater										1	
Yellow-faced Honeyeater	2			1	3						
White-eared Honeyeater	1	2		2							
Brown-headed Honeyeater											
Eastern Spinebill	1	2	1	3							
New Holland Honeyeater	2										
White-cheeked Honeyeater			1								
Little Wattlebird	1	1									
Noisy Friarbird				2		1					
Grey Butcherbird											
Black-backed Magpie					1						
Satin Bower-bird											
Australian Raven						1					

B. SPRING RESULTS

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Collared Sparrowhawk															1													
Topknot Pigeon		3																										
Crimson Rosella		5	2		6	1	1		1			2						5		2	2							
Eastern Rosella																				1								
Fan-tailed Cuckoo													1															
Golden-bronze Cuckoo																	1											
Laughing Kookaburra			1																									
Black-faced Cuckoo-Shrike															1						2							
Superb Blue Wren																								3	3			
Variegated Wren									1														2					
White-throated Warbler																							1					
Brown Warbler		1																									5	
Striated Thornbill	2																						2					
Brown Thornbill			1	2	1	1			1					1						1			1	1	2		2	
White-browed Scrub-wren				2	2				2											1			2					
Rock Warbler																				1								
Eastern Yellow Robin	2	1					1										2			1			1	2	2			
								NO BIRDS OBSERVED																				NO BIRDS OBSERVED

B. SPRING RESULTS (Continued)

SPECIES	SITE NUMBER																												
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Grey Fantail	2		3		2	1	2						2			1								1					
Leaden Flycatcher							1																						
Golden Whistler		4	2	3	2		2						1											1	1				
Rufous Whistler										1						1	3												
Grey Shrike-Thrush					1		1						1																
Eastern Whipbird	1																									1			
Orange-winged Sitella																							1						
White-throated Treecreeper					1								2				1							2			2		
Mistletoe Bird			1		1																								
Spotted Pardalote					3		2				1									2		1			1				
Silvereye	2		11		7																			2					
Lewin's Honeyeater		2		1	1		2																					1	
Yellow-faced Honeyeater					1	1	10																	4	2	1			
White-eared Honeyeater												3		1	1					4		4							
Eastern Spinebill	3			1					1		1		2			1	1					2							
New Holland Honeyeater										7		1		2	4		15												
White-cheeked Honeyeater									11								2				3								
Little Wattlebird		2															3			4									
Noisy Friarbird										2	1							1		4		2	4						
Grey Butcherbird																													
Pied Currawong						2				1													3						

C. SUMMER RESULTS

SPECIES	SITE NUMBER																											
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Glossy Black Cockatoo																										2			
King Parrot						3																							
Crimson Rosella		3						2	3				1	2															1
Brush Cuckoo						1																							
Golden-bronze Cuckoo																	1												
Sacred Kingfisher						1					1																		1
Dollar Bird						1																							
Cicada Bird																											1		
Scaly Thrush				2																									
Variegated Wren																	1												
Brown Warbler		3																											
Brown Thornbill			1						1																		1		
White-browed Scrubwren													1																
Chestnut-rumped Hylacola																			2										
Eastern Yellow Robin						2					1		1			1	1								1	2	3		
Grey Fantail	2								1								2												
Golden Whistler						1																							
Rufous Whistler																	1						1						
Grey Shrike-thrush						2																							
White-throated Treecreeper									1																		1		

C. SUMMER RESULTS (Continued)

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
	SITE NUMBER																											
Spotted Pardalote			1			1											1											
Lewin's Honeyeater		2				3																						
Yellow-faced Honeyeater						2			2		1													2				
White-eared Honeyeater									1						3						2							3
Eastern Spinebill													1		2			1	1									
New Holland Honeyeater																	4											7
White-cheeked Honeyeater												2	2								1							
Little Wattlebird													2		3													
Noisy Friarbird																					1	6	1					2
Red-browed Firetail			4																									
Pied Currawong																					1				1			
Grey Butcherbird																							1					
Satin Bowerbird						12																						

