The biota of the Hawkesbury-Nepean catchment: reconstruction and restoration

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ABSTRACT

Despite 200 years of European settlement, the Hawkesbury-Nepean catchment sustains a rich and diverse fauna. This is a consequence of extensive sandstone environments largely unsuited for development that escaped the extensive habitat modifications affecting the fauna of the grassy woodlands on the Cumberland Plain and Southern Tablelands. The most significant impacts followed the clearing and fragmentation of the vegetation for agriculture. Changed fire regimes, the naturalization of exotic plants and animals, and disease were also factors in the decline of native birds and mammals. Data on frogs and reptiles are limited, but some reptiles have declined in abundance in association with the loss of habitats. Not all native species have been adversely affected by European settlement and a number of birds have increased in abundance and extended their range within the catchment.

Agricultural clearing and urban development have also affected aquatic ecosystems. The pre-European environment was apparently characterised by creek and river systems subjected to periodic floods, but with clear water, low nutrient levels, and clean sandy or rocky substrates. Increased nutrient levels, turbidity and siltation associated with urban and rural effluents, land clearing, foreshore erosion and river bed mining has reduced the extent of seagrass communities in the lower Hawkesbury and changed the substrate of rivers and the estuary. Mangrove communities have expanded. Other impacts on aquatic environments include the removal of riparian vegetation and the draining of wetlands, changes to flow regimes, dredging of channels, pollution of water from domestic, industrial and agricultural sources, changes in salinity, eutrophication of wetlands and the over-exploitation of the aquatic fauna. In freshwater creeks and rivers the native fauna has declined in abundance, while introduced species have spread throughout the catchment. In estuarine and marine environments, the fauna associated with clear water, low siltation rates, and seagrass beds has declined and species that were formerly abundant are now scarce.

The native terrestrial and aquatic fauna in the catchment will continue to decline with urban expansion and better management of human activities within the catchment is urgently required. Further clearing within the catchment is unwise and existing vegetation remnants (including freshwater wetlands) should be protected from development. This is particularly important on the Cumberland Plain and Southern Tablelands where a distinctive fauna is associated with vegetation remnants and the reserve system is inadequate. Similarly provision needs to be made for minimum freshwater flows into the Hawkesbury-Nepean estuary. Nutrient removal from sewage, control of stormwater runoff, and better management of agricultural chemicals, fertilizers and mining within the catchment is necessary to restore water quality. Foreshores should be revegetated. Most importantly, urban expansion and population growth within the catchment should be restricted.

INTRODUCTION

Few continents have been as adversely affected by European settlement as Australia (Adamson and Fox 1982; Recher and Lim 1990). The clearing and fragmentation of native vegetation, over-grazing by domestic stock and feral herbivores, the introduction of the rabbit *Oryctolagus cuniculus*, European fox *Vulpes vulpes* and domestic cat *Felis catus*, and poor management of domestic, agricultural and industrial chemicals and wastes have degraded land and water quality over most of the continent south of the Tropic of Capricorn (Recher, in press). Similar problems are developing in northern Australia and the spread of exotic weeds (e.g., *Mimosa pigra*) and the Cane Toad *Bufo marinus* pose a significant threat to the integrity of the wet tropics. In the context of continental degradation, and despite its proximity to the city of Sydney, the catchment of the Hawkesbury-Nepean appears to have fared better than most. Although affected in various ways by human activities, more than 70 per cent of the catchment is dominated by native vegetation and over half is Crown Land managed for water and nature conservation (Conybeare 1976).

As illustrated by the number of terrestrial vertebrate species, the catchment has an abundant and diverse fauna. Twenty-two species of frogs, one turtle, 42 lizards, 17 snakes, two monotremes, 30 marsupials, 21 bats, six native rodents, the dingo *Canis familiaris dingo*, and over 450 species of birds


Valley of the Grose

have been recorded from the Hawkesbury-Nepean catchment (information in Cogger 1992; Hoskin *et al.* 1991; Strahan 1983). In addition a number of marine mammals visit the Hawkesbury River estuary and nearby ocean waters. The leatherback turtle *Demochelys coricea* is frequently seen in Broken Bay during the summer and the yellow-bellied sea snake *Pelamis platurus* occurs along the ocean shore (Recher, pers. obs.). These terrestrial and marine species are complemented by freshwater (18 species) (Allen 1989) and marine and estuarine fish (>500 species). Even this richness is small in comparison to the numbers of plant and invertebrate species. Majer *et al.* (in press) identified more than 1 000 species of invertebrates from the canopy foliage of two species of eucalypts at one site on the Cumberland Plain. Over 90 per cent of these were undescribed and it would be difficult to even guess at the total terrestrial and aquatic invertebrate species richness within the catchment other than to say, it would be considerable. The richness of the fauna is mirrored in the richness of the vegetation. Beadle *et al.* (1982) list over 2 000 species of native plants within the Greater Sydney Region and the Blue Mountains.

Even though the catchment retains a rich flora and fauna, there have been significant changes as a result of European settlement. At least two of the marsupials and one rodent are now extinct, and more than 15 species of exotic mammals, birds and fish are established within the catchment. The exotic fauna is complemented by more than 450 species of exotic plants that have been naturalized (Beadle *et al.* 1982).

Agriculture, industry and urban expansion have had major effects on the Hawkesbury-Nepean and its tributaries. The impact of European settlement has been greatest on the more fertile soils and gentler topography of the Cumberland Plain, the Southern Tablelands and on riverine flood plains, while the more rugged and nutrient poor sandstones and mountains remain largely undeveloped. There are no comparable aquatic environments to the largely uncleared sandstone vegetation of the catchment that retain a pre-European, or pristine, character. Aboriginal settlement of the catchment may have commenced over 30 000 years BP (Stockton and Holland 1974; Nanson *et al.* 1987; McDonald 1992) and their activities, particularly the use of fire, had largely determined the type and structure of vegetation within the catchment by the time of European colonization in 1788 (Head 1989). McDonald (1992) points to a "myriad of occupation sites" suggesting that the Sydney Region "was most intensively occupied in the last 3 000 years".

In this paper we interpret the impact of human settlement on the biota of the Hawkesbury-Nepean catchment. Our emphasis is on the fauna, but we present our interpretation of changes to the vegetation where this is necessary to explain changes to the fauna. The effects of European settlement since 1788 are presented in the context of Aboriginal modifications to the landscape and its flora and fauna (see Burton 1992; McDonald 1992; Rosen 1992a). Within the limits of an incomplete prehistorical record, we reconstruct those aquatic and terrestrial ecosystems that have been lost or changed by European activities and suggest reasons why these changes have occurred. The existing fauna is described, although again limited by incomplete information. Predictions of future changes and losses are made in the context of catchment management and the growth of Sydney. Recommendations to minimize the worst effects of human activities are presented.

THE LANDSCAPE: PREHISTORY

The fauna of a region is determined by the physical environment (topography, soils, climate), the vegetation (itself a reflection of the physical environment), and historical events. These effects occur on time scales ranging from geological processes (millions of years) through patterns of climate change (hundreds to thousands of years) to more recent or current physical events such as weather, tides and fire (days to centuries). Imposed on these largely physical events are biological processes such as evolution and extinction (decades to millions of years), immigration and colonization (decades to thousands of years), reproduction (days to years) and migration (days to months). Not all of these need to be considered in the same detail to understand the historical patterns of change in the fauna of the Hawkesbury-Nepean catchment, but all need to be understood as processes affecting the survival of species. Human activities have no effect on tectonic events, but they do affect *all* other processes, with the effects measured on time scales

Plate 1 (opposite page). Entitled "Grose Valley, NSW, 1833–1887". Held in the Mitchell Library (ML/SPF). This photo shows the tall trees densely lining the river banks and the striking sandstone escarpment characteristic of much of the Hawkesbury-Nepean catchment.

Plate 2. Entitled "Wingecarribee River, *c.* 1885. Parsonage in distance — near Berrima". Held in the Mitchell Library (ML/SPF). This photo illustrates wet sclerophyll forest along the shore and extensive clearing for pasture in the middle distance.

Plate 3. Entitled "Nepean River, NSW *c.* 1881". Held in the Mitchell Library (ML/SPF). This photo illustrates the dense foreshore forest which would have characterized the entire Hawkesbury-Nepean system prior to rapid clearing by European settlers.

from days to millennia. The capacity of humans to initiate changes that are effectively permanent in the framework of governments (days to years) and the working lives of individuals (decades) needs to be recognized when plans are developed for the management of biophysical systems as complex as a river catchment.

Geology

The Hawkesbury-Nepean River catchment takes in an area of 2.2 million hectares that encloses the Sydney Basin to the north and west (Hall 1927; Conybeare 1976; Herbert 1983). The catchment has an elevational range from sea level to 1 362 m (Mt Bindo) (see Figs 1–3 for the location of places named in the text). Geologically the catchment is dominated by Permian sandstones, shales and coal measures overlain by Triassic sediments (Healy 1972). There are minor igneous intrusions through the sediments (Nashar 1967). The oldest of the Triassic sediments is the Narrabeen Group comprised of conglomerates, lithic and quartz sandstone, and shales that outcrop below the more extensive and dominating Hawkesbury Sandstones. Uplifting during the late Tertiary (8–3 million year BP), perhaps with later tectonic activity (Roy and Thom 1991) formed a plateau over 1 000 m in elevation to the west of Sydney, the Blue Mountains, and the lower Hornsby and Woronora plateaux to the north and south (Healy 1972). The centrally sited Cumberland Plain, underlain by Wianamatta shales, remained low and with little topographic diversity. Features such as the Lapstone Monocline and the courses of rivers through the escarpment are estimated to have originated 15–8 million years BP and may be re-activated pre-Jurassic features (Pickett and Bishop 1992).

The uplifted sediments have been deeply cut by the Hawkesbury-Nepean River and its tributaries. The result is a topographically diverse landscape with exposed sandstones, shales, granites and basalts (Hall 1927; Branaghan and Packham 1967). Extensive Quaternary and Tertiary alluvial deposits occur on the Cumberland Plain, south of Goulburn and around Putty (Conybeare 1976). While climates have been wetter and drier, and warmer and colder, throughout its long history of uplifting and erosion, the catchment has never been glaciated. The absence of glaciation, a history of fires, and the topographic and edaphic diversity of the catchment have contributed to the evolution of a diverse

Plate 4. Entitled "South Creek *c.* 1910". Held in the Mitchell Library (ML/SPF). This photo illustrates a clean South Creek, although there has been extensive clearing along the river bank with what appears to be introduced willow trees in the background on the shoreline.

and species rich vegetation. The more than 2 000 species of native plants make it one of the most diverse botanical regions in Australia (Beadle *et al.* 1982). The diversity of the landscape and the richness of the flora is reflected in the richness of the fauna.

VEGETATION OF THE CATCHMENT

Prior to European settlement more than 95 per cent of the catchment was wooded. Heath (shrub communities) occurred along ridges on shallow or waterlogged soils and extended into *Eucalyptus* woodlands as a shrub or understorey vegetation layer. Small freshwater bogs, swamps and hanging swamps occurred wherever drainage was impeded or there was freshwater seepage. There appears to have been extensive wet areas, reed beds and lagoons or billabongs along the Upper Hawkesbury and the Nepean and the lower reaches of their major tributaries. These occurred in association with paperbarks *Melaleuca* and she-oaks *Casuarina*. A variety of freshwater plants occurred in creeks, rivers, bogs and lagoons. There were extensive beds of ribbon weed *Vallisneria gigantea* in the Nepean and Upper Hawkesbury Rivers and their tributaries (see Burton 1992 and references therein for a more detailed description of the vegetation in the catchment and its historical changes).

Along the Hawkesbury and in Brisbane Water and Pittwater, forests dominated by grey and river mangroves *Avicennia marina* and *Aegiceras corniculatum* occupied shallow intertidal sand and mudflats with fringing subtidal seagrass beds dominated by *Zostera capricorni* in the shallower water and *Posidonia australis* in deeper, more marine water. In places the mangroves were fringed by salt marshes that graded into forests of paperbarks and she-oaks, backed by eucalypts. The rocky foreshores of the lower Hawkesbury, Broken Bay, Cowan Water, Brisbane Water and Pittwater supported algal communities that were probably similar to those currently there and which have been documented by Adam *et al.* (1988), Hutchings and Recher (1977), Moss (1983), and West *et al.* (1985).

Although the vegetation of the catchment is diverse with plant species and distinctive communities reflecting changes in aspect, elevation, topography and edaphic conditions, a coarser division is appropriate for describing the vertebrate fauna. Invertebrates respond to small scale changes in the vegetation and some may be restricted to individual species of plants, but the information available for invertebrates does not allow descriptions at this scale of resolution. Therefore, the history of the fauna of the Hawkesbury-Nepean is described in broad vegetation units based primarily on topographical, edaphic and geological features (Table 1).

Table 1. Principal vegetation formations.*

TERRESTRIAL

- *Low Shrub Lands* (heaths) on broad sandstone plateaux;
- *Tall Shrub Lands* along the coast;
- *Low Open Woodlands and Forests* on sandstone ridges and slopes, usually with a heath understorey;
- *Tall Open Woodlands and Forests* with a grassy understorey on richer soils on the Cumberland Plain and the Southern Tablelands;
- *Tall Open Forests* with a shrub or rainforest understorey on wetter slopes and along gullies and creeks, usually in association with nutrient-rich soils derived from shale or basalt outcrops.

AQUATIC

Freshwater:

- High elevation *bogs, swamps, hanging swamps and streams;*
- Low elevation *springs, swamps, lagoons, marshes, streams and rivers;*

Estuarine:

- *Phytoplankton;*
- *Algal communities on rocky foreshores;*
- *Seagrass beds;*
- *Mangrove forests;*
- *Saltmarsh.*

*Terminology follows Specht *et al.* (1974).

HISTORIC CHANGES TO THE HAWKESBURY-NEPEAN CATCHMENT

There is little information about the biota of the Hawkesbury-Nepean catchment prior to human settlement. The Triassic sediments and more recent alluvial deposits that dominate the catchment contain few fossils. However, it can be assumed that Aboriginal occupation was accompanied by increased fire frequencies and that their impact on the biota of the catchment can not be described as minimal *sensu* McDonald (1992) (see for example Jones 1969; Hughes and Sullivan 1981, 1986 and references therein).

Effects of Aboriginal Occupation

Burton (1992) suggests that the regular use of fire by Aboriginals led to a grassy understorey on shale country and to a shrubby understorey on sandstone. This was probably the result of frequent low-intensity burns set for a variety of reasons including creating a "green pick" to attract game, driving game when hunting and encouraging the growth of food plants (Jones 1969). Open woodlands may also have been maintained by other means, as illustrated by the report of Governor

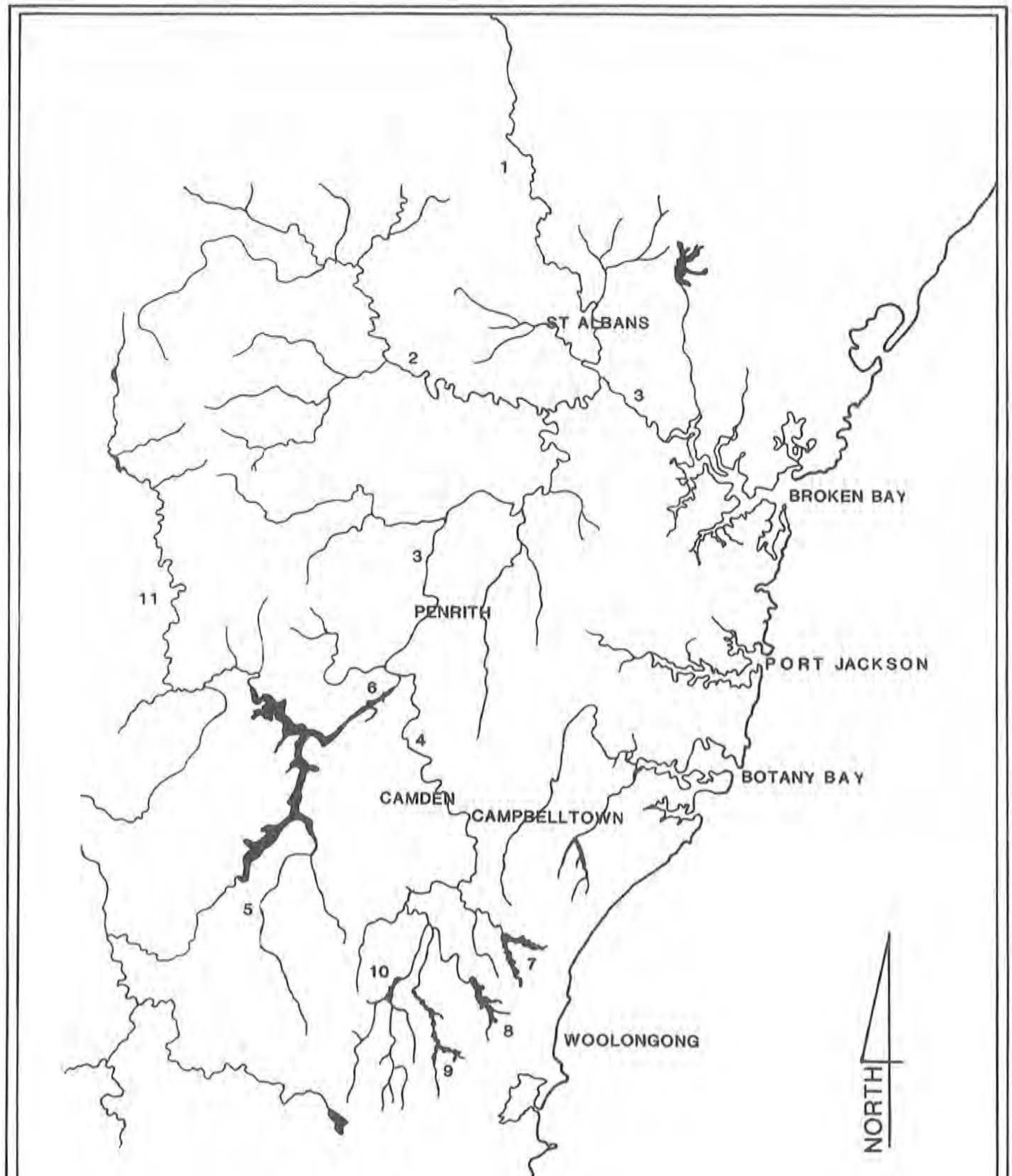

Fig. 1. Maps 1–3: The Hawkesbury-Nepean catchment area with sites mentioned in the text located. Map 1. 1. McDonald River, 2. Colo River, 3. Hawkesbury River, 4. Nepean River, 5. Natti River, 6. Warragamba Dam, 7. Cataract Dam, 8. Cordeaux Dam, 9. Avon Dam, 10. Nepean River, 11. Cox's River.

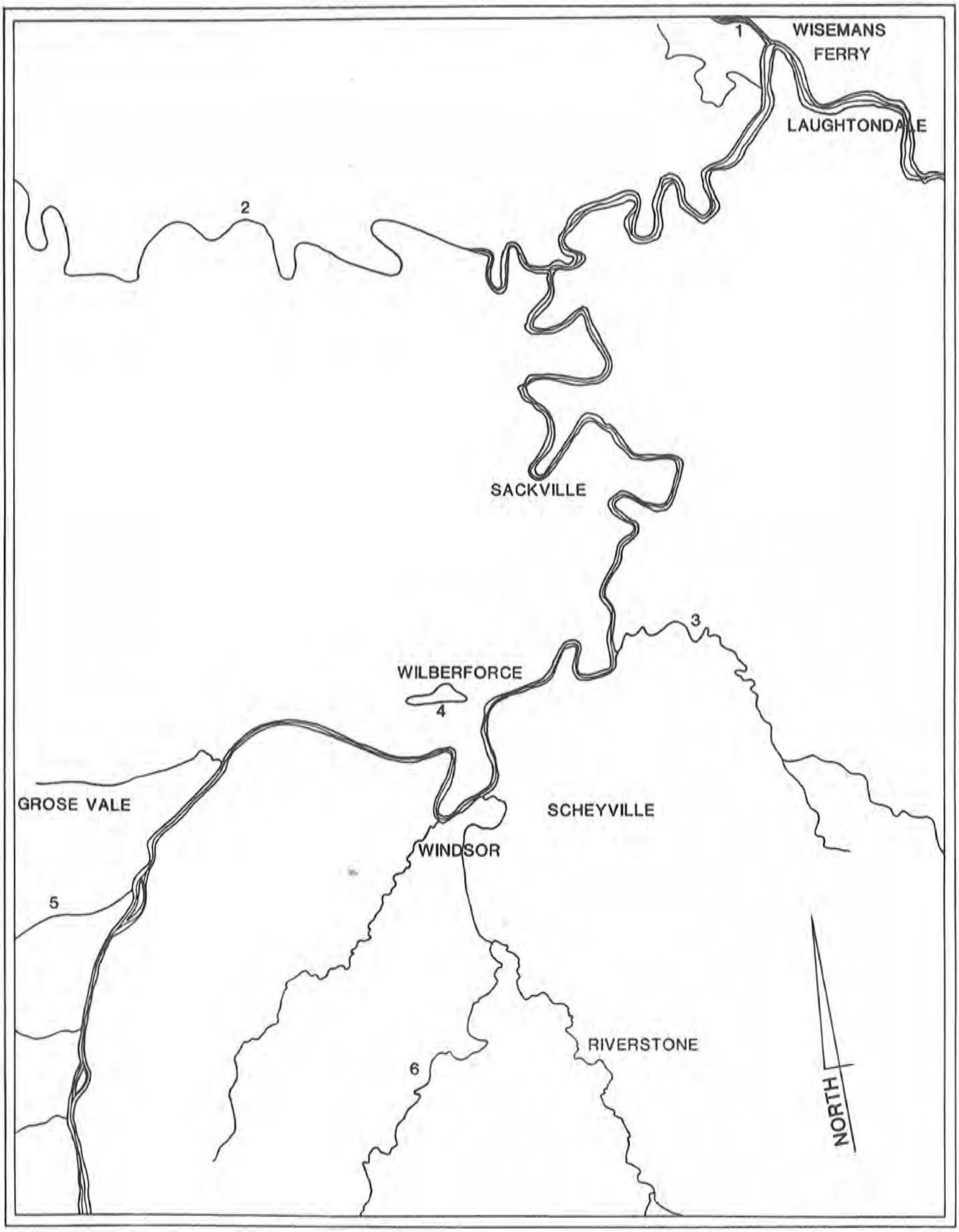

Fig. 2. Map 2. 1. McDonald River, 2. Colo River, 3. Cattai Creek, 4. Bushells Lagoon, 5. Grose River, 6. South Creek.