APPENDIX 5: Bird Species: Plant Community Listings

A. WINTER RESULTS

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
	SITE NUMBER																											
Brown Quail										x																		
Wonga Pigeon					x																							
Yellow-tailed Black Cockatoo					x		x																					
Crimson Rosella		x			x		x											x	x		x	x	x		x			
Eastern Rosella																		x										
Fan-tailed Cuckoo	x					x																						
Golden-bronze Cuckoo						x																						
Laughing Kookaburra						x								x					x									
Black-faced Cuckoo Shrike			x			x													x									
Scaly Thrush		x																										
Superb Blue Wren						x																		x				
Variegated Wren																						x						
Southern Emu Wren																									x			
Brown Warbler		x																									x	
Striated Thornbill			x		x												x					x			x			
Brown Thornbill	x		x	x	x	x	x		x				x			x						x	x	x	x		x	
White-browed Scrub-wren		x	x										x														x	
Large-billed Scrub-wren																											x	
Chestnut-rumped Hylacola																					x							
Rock Warbler																				x		x						

A. WINTER RESULTS (Continued)

SPECIES	SITE NUMBER																										
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Scarlet Robin			X																			X	X					
Eastern Yellow Robin	X	X		X	X	X														X			X					
Grey Fantail		X	X		X	X	X															X					X	
Golden Whistler	X	X	X													X							X				X	
Rufous Whistler										X																		
Grey Shrike-Thrush			X																									
Eastern Whipbird		X			X												X	X	X								X	
Orange-winged Sitella						X																						
White-throated Treecreeper	X		X			X					X											X	X		X			
Mistletoe Bird	X		X		X	X					X										X	X						
Spotted Pardalote	X	X			X	X	X	X				X							X	X	X		X					X
Silvereye	X								X							X	X											
Lewin's Honeyeater		X		X	X																		X		X		X	
Yellow-faced Honeyeater						X	X		X	X								X	X		X	X	X		X			
White-eared Honeyeater									X						X	X		X	X		X							
Brown-headed Honeyeater																	X											
Eastern Spinebill	X		X			X		X	X	X			X	X	X	X		X	X	X	X	X					X	X

A. WINTER RESULTS (Continued)

SPECIES	SITE NUMBER 1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Tawny-crowned Honeyeater										X																			
New Holland Honeyeater										X		X		X	X		X		X										
White-cheeked Honeyeater										X			X		X	X					X								
Little Wattle Bird															X		X		X	X	X								
Noisy Friarbird																						X	X	X					
Pied Currawong																								X					
Grey Butcherbird			X																				X						
Black-backed Magpie																							X	X					
Satin Bower Bird			X																										
Australian Raven														X									X	X					

B. SPRING RESULTS

SPECIES	SITE NUMBER 1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Collared Sparrowhawk															+							+						
Topknot Pigeon		+																										
Wonga Pigeon	+																											
Gang-gang Cockatoo																				+	+							
King Parrot			+		+																					+		
Crimson Rosella		+	+		+	+	+	+	+		+	+	+	+					+	+	+	+	+					
Eastern Rosella																+					+							
Brush Cuckoo							+																					
Fan-tailed Cuckoo					+	+				+			+								+		+		+			
Golden-bronze Cuckoo			+											+			+						+					
Boobook Owl					+																							
Laughing Kookaburra			+					+											+						+			
Superb Lyrebird	+						+						+										+					
Black-faced Cuckoo Shrike													+	+		+			+		+		+					
Cicada Bird																									+			
Superb Blue Wren																								+	+			
Variegated Wren	+				+		+		+	+			+	+			+						+					
White-throated Warbler																							+					

B. SPRING RESULTS (Continued)

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Brown Warbler		+																										
Striated Thornbill	+																						+					
Brown Thornbill	+	+	+	+	+	+			+						+					+		+	+	+	+		+	
White-browed Scrubwren				+	+				+											+			+				+	
Chestnut-rumped Hylacola												+																
Rock Warbler							+					+								+								
Scarlet Robin					+																							
Eastern Yellow Robin	+	+					+						+				+	+		+				+	+	+		
Grey Fantail	+		+		+	+	+				+		+		+	+						+	+	+		+		
Leaden Flycatcher			+				+																	+				
Golden Whistler		+	+	+	+	+	+	+			+		+										+	+			+	
Rufous Whistler										+		+		+		+	+					+		+				
Grey Shrike-Thrush					+		+					+	+	+						+	+	+					+	
Eastern Whipbird	+	+			+						+		+					+							+		+	
Orange-winged Sitella																						+						
White-throated Treecreeper	+		+		+	+	+	+			+		+			+	+						+			+		
Mistletoe Bird			+		+																							
Striated Pardalote												+					+											