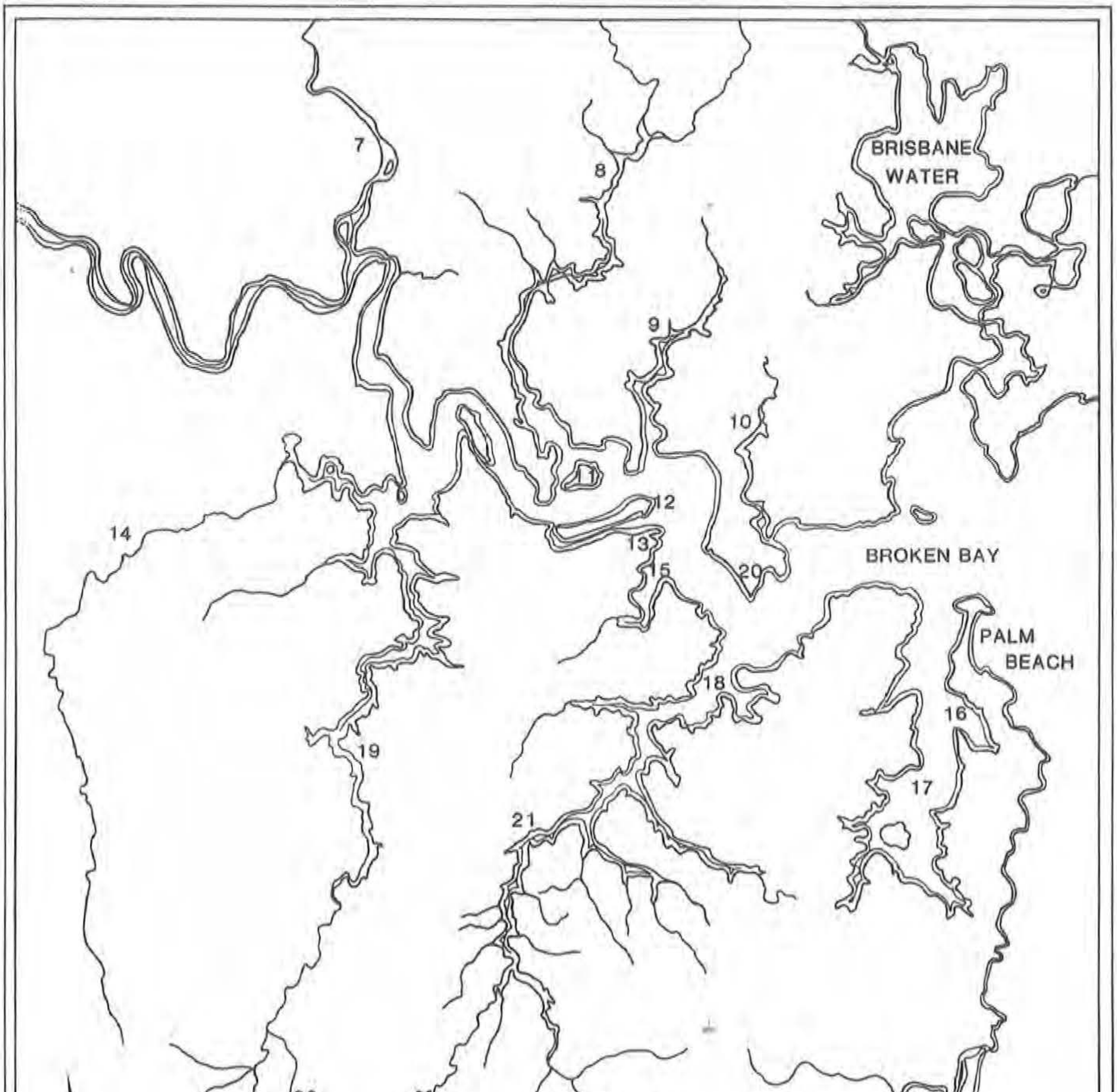

Fig. 3. Map 3. 7. Mangrove Creek, 8. Mooney Mooney Creek, 9. Mullet Creek, 10. Patonga Creek, 11. Dangar Island, 12. Long Island, 13. Brooklyn, 14. Maramara Creek, 15. Porto Bay, 16. Careel Bay, 17. Pittwater, 18. Cowan Water, 19. Berowa Waters, 20. Juno Point, 21. Cowan Creek, 22. Fishpond Creek.

Phillip to Lord Sydney that Aboriginals often set fires at the base of large trees which they left burning causing the trees to fall (HRNSWa). Such fires were used to smoke out possums from tree hollows (Kohen and Lampert 1987).

While it is probable that open woodlands with a grassy understorey on the Cumberland Plain, the Hornsby Plateaux, the Southern Tablelands and on richer soils throughout the sandstone country were the result of Aboriginal burning practices, it is harder to reconcile Aboriginal occupation with the shrubby understorey on Hawkesbury Sandstone. Sandstone vegetation is not productive and presently sustains only sparse populations of native wildlife (Recher, pers. obs.). This is a consequence of the nutrient poor and shallow sandstone soils and the rapid drainage and evaporation of water. It is therefore unreasonable to expect that Aboriginals would have occupied dry sandstone habitats on a permanent basis or in large numbers. Aboriginal occupation was probably concentrated along the major rivers and estuaries and on the best soils where food was relatively abundant.

It is unlikely that sandstone vegetation was burnt by Aboriginals on a regular basis other than to clear vegetation along movement corridors or to create openings for ceremonies. No doubt there were accidental burns when fires set in grassy woodlands escaped into sandstone habitats and, if burnt frequently (i.e., one or two year intervals), a grassy understorey with few shrubs can be established on Hawkesbury Sandstone (Recher, pers. obs.). The impression in the early accounts of some explorers (reported in Benson and Howell 1990; Jervis 1936; White 1971) of a different and more open vegetation on the sandstone may be a consequence of European travellers choosing the easiest (most direct and most open) routes to follow. These would have coincided with the tracks followed by Aboriginals that were fire maintained. Other explorers including Evans and Hunter however complained of dense undergrowth in sandstone country (Evans in Mackaness 1978; Hunter 1973, p. 138).

Where Aboriginals occupied sandstone regions, remains from their middens indicates that they hunted in the more productive grassy woodlands and tall open-forests (wet sclerophyll) on the most fertile soils. Information on the kinds of animals taken by Aboriginals along the Hawkesbury-Nepean are available from two sites. Attenbrow (1987) analysed Aboriginal occupation of the Upper Mangrove Creek catchment and Wood (1989) reported on a site on the Barrenjoey Peninsula, Pittwater. The majority of mammals identified from remains found in these deposits were species typical of grassy woodlands (Tables 2, 3). Among the animals identified were eastern grey kangaroo *Macropus giganteus*, red-necked wallaby *M. rufogriseus*, and common wombat *Vombatus ursinus*.

Table 2. Some marsupials of grassy woodlands in eastern Australia.

Species	Status
Eastern Quoll *Dasyurus viverrinus*	Extinct on mainland*
Common Dunnart *Sminthopsis murina*	Common
Thylacine *Thylacinus cyanocephalus*	Extinct
Long-nosed Bandicoot *Perameles nasuta*	Declining**
Southern Brown Bandicoot *Isoodon obesulus*	Endangered**
Koala *Phascolarctos cinereus*	Endangered**
Common Wombat *Vombatus ursinus*	Common**
Sugar Glider *Petaurus breviceps*	Common**
Brush-tailed Possum *Trichosurus vulpecula*	Common**
Feathertail Glider *Acrobates pygmaeus*	Common**
Tasmanian Bettong *Bettongia gaimardi*	Extinct on mainland*
Rufous Bettong *Aepyprymnus refescens*	Endangered*
Red-necked Wallaby *Macropus rufogriseus*	Common**
Eastern Grey Kangaroo *M. giganteus*	Common**

*Known to have occurred on the Cumberland Plain.
**Extant in the Hawkesbury-Nepean Catchment.

The presence of koala *Phascolarctos cinereus* and yellow-bellied glider *Petaurus australis* in the deposits is indicative of fertile soils, while the remains of greater gliders *Petauroides volans* indicates that hunting also occurred in tall open-forests. Benson's (1981) description of the vegetation of the Upper Mangrove Creek catchment is consistent with this interpretation. According to Benson, the alluvial flats of Mangrove Creek to its junction with the Hawkesbury River supported a tall open-forest of Dean's blue gum *E. deanei* and rough-barked apple *Angophora floribunda*. On drier sites with exposed Narrabeen shales there is an open-forest of forest red gum *E. tereticornis* and thin-leaved stringybark *E. eugenoides*. Benson (1981) reported that both associations had an open understorey and shrub layer with a grassy ground cover that was maintained by fire and grazing. Although the tree canopy would have been higher before logging and clearing by Europeans, the structure of both associations would have been similar during Aboriginal occupation. Both associations support a rich and diverse fauna.

The creation and maintenance of open, grassy woodlands by Aboriginals encouraged a particular assemblage of animals. Early colonial accounts of the fauna of the Sydney Region are restricted to descriptions of the

Table 3. Mammals recovered from archaeological sites.

Species	Location: Upper Mangrove Creek[1]	Location: Barrenjoey Peninsula[2]
MACROPODIDAE		
Macropus giganteus	×	×
M. robustus	×	×
M. parma		×
M. rufogriseus	×	×
Wallabia bicolor	×	×
Petrogale penicillata	×	×
POTOROIDAE		
Thylogale thetis		×
T. sp.	×	×
Bettongia gaimardi	×	
B. spp.		×
Potorous tridactylus		×
P. sp.	×	
PHALANGERIDAE		
Trichosurus vulpecula	×	×
T. sp.		×
PETAURIDAE		
Pseudocheirus peregrinus	×	×
P. spp.		×
Petauroides volans	×	×
Petaurus breviceps	×	×
P. australis	×	
BURRYAMIDAE		
Acrobates pygmaeus	×	
Cercartetus nanus	×	
PERAMELIDAE		
Isoodon obesulus		×
I. sp.	×	×
Perameles nasuta	×	
VOMBATIDAE		
Vombatus ursinus	×	
V. hirsutus	×	
PHASCOLARCTIDAE		
Phascolarctos cinereus	×	
DASYURIDAE		
Dasyurus maculatus	×	
D. sp.	×	
Antechinus swainsonii	×	
A. stuartii	×	×
A. cf. *flavipes*	×	
ORNITHORHYNCHIDAE		
Ornithorhynchus anatinus	×	
TACHYGLOSSIDAE		
Tachyglossus aculeatus	×	×
CANIDAE		
Canis familiaris	×	
C. f. dingo		×
MURIDAE		
Rattus fuscipes	×	×
R. lutreolus	×	
PSEUDOMYIDAE		
Pseudomys oralis	×	
P. novaehollandiae	×	

[1]Attenbrow (1987). [2]Wood (1989).

larger and preferred edible fauna (e.g., eastern grey kangaroo , emu *Dromaius novaehollandiae*), but enough was described to link the mammal fauna of the Cumberland Plain and Southern Tablelands with that of the better known woodland faunas of the Northern Tablelands (Jarman and Johnson 1977) and the Bega Valley (Lunney and Leary 1988). These faunas were rich in mammal species, some of which occurred on the Cumberland Plain, but are now extinct (Table 2). Others, such as the koala and brush-tailed possum *Trichosurus vulpecula*, persist in the Hawkesbury-Nepean catchment. Open, grassy woodlands also sustained a unique avifauna, but early accounts from the Sydney region only refer to the larger and more conspicuous species. Reporting on the avifauna of the County of Cumberland (Greater Sydney), Hindwood and McGill (1958) considered the emu to be abundant and important in the lives of Aboriginals, but Attenbrow (pers. comm.) points out that emu remains are uncommon in archaeological faunal assemblages from coastal regions. Australian bustards *Ardeotis australis* may have occurred in small numbers on the Cumberland Plain (HRNSWb), but were apparently common on the Southern Tablelands (Atkinson 1980). Waterfowl, quail, parrots and other game birds were described as abundant in early accounts.

Apart from the communities along waterways where numbers were sustained by the productivity of the aquatic environment, Aboriginal populations in the catchment were not large (McDonald 1992). Governor Phillip estimated the number of Aboriginals in the coastal area from Botany Bay to Broken Bay at 1 500 people (in McDonald 1992). Kohen (1986 in McDonald 1992) estimated that 500 to 1 000 people occupied the western Cumberland Plain at the time of European settlement. The total population in the Sydney region may only have been 2 000–3 000 people (McDonald 1992). Moreover, they lacked the technology, other than the firestick, to intensively exploit their environment. However, Lunney (pers. comm.) suggests that the concentration of Aboriginals along waterways may have had a major effect on the vertebrate fauna within a 20–30 km distance. Lunney reasons that this is a comfortable hunting distance and that marsupials, large birds and reptiles within this zone would have been intensively hunted. For example, he suggests that the reason koalas were not recorded during the first 10 years of European settlement was that their numbers around Port Jackson and along the Hawkesbury-Nepean River were low as a result of Aboriginal hunting. It was not until the Aboriginal population was reduced following contact with Europeans that koalas increased

in numbers. Attenbrow (pers. comm.) reports that koala remains are rarely found in archaeological sites. This would indicate either that koalas were not eaten or that, as suggested by Lunney, their numbers were low. Koalas would have been a particularly easy prey for Aboriginal hunters.

European Colonization

The pattern of European colonization of the Hawkesbury-Nepean catchment and the development of industry and agriculture are described by Rosen (1992a,b). Burton (1992) reviews the impact of these developments on the landscape. In this section the impact of European settlement on the fauna of the catchment is summarised for three periods, 1788–1888, 1889–1939, and 1939–1992. They are somewhat arbitrary, but represent the level of information available and the nature of the changes taking place in the landscape that affected fauna.

1788–1888

The first 100 years of the colony was a period of agricultural development accompanied by extensive clearing and fragmentation of the native vegetation. Agriculture was concentrated on the better quality shale and alluvial soils of the Cumberland Plain and Southern Tablelands that had supported open, grassy woodlands and tall, open-forests. The Sydney region remains one of the richest agricultural areas of the state; a reflection of the intensity of agriculture, an abundance of water and the proximity to the Sydney markets rather than the quality of the soils. By the 1870s the Southern Tablelands sustained a thriving dairy industry supplying Sydney by refrigerated railway vans (Jervis 1968).

The expansion of agriculture was preceded and accompanied by timber-getting. There were few controls over logging activities and no efforts were made to manage forests for a sustainable harvest. Early records indicate that timber was both cleared and harvested from the banks of creeks and rivers with little regard to bank stability, erosion or siltation. Often timber that was being cleared was pushed into water courses to remove it from farmland. The first concerns about the practices of clearing came from a ship's captain in 1795 who objected to trees being pushed into otherwise navigable waters (Collins 1798). Local supplies of Hawkesbury cedar *Toona australis* were diminished and as early as 1802 Governor King issued orders to control timber getting on the Hawkesbury (HRNSWc). Among other things the regulation was designed to stop the clearing of vegetation along river banks and protect navigable waters. However, by 1826 most of the alluvial land along the Hawkesbury-Nepean had been cleared and was being cultivated (Powell 1988). River banks were undermined and collapsed into the river (Atkinson 1826). Government proclamations appeared to have had little effect and logging in Warringah Shire during the 1850s was accompanied by extensive erosion affecting Cowan Creek (Wing 1991).

Logging occurred along all the shores and tributaries of the Hawkesbury-Nepean River; Broken Bay, Brisbane Water, Cowan Creek, Mangrove Creek, Berowra Waters, Marramarra Creek, the Nepean River, Cattai Creek, the Colo River, the Grose Valley and so on (Rosen 1992a). Little logging would have occurred in the open- and low open-forests (dry sclerophyll) and woodlands on Hawkesbury Sandstone that are generally of poor quality for timber production. It was the moist, tall open-forests on the rich alluvial soils along the major water courses and those on the shale soils of the Cumberland Plain and Hornsby Plateau and elsewhere that were the most sought after. Where these forests were not cleared for agriculture or residential development, logging persisted into the 20th Century along the Hawkesbury-Nepean, its tributaries and in the Blue Mountains.

Native wildlife was an important source of food and sport throughout the early days of the colony and early accounts describe hunting and eating ducks, magpies, hawks, crows, pigeons, emu, and kangaroo among other game (Atkins 1792; Hunter 1793, p.139). In addition, a variety of aquatic resources were exploited. In the 1830s mangroves were harvested along the Hawkesbury and from Brisbane Water and burnt for ash required for soap manufacture (Banks 1988). Shell was harvested from Aboriginal middens and burnt for lime (Pearson 1981). When these were depleted, live oysters were used (Powell 1988). In the 1860s taking oyster shell from the Georges River was prohibited (Roughley 1922) and the industry shifted to Botany Bay and Broken Bay.

Aboriginal stone engravings on rocks overlooking Broken Bay and the Pacific Ocean

Plate 5 (opposite page). Entitled "Perch fishing on the Grose January 1913". Held in Mitchell Library (ML/GPO 30353). This photo illustrates the long-recognized richness of the aquatic ecosystem of the Hawkesbury-Nepean, and the secluded recreational value near an already large city.

depict whales and a whaling station was established early in the 19th century at Mosman on Port Jackson. Whales were taken from both near shore (probably southern right *Eubalaena australis* and humpback *Megaptera novaeangliae* whales) and at sea. The numbers of whales processed declined from the 1850s onwards, although there was a brief revival in the 1890s (Australian Encyclopedia 1958; Dakin 1938). Southern right and humpback whales are listed as endangered in New South Wales (National Parks and Wildlife Service Act, 1974, Schedule 12), but since the 1980s have been sighted regularly along the coast in the Sydney region.

River and estuarine environments were also affected by silt from eroding agricultural lands, poor logging practices and de-stabilized foreshores. Quantities of trees and timber that were pushed or fell into the Hawkesbury-Nepean and its tributaries contributed to significant changes in river channels and shallows by the mid 1820s (Atkinson 1826). Descriptions in Rosen (1992a) suggest that these were probably local at first, but with time affected an increasingly large section of the Hawkesbury-Nepean. Water pollution was also a problem in the first century of the colony. By 1844 there were complaints about smells coming from the Hawkesbury and the disposal of dead dogs in the river (*Hawkesbury Courier and Agricultural Advertiser*, 1844 and 1845). From the commencement of settlement in the Hawkesbury-Nepean catchment domestic, agricultural and industrial wastes were routinely discharged into the nearest watercourse (Rosen 1992a). The early 1880s were dry years and water quality in the Nepean and Upper Hawkesbury declined (Royal Commission 1887). After the establishment of a water supply for Sydney, the Nepean almost ceased to flow. During the 19th Century, South Creek was badly polluted by wastes from the Riverstone Meat Works, tanneries and wool scouring operations. Efforts were made to remove wastes before discharging the water in the river, but these were ineffectual and largely cosmetic (*The Hawkesbury Chronicle and Farmers' Advocate* 21 June, 1884, and 6 September, 1884). Domestic wastes were discharged into open gutters. *The Hawkesbury Chronicle and Farmers' Advocate* (June 21, 1884) campaigned for a sewerage system before the Hawkesbury was converted into a "huge sewer".

The first century of the colony also saw the establishment of a variety of exotic plants and animals within the catchment of the Hawkesbury-Nepean. Cats accompanied the first ships to Port Jackson. By 1801 a herd of feral cattle numbering five or six hundred animals had crossed the Nepean and invaded the mountains (HRNSWd, King, 10th March 1801). Blaxland had established a rabbit warren on his property at Luddenham and by 1833 the animals were thriving (Harvard 1943). Probably these animals did not survive, but through the 19th century acclimization societies were active in the introduction of exotic species. Brown trout *Salmo trutta* were introduced via Tasmania and Victoria into the Wollondilly, Upper Nepean and Nattai Rivers in 1888 (Roughley 1966). The exotic fauna was complemented by a garden of exotic plant species, many of which naturalized. Willows *Salix* spp. were established along the Nepean by the 1830s and introduced pasture plants had largely replaced native grasses on the Cumberland Plain (Wood 1930; Elizabeth Macarthur).

The first 100 years of European settlement of the Hawkesbury-Nepean catchment concluded with major impoundments designed to provide Sydney with a reliable supply of water. In 1880 work commenced on a system of dams known as the Upper Nepean Scheme on the headwaters of the Nepean, Cataract, Cordeaux and Avon Rivers (Aird 1961). Ultimately the impoundment of the waters of the catchment had major ecological effects on the Hawkesbury-Nepean.

1889–1938

The pattern of environmental change and development of the catchment continued unabated from the latter part of the 19th century to the commencement of the second World War. By the 1880s dredging was necessary to permit shipping on the Upper Hawkesbury. The Macdonald River had shallowed and was closed to shipping by the 1870s, but flooding in 1889 and later added still more sand to the alluvial flats (Henry 1977). Settlement, the construction of roads and the railway, industrialization and mining carried the problems of pollution and siltation of waterways into the Blue Mountains (Rosen 1992a). Sand and mud deposits blocked channels and impeded navigation not only on the Macdonald, but on the Hawkesbury and Nepean Rivers and their major tributaries (Hall 1927).

Not all the changes in the Hawkesbury-Nepean River and its tributaries are necessarily of human origin (see Hall 1927). Erskine (1986) and Erskine and Melville (1983) argue that, at least for the Colo and McDonald Rivers, cyclical climatic changes affecting erosion rates and patterns of flooding override any human factors. There is also an argument that Aboriginal burning practices greatly

Plate 6. Entitled "The weir on the Nepean at Wallacia, June 1918". Held in the Mitchell Library (ML GPO 18159). Weirs on the Nepean deepened the river.

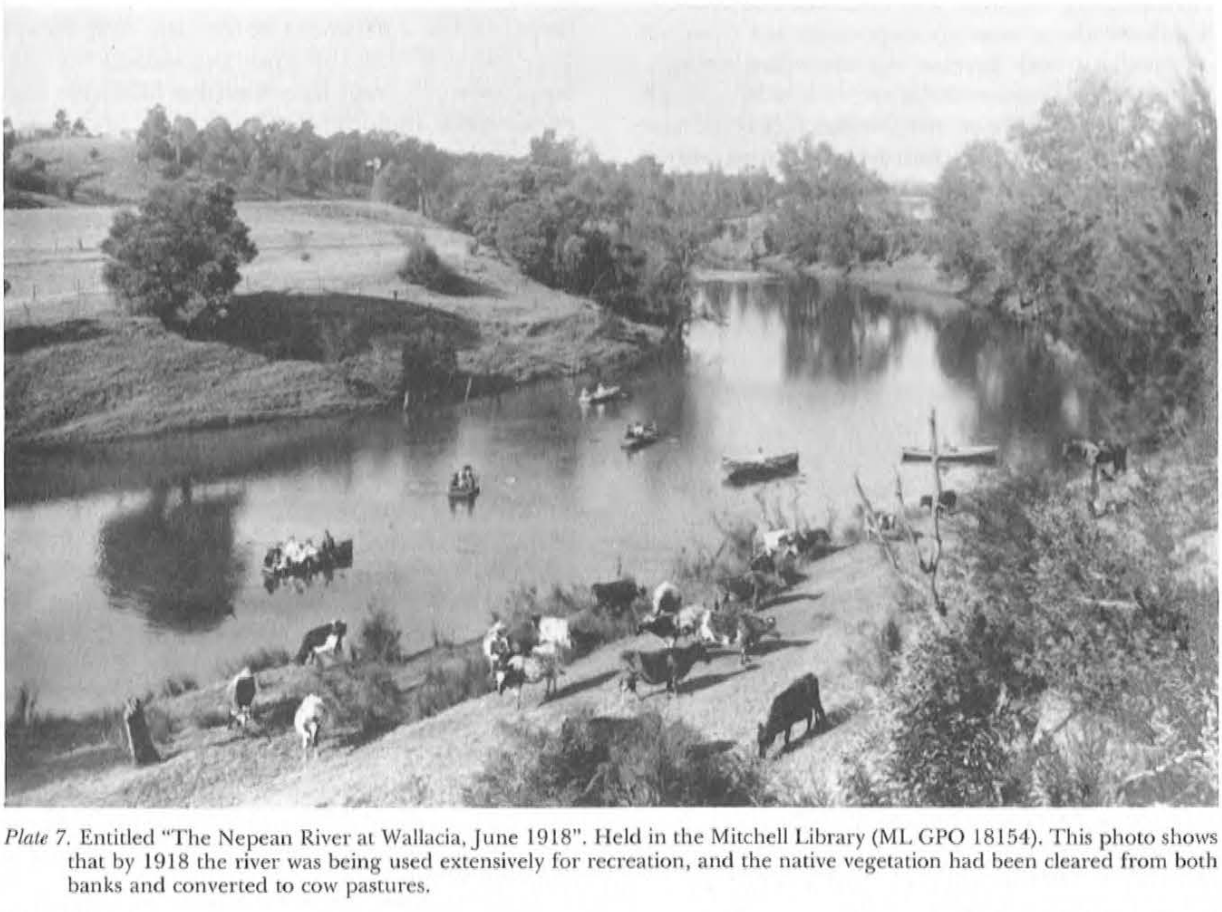

Plate 7. Entitled "The Nepean River at Wallacia, June 1918". Held in the Mitchell Library (ML GPO 18154). This photo shows that by 1918 the river was being used extensively for recreation, and the native vegetation had been cleared from both banks and converted to cow pastures.