B. SPRING RESULTS (Continued)

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17
Spotted Pardalote	+				+		+				+			+			
Silvereye	+		+		+	+						+	+	+		+	+
Lewin's Honeyeater		+		+	+		+										
Yellow-faced Honeyeater					+	+	+										
White-eared Honeyeater												+		+	+		
Brown-headed Honeyeater														+			
Eastern Spinebill	+	+	+	+					+		+		+	+		+	+
New Holland Honeyeater										+		+	+	+	+		+
White-cheeked Honeyeater	+									+							+
Little Wattle-bird			+														+
Noisy Friarbird											+	+		+			
Pied Currawong					+	+			+		+			+			+
Grey Butcher-bird																	
Australian Raven					+						+						

SPECIES	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
Spotted Pardalote		+		+	+	+	+				
Silvereye			+		+	+					
Lewin's Honeyeater								+		+	
Yellow-faced Honeyeater					+	+	+	+			
White-eared Honeyeater		+		+							
Brown-headed Honeyeater											
Eastern Spinebill				+				+	+		
New Holland Honeyeater	+										
White-cheeked Honeyeater			+								
Little Wattle-bird		+	+			+					
Noisy Friarbird	+	+	+	+	+			+			
Pied Currawong		+			+						
Grey Butcher-bird				+							
Australian Raven		+			+						

C. SUMMER RESULTS

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
	SITE NUMBER																											
Glossy Black Cockatoo																									+			
King Parrot					+	+																+						
Crimson Rosella		+		+		+		+	+				+	+					+		+		+					+
Brush Cuckoo						+																						
Golden-bronze Cuckoo																	+											
Boobook Owl					+																							
Tawny Frogmouth																+												
White-throated Nightjar					+																							
Laughing Kookaburra					+																				+			
Sacred Kingfisher						+					+												+					+
Dollar Bird						+																	+		+			
Superb Lyrebird		+		+																								
Black-faced Cuckoo-shrike																						+						
Cicada Bird																						+			+	+		
Scaly Thrush				+																								
Variegated Wren						+		+		+							+								+	+		+
Southern Emu Wren																								+				
Brown Warbler		+																									+	
Striated Thornbill																	+											
Brown Thornbill		+	+		+				+				+													+		

C. SUMMER RESULTS (Continued

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
White-browed Scrubwren				+		+							+																
Chestnut-rumped Hylacola																			+										
Rock Warbler									+		+																		
Eastern Yellow Robin				+	+	+					+		+			+	+					+			+	+	+		
Grey Fantail	+		+	+			+		+				+				+						+						+
Leaden Flycatcher						+																							
Black-faced Monarch						+																							
Golden Whistler				+	+	+							+															+	
Rufous Whistler						+								+			+						+						
Grey Shrike-thrush						+																				+			
Eastern Whipbird	+				+		+										+											+	+
Orange-winged Sittella																													+
White-throated Treecreeper				+		+			+				+										+			+	+		+
Mistletoe Bird													+									+							
Spotted Pardalote			+			+											+												+
Silvereye																	+					+							
Lewin's Honeyeater		+		+	+	+																						+	
Yellow-faced Honeyeater						+			+		+												+		+				
White-eared Honeyeater									+			+		+	+							+							+
Eastern Spinebill									+				+	+	+		+		+	+									+

C. SUMMER RESULTS (Continued)

SPECIES	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
	SITE NUMBER																												
New Holland Honeyeater														+	+		+												+
White-cheeked Honeyeater						+	+		+			+	+	+			+					+	+						
Little Wattlebird													+	+	+								+						
Noisy Friarbird																						+	+	+	+	+			+
Red-browed Firetail			+																										
Olive-backed Oriole						+																							
Pied Currawong																						+				+	+		
Grey Butcherbird																						+		+					
Black-backed Magpie														+															+
Satin Bowerbird						+																							
Australian Raven					+																								

APPENDIX 6: Herpetofauna: habitat information

Green Tree Frog *Litoria caerulea*

A breeding congregation occurred in the Mooney Mooney Creek sand mining area. Also found in community 6.

Dwarf Tree Frog *L. fallax*

Found only in the sand-mined area beside Mooney Mooney Creek. This species generally occurs near water.