increased erosion and deposition rates (Hughes and Sullivan 1981). Changes in the catchment following Aboriginal settlement may therefore have been as significant as many following European colonization.

The Cataract Dam was completed in 1907, the Cordeaux dam in 1926 and the Nepean Dam in 1935. The three dams when completed, controlled 76 per cent of the water of the Upper Nepean catchment. The remainder of the catchment was partially controlled by compensation weirs on the Nepean and Cataract Rivers to provide water for agriculture. Increasingly large amounts of water from the catchment were diverted for domestic and industrial use. Most of this water is discharged as waste outside the catchment.

Writing in the 1930s, Pidgeon (1937) considered the catchment's sandstone vegetation outside urban areas to be relatively undisturbed, although fires were a problem. Accounts of the 1930s describe an almost idyllic environment along the Nepean and Upper Hawkesbury with an abundance of native wildlife including platypus *Ornithorhynchus anatius*, waterfowl and fish. This is echoed in interviews with long-time Hawkesbury residents (see Rosen 1992b). Water in the Hawkesbury lagoons was clear and drinkable. Similarly there was an impression of "virgin" or undisturbed forests on the Castlereagh-Windsor Terrace (Maze 1943). Such impressions are not surprising. Little of the sandstone vegetation had been cleared and it is probable that by the 1930s many marginal agricultural areas had been abandoned and allowed to revegetate. As in the 1990s, the presence of a few abundant and conspicuous native species conceals the extinctions that took place in the past.

Accounts from the Sydney region at the turn of the century suggest that a disease affected many native mammals. Prior to about 1904 the eastern quoll *Dasyurus viverrinus* and spotted-tailed quoll *D. maculatus* were common donations to the Sydney zoo from people in the out-lying districts of Sydney who had trapped them in their chicken coops (Recher 1972). There were then a series of accounts of quolls appearing sick and dying. Shortly afterwards donations of these animals to the zoo ceased. Native cats survived in the suburbs of Roseville (until the 1930s) and Vaucluse (until 1964) (Recher 1972). Because native cats established dens in houses, the Vaucluse population was considered a problem by the Fauna Protection Board. Pest animals were live-trapped by the Fauna Panel and released in sandstone parks with little regard to the suitability or otherwise of the habitat. Eastern native cats are now extinct on mainland Australia, but the spotted-tailed quoll persists in New South Wales with populations along the lower Hawkesbury at least until the early 1980s (Recher, unpubl.).

The disease that spread through these marsupial populations in eastern Australia in the first decade of the 20th century may have been toxoplasmosis, a parasitic infection spread by domestic cats and to which some marsupials appear susceptible. The disease itself may not have caused the extinction of any native mammals within the Hawkesbury-Nepean catchment, but along with habitat destruction and the spread of the European fox at about the same time, it was probably a contributing factor and therefore a consequence of European settlement.

Evidence of continuing environmental change through the early part of the 20th century is given by frequent references to introduced species. Throughout the early part of the century rabbits and wild cattle were a problem along the Nepean and Upper Hawkesbury Rivers (Maiden and Cambage 1909; Musgrave 1925b). Carp *Cyprinus carpio* and goldfish *Carassius auratus* were well established in the catchment before the first World War (Rosen 1992b) and the banks of the Nepean were lined by a mixture of native and exotic trees, including willows, elms, and privet (Musgrave 1925b). The majority of Australians accept these introduced species as natural and would not see them as evidence of environmental change and degradation.

1939–1992

The fifty years from the end of the 1930s to the beginning of the 1990s was a period of unprecedented growth and development in the Hawkesbury-Nepean catchment. Construction of the Warragamba Dam was completed in 1959. It has a catchment of 8 931 km^2. According to Harris (1984a), there are more than 80 impoundments of various types in the catchment. The immense water supply these made available to Sydney enabled a reticulated water supply and sewerage to be progressively extended throughout the catchment. Only small areas remain unsewered in 1993. The impounding of Mangrove Creek in the 1980s enabled the reticulation of water to the Central Coast, but further reduced the input of fresh water into the estuary.

Accompanying these developments was the massive growth of Sydney's population from less than one million in 1939 to over 3.5 million in 1993 and the spread of the city into the catchment of the Hawkesbury-Nepean.

The environmental changes within the Hawkesbury-Nepean catchment that affect its fauna cannot been seen in isolation from the growth of Sydney and the increasing urbanization of the Cumberland Plain, the Central Coast and along the transportation corridors through the Hornsby Plateau, the Blue Mountains, the Illawarra District and the Southern Tablelands. Although problems with water quality in the Hawkesbury-Nepean and its tributaries were evident as early as the 1830s, the increasing amounts of domestic sewage discharged into the catchment's waterways have had a major impact on water quality since the 1960s (Collis 1978; Oliff and Brown 1978). As any long-time resident would attest, there has also been a progressive decline in air quality within the Sydney Basin from the 1970s, but as yet there are no obvious effects on native vegetation.

Throughout this period water quality continued to be affected by erosion and siltation from road construction, residential and urban development, but at increased rates as the Sydney metropolitan area expanded. River bed and foreshore mining for sand and gravel to meet the growing demands of Sydney for building aggregate (Wallace 1977) substantially increased the silt load carried by the Hawkesbury-Nepean. Nutrient-rich run-off from residential areas, the use of chlorinated hydrocarbons and other biocides in agriculture and for domestic purposes (e.g., termite control), siting of hazardous waste dumps in the catchment, increased boating and associated foreshore erosion, heavy metals and toxins from marine anti-fouling paints, oil and other hydrocarbons from boats, marinas and roads washed or discharged into the river, changed fire regimes associated with broad area prescription burning and greater commercial and recreation fishing pressure throughout the catchment are just some of the factors associated with the growth of Sydney and modern technology that have affected water quality and the biota of terrestrial and aquatic ecosystems throughout the catchment. All became significant in environmental change as population growth accelerated and increasingly large numbers of people lived, worked and played within the catchment.

IMPACT OF EUROPEAN SETTLEMENT

The impact of European activities on Australia's biota did not escape early notice. The proclamations and regulations of Governor King to conserve forests and protect foreshores are the earliest expressions of concern. The need to protect wildlife was debated in the New South Wales legislature and legislation passed in the 1860s (Reed 1991). Although initial concern was for introduced game species, protection was soon extended to native wildlife seen as beneficial to agriculture (e.g., insect-eating birds). By way of contrast, bounties were paid on fruit-eating birds and a Noxious Birds Destruction Society formed at Bulga in 1890 (Anon. a 1892). By the turn of the century species (e.g., bettongs, wallabies), that had been hounded as pests only ten years earlier, were being protected to conserve them from extinction (Recher and Lim 1990). However, concerted efforts were still directed at some species considered pests, e.g., 270 flying foxes were poisoned on one property near Goulburn in 1914 (Anon. b 1914).

In 1892 Alex Hamilton presented a paper to the Royal Society of New South Wales in which he identified the three principal causes of the decline of Australia's biota as a consequence of European settlement (Hamilton 1892). These were;

1. *habitat destruction, fragmentation and modification* as a result of road construction, changed fire regimes, logging, mining, clearing for agriculture, and overgrazing;
2. the *introduction of exotic animals;*
3. the *introduction of exotic plants.*

Hamilton's analysis is perceptive and, with respect to the terrestrial flora and fauna, accurate. For aquatic ecosystems it is incomplete and did not consider the effects of changed water flows, barriers to the movement of aquatic organisms, increased temperatures, modified water chemistry, increased nutrient loads, increased turbidity, siltation, and chemical contamination of water quality and aquatic organisms. These are consequences of agricultural development and the discharge of domestic, industrial and agricultural wastes into watercourses.

The factors identified by Hamilton in 1892 as affecting Australia's biota and those listed above as affecting water quality, can assist in explaining the changes to the biota of the Hawkesbury-Nepean catchment.

Changes to the Terrestrial Fauna

The earliest impact on the terrestrial fauna as caused by the expansion of agriculture

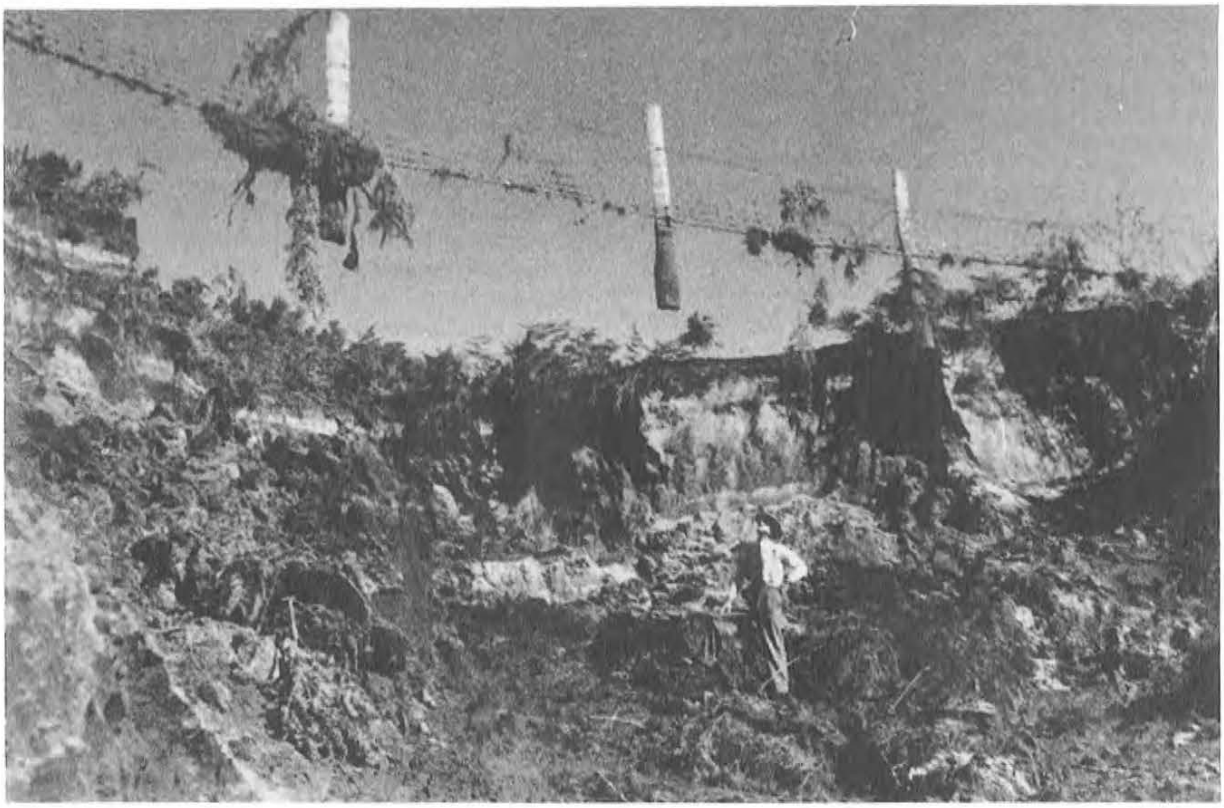

Plate 8. Entitled "Soil washed away Colo River, 28 June 1949". Held in the Mitchell Library (ML GPO 48596). This photo demonstrates the massive erosion of the alluvial flats along the Colo River following floods. While the impact on terrestrial ecosystems is visually obvious, the consequences to the aquatic ecosystems are no less far reaching.