Leaf Green Tree Frog *L. phyllochroa*

Heard in closed forest, this species is usually found in vegetation bordering water.

Broad-palmed Frog *L. latopalmata*

Less water-dependent, this species was recorded from community 6.

Freycinet's Frog *L. freycineti*

This species was present in large numbers along Rat Gully and in the Mooney Mooney Creek sand-mined area. It was also trapped in open forest with a moist understorey (Community 2B).

Rocket Frog *L. nasuta*

One specimen collected at Western end of corridor 1.

Bleating Tree Frog *L. dentata*

Usually associated with large coastal swamps and ponds, this species was recorded from open forest with moist and dry understoreys, low open forest/open woodland and the sand-mined area beside Mooney Mooney Creek.

Brown Frog *Limnodynastes peroni*

A widespread and adaptable species, collected in open forest with dry and wet understoreys.

Giant Burrowing Frog *Heleioporus australiacus*

This species seemed to prefer drier, sandy localities, being collected in closed heath and low open forest/open woodland.

Red-crowned Toadlet *Pseudophryne australis*

The only species recorded which is restricted to the Hawkesbury Sandstone. Within this range, however, it occurs widely in drier habitats - being recorded from closed heathland, low open forest/open woodland and open forest with a dry understorey. Also recorded from open forest with moist understorey.

Common Eastern Froglet *Ranidella signifera*

Apart from closed forest, this species was observed in all the plant communities studied - closed heathland, sedgeland, low open forest/open woodland, open forest with wet or dry understoreys. It seemed to prefer moister habitats, being most numerous in open forest with a wet understorey, along the larger creeks, and in the sand-mined area near Mooney Mooney Creek.

Gray's Toadlet *Uperoleia marmorata*

Collected only from the sand-mined area near Mooney Mooney Creek.

Lesueur's Velvet Gecko *Oedura lesueurii*

Found only under loose rock on rocky outcrops.

Southern Leaf-tailed Gecko *Phyllurus platurus*

Collected in closed forest and open forest with a moist understorey, so may prefer moister habitats.

Burton's Snake Lizard *Lialis burtonis*

Collected in low open forest/open woodland.

Common Scaly-foot *Pygopus lepidopodus*

Observed several times in the drier habitat of low open forest/ open woodland.

Bearded Dragon *Amphibolurus barbatus*

Recorded once in low open forest/open woodland.

Mountain Dragon *A. diemensis*

Widely but sparsely distributed through the study area, recorded from open forest with dry understorey and low open forest/ open woodland.

Eastern Water Dragon *Physignathus lesueurii*

This species was associated with most of the larger creeks.

Bouton's Snake-eyed Skink *Cryptoblepharus boutonii*

One specimen collected, from pit-trap in low open forest/ open woodland

Copper-tailed Skink *Ctenotus taeniolatus*

A common skink which seemed to prefer drier habitats, having been recorded from rocky outcrops, low open forest/open woodland, open forest with a dry understorey, and heathland. Also collected in sedgeland.

Cunningham's Skink *Egernia cunninghami*

Frequently found under loose rocks on rocky outcrops.

White's Skink *E. whitii*

Common under loose rocks on rocky outcrops. Also collected from sedgeland.

Fence Skink *Lampropholis delicata*

Perhaps the commonest and most widespread skink in the study area, having been collected from closed heath, sedgeland, low open forest/open woodland and open forest with a moist understorey. Not recorded from closed forest.

Weasel Skink *L. mustelina*

Apparently preferred moist habitats, being collected in closed forest and open forest with a moist understorey.

Red-throated Skink *Leiolopisma platynota*

This species seemed to prefer the drier country of low open forest/open woodland.

Three-toed Skink *Saiphos equalis*

This species preferred damp habitats, being found in closed forest and open forest with a moist understorey.

Eastern Water Skink *Sphenomorphus quoyi*

A common species along most creeks.

Barred-sided Skink *S. tenuis*

Most commonly found in closed forest, although once observed in open forest with a dry understorey.

Pink-tongued Lizard *Tiliqua gerrardi*

One specimen trapped in closed forest.

Blue-tongued Lizard *T. scincoides*

Occasionally observed in drier habitat, notably open forest with dry understorey and low open forest/open woodland.