Plate 9. Entitled "Silt in orchard, Colo River near Windsor, 28 June 1949". Held in the Mitchell Library (ML GPO 48599). This photo starkly illustrates the heavy silt deposits following the Colo River floods of June 1949. It presents a stark contrast to Plate 8 and demonstrates that the foreshore environment was undergoing major physical changes following clearing.

across the Cumberland Plain and on to the Southern Tablelands. The clearing and fragmentation of native vegetation, the dramatic decline of the Aboriginal population and subsequent changes in fire regimes leading to changes in the structure and floristic composition of the vegetation, over-grazing, hunting and the introduction of exotic animals were factors that quickly led to the early destruction of the distinctive mammal fauna of the open, grassy woodlands of the Cumberland Plain and better quality soils of the Hornsby Plateau. These effects were felt later on the Southern Tablelands and elsewhere in similar habitats throughout New South Wales (Jarman and Johnson 1977; Lunney and Leary 1988). The cessation of hunting by Aboriginal people reduced predation pressures, possibly allowing some species (e.g., koala, goanna *Varanus varius*) to increase in numbers.

Early accounts of the fauna of the Cumberland Plain, along the Nepean and Upper Hawkesbury Rivers and the lower Blue Mountains describe a rich and abundant fauna. These accounts are confirmed by the richness of faunal assemblages uncovered in archaeological sites (e.g., Table 3). Kangaroos, wallabies, emu, rat kangaroos or bettongs (probably Tasmanian *Bettongia gaimardi* and rufous *Aepyrprymnus rufescens* bettongs) appear to have been common and were frequently referred to in early diaries, mostly as a source of food or sport. Bennett (1834) reported rat kangaroos as abundant in the "Stringy Bark Ranges" near the Wollondilly River during the early 1830s. Travelling in 1802, Ensign Francis Barrallier described the flood plain of the Wollondilly River as having ". . . a great quantity of kangaroos of different kinds. . . ." He went on to write "Such wild animals as the warring, kangaroo, opossum, wombat etc., would afford . . . colonists a great variety of food . . ." (Barrallier 1802) ("warring" may be "waringal", an Aboriginal name for the dingo, *Canis familiaris dingo*). Waterfowl and other large birds were especially abundant and there are frequent references in early accounts to ducks, swans (black swan *Cygnus atratus* and other large (edible) birds including emu, pigeons, quail and lyre bird *Menura superba*.

Other mammals referred to in early diaries were koala, brush-tailed rock wallaby *Petrogale penicillata* and gliding possums. The gliding possums most likely to have been encountered by early settlers were the sugar glider *Petaurus breviceps*, greater glider *Petauroides volans*, and feathertail glider *Acrobates pygmaeus*. The long-nosed potoroo *Potorous tridactylus* was described in Governor Phillip's account of the colony in 1789 from a specimen taken at Botany Bay and it probably occurred throughout the region (Strahan 1983). Potoroo bones have been recovered from archaeological sites in the Upper Mangrove Creek catchment (Attenbrow 1987) and from the Barrenjoey Peninsula on Pittwater (Wood 1989) (Table 3).

The richness of the pre-European mammal fauna is illustrated by the range of archaeological material recovered from the Upper Mangrove Creek and Barrenjoey sites (Table 3). Kangaroos, wallabies, possums, gliders, bandicoots, and wombats are represented along with a number of smaller species. In all, 33 species of mammals were identified between the two locations with more than half (18 species) found at both locations.

Although early descriptions of the fauna, including specimens collected by visiting naturalists and material recovered from archaeological sites, are hardly quantitative or unbiased, along with modern records they provide the information to reconstruct the terrestrial vertebrate fauna of the Hawkesbury-Nepean catchment as it probably was in 1788. In the following accounts only key species are mentioned and our emphasis is on mammals and birds. It should be stressed that the habitats and their faunas as they existed in 1788 are constructs based on our interpretation of early accounts. We have relied heavily on our knowledge of the modern fauna found in similar habitats outside the Hawkesbury-Nepean catchment.

Open, grassy woodlands

Open, grassy woodland is an anthropogenic landscape that was probably restricted to well drained sites with relatively fertile soils on the Cumberland Plain, Hornsby Plateau, Southern Tablelands, and flood plains and shale soils of the larger tributaries (e.g., Mangrove Creek, the Wollondilly, Macdonald and Grose Rivers) (e.g., see Benson 1981). The fauna was probably typical of that found in similar habitats on the Northern Tablelands (Jarman and Johnson 1977) and the Bega River Valley (Lunney and Leary 1988) (Table 2).

Although not reported by early explorers, platypus were abundant in the Hawkesbury-Nepean and tributaries above Wiseman's Ferry (see interviews in Rosen 1992b) and were probably common throughout the catchment. In interviews (Rosen 1992b), Jim Drinnan saw platypus in the Nepean at Camden until about 1960 when the river dried up in a long drought. Fred Smith of Wilberforce described platypus as abundant in the Hawkesbury at least through the 1930s. Comments of other long-time residents indicate that platypus are still present in the Hawkesbury, but in reduced numbers. Their status in the various tributaries is unknown. It is considered rare by Harris (pers. comm.).

Another aquatic mammal expected in the catchment is the water-rat *Hydromys chrysogaster* (Strahan 1983). The water-rat can persist close to human habitation and was recorded in Port Jackson at Drummoyne between 1967 and 1969 by Recher (unpubl.). Recher also observed a water-rat on Broken Bay between Pearl Beach and Patonga in 1969, but it has never been recorded by Harris (pers. comm.). Both species are adversely affected by changed water regimes, recreational motor boating and water pollution. *Hydromys* was not identified at either the Upper Mangrove Creek or Barrenjoey archaeological sites (Table 3).

On the open grasslands, echidna *Tachyglossus aculeatus*, eastern native cat, brush-tailed phascogale *Phascogale tapoatafa*, long-nosed bandicoot *Perameles nasuta*, southern brown bandicoot *Isoodon obesulus*, koala, common wombat, sugar glider, brush-tailed possum, Tasmanian bettong, rufous bettong, red-necked wallaby, and eastern grey kangaroo among others were probably common (Tables 2 and 3). The bettongs and eastern quolls no longer occur in the catchment and bandicoots have declined significantly in abundance since the 1960s. The avifauna of open, grassy woodlands included the emu and may have included the Australian bustard on the Cumberland Plain. Atkinson (1980), writing of what were probably observations during the 1860s in the Goulburn district, described the bustard as not infrequent, whereas it had become rare elsewhere, implying former abundance.

Both the large mammal and bird faunas of the open, grassy woodlands were complemented by a wide variety of smaller species including dasyurid insectivores (*Antechinus*, *Sminthopsis*), native rodents (bush rat *Rattus fuscipes*, swamp rat *R. lutreolus*, and *Pseudomys* spp.). Brown antechinus *A. stuartii* and common dunnart *S. murina* have been found in archaeological sites on the Barrenjoey Peninsula (Wood 1989). Sites in the Upper Mangrove Creek catchment yielded brown antechinus, dusky antechinus *A. swainsonii*, bush rat, swamp rat, Hastings River mouse *P. oralis*, and New Holland Mouse *P. novaehollandiae* (Attenbrow 1987). New Holland and Hastings River Mice have restricted distributions in eastern Australia (Strahan 1983) and the Hastings River Mouse is listed as endangered in New South Wales (Schedule 12 of the National Parks and Wildlife Act, 1974). Apart from sub-fossil remains, it has not been recorded from the catchment. The New Holland Mouse is more abundant and was rediscovered in the 1960s in Ku-Ring-Gai Chase and Brisbane Waters National Parks, where it is associated with low open-forest and heaths (Posamentier and Recher 1974; Strahan 1983). Most of the smaller ground-dwelling mammals persisting in the catchment are absent from remnant woodlands.

The status of bats is unclear, but most of the 15 or more species present in 1788 probably persist in the catchment. However, many are excluded from the more densely settled agricultural and urban areas (Lunney, pers. comm.). Changes to the avifauna parallel the impact of European settlement on the mammal fauna.

With more than 100 species, open, grassy woodlands have a particularly rich avifauna (Keast 1981). This avifauna has a wide distribution in eastern Australia along the tablelands and on to the slopes and plains. It extended to the coast on the Cumberland Plain and in the Hunter River Valley, but has contracted in distribution and diversity with the modification of woodlands by agriculture. Some of the best information on the decline of this avifauna comes from sites on the Cumberland Plain in the catchment of the Hawkesbury-Nepean (see Hindwood and McGill 1958; Hoskin *et al.* 1991, 1992).

Originally the avifauna of the grassy woodlands included a large number of ground-dwelling and/or ground-foraging species (Keast 1981; Hoskin *et al.* 1991). This included stone-curlew *Burhinus magnirostris*, quail, pigeons, robins *Petroica*, eastern whiteface *Aphelocephala leucopsis*, brown treecreeper *Climacteris picumnus*, finches, white-winged chough *Corcorax melanorhamphus*, butcherbirds *Cracticus* spp. and magpies *Gymnorhina tibicen*. It is evident from early accounts that quail, pigeons and magpies were abundant at the time of first settlement and were frequently eaten. Except for stone-curlew, most species appear to have persisted in remnant woodlands in reasonable numbers until the 1950s (Hindwood and McGill 1958), but declined rapidly with increasing urbanization during the 1960s (Hoskin *et al.* 1991). Whitefaces, quail, native pigeons, red-capped robin *P. goodenovii*, brown treecreeper and finches have become rare or disappeared from the Cumberland Plain in the last thirty years, while other ground-dwelling and/or ground-foraging species have declined in abundance (see

Hoskins *et al.* 1991). More recently there have been declines in the abundance of other birds, most notably the honeyeaters (Meliphagidae) and lorikeets (*Trichoglossus, Glossopsitta*) (Hoskin *et al.* 1991; Recher, unpubl.).

These patterns of change in the woodland mammal and bird faunas are not restricted to the Hawkesbury-Nepean catchment, but typify changes in the distribution and abundance of woodland faunas throughout Australia (e.g., Recher and Lim 1990; Recher, in press; Doug Robinson (Victoria) 1993); David Paton (South Australia) (pers. comm.) and Bob Fox (Northern Territory) (pers. comm.). Of the woodland bird species that have declined in abundance and which were previously common within the catchment, only the regent honeyeater *Zanthomiza phrygia* is endangered nationally.

There are few accounts of the original reptile, frog or invertebrate faunas of grassy, open-woodlands within the Hawkesbury-Nepean catchment. Mention is made of snakes, particularly during floods, but there is no reference to large lizards (e.g., goannas, blue tongues *Tiliqua*). As lizards were eaten by Aboriginals and are easily hunted, it is possible that populations were sparse. On the basis of published information, there is no evidence of a loss of reptile or frog species that would be expected to occur in the grassy woodlands of the catchment but see Ferraro in Footnote to References. Water dragons *Physignathus lesueurii* have, however, declined as river foreshores were cleared of vegetation (Lunney 1986). Musgrave (1925) had described the water dragon as "one of the most familiar sights of the [Nepean] river. . . ."

There is little detailed information on terrestrial invertebrate communities for most of Australia. Illustrative of the lack of information are the results obtained during surveys of eucalypt canopy invertebrates in box/ironbark woodlands at Scheyville on the Cumberland Plain during 1987. Using chemical fogging techniques and sampling throughout the year, Majer *et al.* (in press) collected more than 1 000 species of invertebrates from the Upper canopy of grey box *Eucalyptus mollucana* and narrow-leaved ironbark *E. crebra* trees. Of these, more than 90 per cent are undescribed. Some are likely to be restricted to the remnant woodlands on the Cumberland Plain, but in the absence of comparative data the uniqueness of this fauna cannot be determined.

Tall Open-forest and Open-forest

Closed-forest and tall open-forest (often with an understorey of rainforest plants) occurred throughout the catchment at lower elevations along watercourses and on moist, nutrient rich soils (for example, see Benson 1981; Benson and Fallding 1981; Burton 1992). These forests were heavily logged from the initiation of the settlement at Port Jackson. Open-forests and woodlands occurred on the drier slopes and ridges and were subject to more frequent fires than tall open-forest. Where fire frequency was increased by humans, a grassy understorey with scattered shrubs was created (see Benson 1981). Where fires were less frequent, shrub vegetation was probably more abundant. Open-forests on nutrient rich soils were extensively cleared for agriculture.

Although heavily exploited for their timber and affected by agricultural clearing and urban expansion, in some ways tall open-forest and open-forest in the Hawkesbury-Nepean catchment was less affected by European settlement than the grassy woodlands and retains a greater complement of the original fauna. These forests were rich in arboreal marsupials with early references to "squirrels", opossums and gliding possums and the prospects for a lucrative fur trade (Atkinson 1980; Atkinson 1826). Arboreal mammals in these habitats included koala, common ringtail possum *Pseudocheirus peregrinus*, greater glider, yellow-bellied glider *Petaurus australis*, sugar glider and feathertail glider (see Strahan 1983 for habitat details). All recorded arboreal species persist in the catchment, but with reduced populations.

Writing in the 1860s, Atkinson (1978) reported koalas at Wisemans Ferry on the Hawkesbury River and in the Grose River Valley. Koalas persisted through the 1920s and 30s along the river at Ebenezer (Harold Hall, Athol Kemp in Rosen 1992b). A koala was seen at Laughtondale in 1991/92 (Frank Laughton in Rosen 1992b) and recently at Wilberforce (Athol Kemp in Rosen 1992b). A large colony occurs at Campbelltown on the Georges River just outside the Hawkesbury-Nepean catchment. Koalas were reported by local residents to H. Recher as having occurred until fairly recently at Porto Bay near Brooklyn, but were eliminated by wildfire in the early 1980s. Suitable habitat for koalas occurs elsewhere along most of the Hawkesbury at Brooklyn (e.g., Long Island) and along the northern foreshore from Juno Point to Wiseman's Ferry. Koalas occur in tall open-forest along Mooney Mooney Creek and persist on the Palm Beach Peninsula (Recher, pers. obs.). Although remains are not abundant in archaeological sites, koalas were recorded from middens on Upper Mangrove Creek (Table 3). Attenbrow (pers. comm.) found a fresh skull at Mangrove Creek in 1982.

Other mammals in these forests included wombats, spotted-tailed quoll, long-nosed potoroo, bettongs, brush-tailed rock wallaby and parma wallaby *Macropus parma*, as well as antechinus, native rodents and bats (Tables 2, 3). Fruit bats or flying-foxes *Pteropus* were probably common, but are not mentioned in early accounts. The little red flying-fox *P. scapulatus* was recovered from Aboriginal sites in the Upper Mangrove Creek catchment (Table 3).

The impact of European settlement on the brush-tailed rock wallaby is typical for most of the mammals of these habitats. In early accounts they are described as plentiful, occurring widely throughout the catchment (see Table 3). They appear to have been a popular sport animal with the early settlers (Atkinson 1980; Musgrave 1925), probably because of the ease with which they could be shot. On his visit to the Blue Mountains in 1836, Charles Darwin reflected on the intensity with which native animals were hunted and predicted the early extinction of the kangaroo. His prediction about kangaroos was wrong, but sport hunting and hunting for food appears to have had an early and significant impact on many of the larger mammals and birds in the Hawkesbury-Nepean catchment. This includes the rock wallaby which now has a very restricted distribution in the Blue Mountains where it is reported to be declining in numbers (Jones, pers. comm.).

The avifauna of tall open- and open-forests includes species restricted to gully and rainforest habitats on nutrient rich soils. These include brown warbler *Gerygone mouki*, large billed scrubwren *Sericornis magiorostris* and Lewins honeyeater *Meliphaga lewinii*, which are indicator species of rainforest understorey vegetation. Lyrebirds were and are abundant. The avifauna of these forests within the catchment exceeds 120 species (Recher, unpubl.; Hoskin *et al.* 1991). Those species most affected by European activities, particularly logging and hunting, include the various fruit-eating or rainforest pigeons and the brush turkey *Alectura lathami*. Gould commented that the brush turkey was nearly exterminated [by hunting] by 1840. As a rainforest species, the brush turkey was probably restricted in distribution within the catchment and would have been particularly susceptible to the predations of the early cedar cutters (Hindwood and McGill 1958). Wompoo *Megaloprepia magnifica*, topknot *Lopholaimus antarcticus*, white-headed *Colomba norfolciensis* and brown pigeons *Macropygia phasianella* probably occurred throughout the catchment in rainforest and wet sclerophyll habitats, but are not specifically referred to in early accounts. All were considered rare or vagrant during the 1950s, but have since become more frequent in occurrence following the recovery of populations in northern New South Wales (Date and Recher 1988; Hoskin *et al.* 1991).

As with grassy woodlands, there are few data on the original occurrence of reptile, frog and invertebrate species in these forests.

Open- and Low Open-woodlands

Open- and low open-forests and woodlands are the dominant vegetation on the extensive sandstone habitats within the catchment. Although they sustain a rich flora and fauna and have been less affected by agriculture, forestry and urbanization than forests on richer soils, sandstone communities are not productive habitats. With the notable exception of nectar-feeding birds, most vertebrates occur sparsely (Recher, pers. obs.). There is no evidence of significant changes in the fauna of the open- and low open-woodlands of the sandstone. Among mammals these habitats continue to sustain populations of swamp wallaby, antechinus, possums, native rodents and bats (Recher, pers. obs.).

Bird populations in open-woodlands on sandstone are sparse with the greatest numbers concentrated along water courses (Recher, unpubl.). The low numbers result from the low nutrient status of the soils and consequent low productivity of the vegetation and associated invertebrate communities (see Majer *et al.* 1989, 1992 and Recher 1985 for discussions on the relationships between soil nutrients, invertebrate abundances, and vertebrate faunas). Nectar-feeding birds (e.g., honeyeaters, lorikeets) congregate on nectar-rich blossoms of eucalypts and understorey shrubs (e.g., banksia *Banksia*, waratah *Telopea*) and, while there appears to be a decline in their numbers (see below), it is not necessarily associated with changes in the sandstone habitats.

The open-woodlands of the Hawkesbury Sandstone are critical habitat for two species of birds; the glossy black cockatoo *Calyptorhynchus lathami* and the rock warbler *Origma solitaria*. Both are listed as endangered in New South Wales by the National Parks and Wildlife Service (Schedule 12 of the National Parks and Wildlife Act, 1974). The rock warbler is endemic to New South Wales and restricted to

Plate 10. Entitled "Soil erosion — Camden". Held in the Mitchell Library (ML GPO 48926). The magnitude of the loss of the habitat for the native terrestrial fauna is apparent in this bleak photo.

Plate 11. Valley of the Nepean, Gibraltar Rock, showing the natural vegetation and giving an insight into how the entire valley system would have looked like pre-1788. Photo by Lisa Iley.

sandstone habitats where it forages at the interface of rock outcrops and soil. Recent reports suggest a decline in numbers (Hoskin *et al.* 1991) and the species may be sensitive to increased fire frequencies associated with prescription burning and more frequent wildfires of human origin. The cockatoo has probably never been abundant. It feeds primarily on the seeds of she-oaks and requires a large tree hollow for nesting. It has been adversely affected by agricultural clearing and forestry practices throughout its distribution in eastern Australia. The bird is frequently seen along the Hawkesbury River (Recher, pers. obs.) and the Hawkesbury-Nepean catchment may be its most important refuge in Australia.

Several interviews with long-time residents of the Hawkesbury-Nepean suggest declines in the abundance of small birds in rural and suburban environments over the past 20 to 30 years. Generally, urban and suburban environments in the Sydney region have many fewer bird species than the less disturbed rural and forest environments and there have been regular complaints in the Sydney press since the early 1970s about declines in the numbers of native birds in the suburbs (Recher 1972). Comments in the interviews with long-time residents extend these concerns into the rural environment of the Hawkesbury-Nepean where quail, finches, wrens and robins are among the birds reported as being less common than formerly. These are consistent with the comments in Hindwood and McGill (1958) and Hoskin *et al.* (1992), that many species in the County of Cumberland have declined in numbers.

Species that were abundant as recently as the 1950s are now rare (e.g., Nankeen night-heron *Nycticorax caledonicus*, jacky winter *Microeca leucophaea*, azure kingfisher *Ceyx azureus*, diamond firetail *Emblema guttata*). There is the implication in some of the interviews (e.g., Athol Kemp in Rosen 1992b) that the decline of small birds was associated with the increased use of agricultural insecticides and herbicides from the 1960s. As pesticide use declined in the late 1980s, bird numbers increased. Interestingly, Kemp comments on the disappearance of the willy wagtail *Rhipidura leucophrys* from the Ebenezer area. Wagtails appear to be sensitive to pesticide use and have also declined throughout southwestern Western Australia in association with the use of agricultural and domestic pesticides. Increases in the numbers of pied currawongs *Strepera graculina*, an important predator on nests and small birds, competition from the introduced Indian mynah *Acridotheres tristis*, increased numbers of domestic dogs and cats, changes in the composition of vegetation along the foreshores of the Nepean and Upper Hawkesbury Rivers from one dominated by native vegetation to one dominated by exotics (e.g., privet, willow) and extensive clearing of remnant bushland, are other factors in the decline of the local avifauna.

As in the case of other terrestrial habitats, there are few data on the distributions and abundances of reptiles, frogs or invertebrates in open-woodlands within the catchment. The same sources that reported a loss of koalas at Porto Bay following wildfire, said that there was a decrease in the numbers of snakes, goannas and pythons following the fire. Comments in interviews (Rosen 1992b) with long-time residents of the Hawkesbury-Nepean indicate that numbers of snakes can fluctuate greatly according to the incidence of floods with particularly high numbers of red-bellied black snakes *Pseudechis porphyriacus* in the 1930s. In his interview Athol Kemp thought goannas were less common than formerly. Goannas are a frequent victim of automobiles, and a decline in the number of goannas near settlements is expected as population densities increase and automobile traffic escalates. Cats and dogs, as well as cars, may also affect the numbers of goannas, blue-tongue lizards, bearded dragons *Pogona barbata* and jacky lizards *Amphibolurus muricatus* along roads and in suburban areas.