Diamond Python *Morelia spilotes*

Occasionally observed near Camp Kariong in low open forest/open woodland (K. Paull, pers. comm.).

Common Tree Snake *Dendrolaphis punctulatus*

Occasionally observed near Camp Kariong, particularly in vegetation bordering Rat Gully (K. Paull, pers. comm.).

<u>Common Death Adder *Acanthophis antarcticus*</u>

Collected near Camp Kariong in low open forest/open woodland (K. Paull, pers. comm.).

<u>Yellow-faced Whip Snake *Demansia psammophis*</u>

Observed in closed heathland and low open forest/open woodland.

<u>Red-naped Snake *Furina diadema*</u>

Observed once under loose rock on a rocky outcrop.

<u>Eastern Tiger Snake *Notechis scutatus*</u>

Collected near Camp Kariong in low open forest/open woodland (K. Paull, pers. comm.).

<u>Red-bellied Black Snake *Pseudechis porphyriacus*</u>

Occasionally seen in low open forest/open woodland.

<u>Eastern Brown Snake *Pseudonaja textilis*</u>

Seen twice in creek beds.

APPENDIX 7: Fish survey and hydrological stations: map references

The map references below refer to the Central Mapping Authority of New South Wales maps:

GUNDERMAN: 9131-111-S First Edition 1:25000 series N.S.W. (Gun).
GOSFORD: 9131-11-S First Edition 1:25000 series N.S.W. (Gos).

Station No.	Hydrological	Seine nets	Gill nets
1	Gun: 35539630	Gun: 35679627	Gun: 35539630
2	Gun: 36559773	Gun: 35649636	Gun: 36559773
3	Gun: 37009756	Gun: 36939759	Gun: 37080773
4	Gun: 37209798	Gos: 37989790	Gos: 37469810
5	Gos: 38519804	Gun: 35659650	Gun: 37169823
6	Gun: 37189842	Gun: 36349767	Gos: 37559923
7	Gos: 37559923	Gun: 35539654	Gun: 36059690
8	Gos: 37839976		
9	Gun: 37159854		
10	Gos: 37469810		

APPENDIX 8: Fish survey: detailed results

A. SEINE NETS

Species / Station	Sept 1978 S1	S2	S3	S4	S5	S6	S7	Nov 1978 S1	S2	S3	S4	S5	S6	S7
Anguilla reinhardti														
Arenogobius bifrenatus							+					17		22
A. frenatus												12		
Centropogon australis														4
Chrysophrus auratus														3
Engraulis australis												12		
Favonigobius exquisitus							+					6		
F. tamarensis							+					3		1
Gerres ovatus												9		26
Hemirhamphus ardelio	1			8	34	21	90	1				28		11
Johni antarctica														
Liza argentea								1^{J}						
Mugil cephalus				18^{J}			9	1^{J}						77^{J}
Mylio australis												2		8^{0}
Myxus elongatus								1^{J}						27^{0}
Notesthes robusta														
Percalates colonorum														
Platycephalus fuscus							4							
Pomatomus saltator														
Redigobius macrostoma												2		
Rhabdosargus sarba														6^{0}
Sillago ciliata						1^{0}						1		
S. maculata						1^{0}								
Velambassis jacksonensis								1				8		

B. GILL NETS

Species / Station	Sept 1978 G1	G2	G3	G4	G5	G6	G7	Nov 1978 G1	G2	G3	G4	G5	G6	G7
Anguilla reinhardti							1							
Arenogobius bifrenatus														
A. frenatus														
Centropogon australis														
Chrysophrus auratus														
Engraulis australis														
Favonigobius exquisitus														
F. tamarensis														
Gerres ovatus												2	1	8*
Hemirhamphus ardelio														
Johni antarctica							1				1*			1*
Liza argentea	6	31*		4		5*	14						2	
Mugil cephalus		29*		15		1*	7				4*		6	27*
Mylio australis	2													
Myxus elongatus						1*								
Notesthes robusta							3					1		2*
Percalates colonorum	1						3							
Platycephalus fuscus	1						1							1*
Pomatomus saltator														1*
Redigobius macrostoma														
Rhabdosargus sarba														
Sillago ciliata														
S. maculata														
Velambassis jacksonensis														

J - Juvenile fishes 0 year class   0 - Immature fishes 1+ year class   * - Net set overnight (10hr)