Heathlands

Throughout the Hawkesbury-Nepean catchment heath communities grade into the open-woodlands and forests of the sandstone, as an understorey shrub layer. Despite this, heaths support distinctive bird and mammal communities and, probably, distinctive reptile, frog and invertebrate faunas. Data on the latter groups are too limited for interpretation. Among mammals, the sandstone heaths near the coast (e.g., Brisbane Water National Park) are centres of abundance for the New Holland mouse and the eastern chestnut mouse *P. gracilicaudatus* (Posamentier and Recher 1974; Strahan 1983). Pygmy possum *Cercatatus nanus*, antechinus, long-nosed bandicoot, and swamp wallaby are also common (Recher, pers. obs.).

Heathlands are critical habitats for chestnut-rumped heathwren *Hylacola pyrrhopygia*, southern emu wren *Stipiturus malachurus*, tawny-crowned honeyeater *Phylidonyris melanops* and ground parrot *Pezoporus wallicus* (Recher 1981). The ground parrot is extinct in the

Hawkesbury-Nepean catchment, but was abundant at Maddens Plains where 39 were collected in August 1885 (Hindwood and McGill 1958). The decline of the ground parrot may be the result of changed fire regimes, particularly increased fire frequency. Heathland and open-woodland avifaunas within the Hawkesbury-Nepean catchment have also been adversely affected by European activities outside the catchment area. The number of honeyeaters congregating on coastal heaths during the winter flowering of the nectar-rich heath vegetation within the catchment (e.g., Brisbane Water National Park) has decreased since the late 1960s (Recher, unpubl.). Similar changes have occurred along the north coast of New South Wales (D. Milledge, pers. comm.). Other species to decline within the catchment include the swift parrot, a migrant from Tasmania, and the red-tailed black cockatoo (Hindwood and McGill 1958). The declines in the abundances of honeyeaters, the swift parrot and the cockatoo are widespread. The reduced numbers of these birds on a continental scale is one of the consequences of habitat loss and fragmentation resulting from agricultural clearing and more intensive forestry practices (e.g., pulpwood logging) (Recher 1990; in press; Recher and Lim 1990). The numbers of these birds now reflect the reduced capacity of the most affected habitats to sustain populations, and further declines in abundance throughout the Hawkesbury-Nepean catchment are inevitable, despite the availability of suitable habitat.

The Impact of Europeans on the Aquatic Environment

Apart from sub-fossil material in Aboriginal middens and river deposits, there are no data on the distribution and abundance of freshwater, estuarine or marine organisms within the Hawkesbury-Nepean catchment that permit a precise historical review of changes. However, data obtained since the 1970s (e.g., Hutchings and Recher 1974; Hutchings and Murray 1984; Hutchings *et al.* 1977; Jones 1987, 1990) are useful as a modern benchmark which will allow monitoring of changes to the fauna during the 21st century. The following account is therefore an interpretation based on the most probable series of events affecting the aquatic fauna as a consequence of European settlement. Rather than separate freshwater, estuarine and marine components of the fauna, they are treated together, as all have been affected in similar ways.

The Physical Environment

Early descriptions of the physical environment along the Hawkesbury-Nepean are important in reconstructing the aquatic biota and its ecology prior to European settlement. The first accounts of the Hawkesbury River estuary by Governor Phillip's party refer to shallows at the entrance to Brisbane Water and to banks of sand and mud as they travelled further up. There were mangroves, and the land was low and swampy. There was a narrow bar at the entrance to Pittwater with about 6 m of water at low tide. The opening to the south-west above Dangar Island was described as shallow; this must be the passage between Long Island and Brooklyn which is now blocked by the rail causeway. Mullet Creek was found to be shallow with only 1.5–2 m of water, about the same as it is today at high tide (Recher, pers. obs.). Mooney Mooney Creek had an average depth of about 2 m for some 12 kms above its mouth. Just below the junction of the Hawkesbury and Macdonald Rivers, Hunter (1793, pp 142–44) considered the average depth of the Hawkesbury to be from 5 to 13 metres. The water was fresh even at high tide. Mangroves dominated the foreshores downstream, while reeds dominated the fresher reaches. Shoals extended from low mangrove and marshy points (Hunter 1793, pp. 142–44). The Macdonald River was generally shallow (1–4 m in depth) with rocky banks and low marshy areas. Further up the Macdonald large trees had fallen into the river. The description of the Colo River is similar. The Hawkesbury at the mouth of the Colo was thirteen metres. Above the Colo the depth of the Hawkesbury varied between four to thirteen metres near Richmond Hill. These depths indicated that the Hawkesbury was "navigable for the largest merchant ships to the foot of Richmond Hill" (Hunter 1793 pp. 148–50). On high tide it was possible for Phillip's party to reach the junction of the Grose River despite frequent groundings (Hunter 1793, pp. 152–53).

At the Grose River, Hunter noted evidence of flood waters reaching 10–13 m above the level of the river. Similar signs of flooding had been noticed earlier some 20 km downstream. The first settlers along the Hawkesbury soon experienced flooding when in March 1799 the river rose by 16 metres. There were frequent floods in 1800/01 which caused considerable damage and the loss of crops (Rosen 1992a). Flooding remained a feature of the Hawkesbury-Nepean River and its tributaries through the 19th and 20th centuries and did not cease with the construction of dams in the catchment. Nonetheless, the impoundments on the

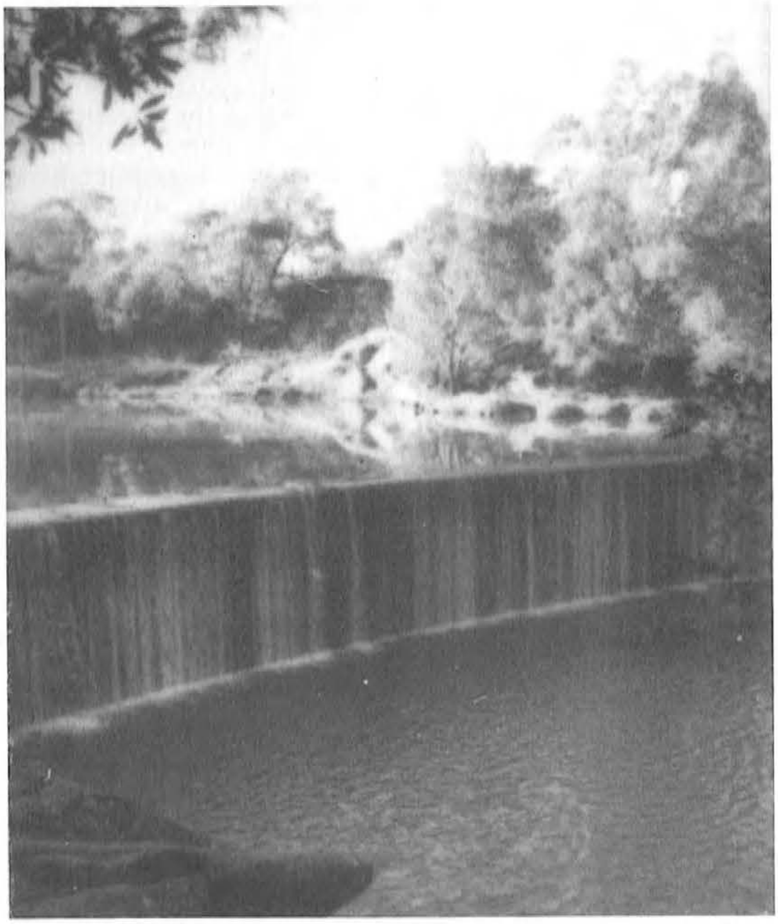

Plate 12. The weir on the Nepean at Wallacia, 1993. Seventy years after the photo shown in Plate 6, this weir continues to affect river flow and aquatic ecosystems. Photo by Lisa Iley.

Plate 13. South Creek, Windsor, 1993. The degradation evident by 1910 (see Plate 4) has continued and both the aquatic and terrestrial habitats barely resemble the pre-European state. Photo by Lisa Iley.

Hawkesbury-Nepean River system have restricted the frequency and amplitude of flooding (W.C.I.C. 1973; Harris 1984a). They have also restricted the flow of freshwater; something most evident during drought. For example, during the 1979/82 drought, the stored volume of water on the Hawkesbury system was reduced to less than half of their capacity (J. Bellamy, in Harris 1984a) and the flow of water in the Nepean and Upper Hawkesbury Rivers was significantly reduced.

The picture that emerges from colonial accounts is of a river and estuary subject to frequent flood surges in its Upper reaches and tributaries; that had extensive shallows and shoals; that was fringed by mangroves and salt marsh along estuarine shores, and by reeds, marshes and swamps above maritime influence. We know that in the Upper reaches of Brisbane Water there were mud and sand flats, but descriptions elsewhere in the system only mention sand, gravel and stone. No doubt there were muddy or silty shallows as well, particularly in association with mangroves. The shells in Aboriginal middens and Holocene deposits exposed in dredging operations (e.g., Brooklyn, Dangar Island) contain many of the same species of molluscs as occur presently on mud flats at Careel Bay in Pittwater (see Hutchings and Recher 1974; Hutchings *et al.* 1977). Common species in middens and dredge spoil include Sydney cockle *Anadara trapezia*, mud oyster *Ostrea angasi*, rock oyster *Saccostrea commercialis* and Sydney whelk *Pyrazus ebeninus*. Cockles and whelks are associated with sea grass beds and sandy muds in the shallows (see Hutchings and Recher 1974; Hutchings *et al.* 1977). The rock oyster is abundant on rocky substrates in the intertidal zone. The mud oyster is sub-tidal on firm substrates and was extremely abundant at the time of European settlement on all estuaries from the Clarence River south (Roughley 1925). It is now rare in New South Wales.

Thus, at the beginning of European settlement, there was probably an estuarine environment in the lower Hawkesbury similar to that found today in Pittwater and Brisbane Water. Reconstructed the environment would probably look like the following:

Except in flood, the Hawkesbury-Nepean, its tributaries and branches (e.g., Mooney Mooney Creek, Berowra Waters, Mullet Creek, Mangrove Creek) had clear water, stable vegetation along the foreshores, extensive sea grass beds (*Zostera*) in the shallows, and mostly clean sandy substrates in deeper water. Upstream the substrates tended to be coarse sands and gravels or rocky with rocky foreshores. Silts would have occurred in and among the sea grasses and mangroves, but the extensive muddy shoals and fine, silty bottoms that characterise the lower Hawkesbury in 1993 probably did not exist. Most long-time residents of the Nepean and Upper Hawkesbury interviewed for this study describe the river as clear, clean and drinkable at least through the 1930s. This was after extensive shallowing had occurred in the Nepean and Macdonald Rivers. In the fresh reaches, extensive beds of freshwater ribbon weed were abundant enough to harvest as cattle feed (Rosen 1992b).

These accounts are supported by conversations with older residents on Dangar Island and in the Brooklyn region (Recher, unpubl.). Early residents on Dangar Island recalled the southeast shoals off the island as being clear with a stony/shell bottom. The water was deeper and fishing was good from the shore. These conditions apparently persisted through the 1940s, but the shoals are now deeply covered by fine muds (Recher, pers. obs.). Fishing from the shore is poor, although the flats remain an important nursery area for many species (Recher, pers. obs.).

This relatively recent deposition of fine silts has occurred in most of the lower Hawkesbury. For example, the resort at Fishermans Point (opposite Bar Point) at the turn of the century had a sandy beach, which became covered in deep silt and was colonized by mangroves in the 1970s (Recher, pers. obs.). Blacker (1977) reported an expansion of mangrove habitats in Pittwater and Cowan Creek from 1940 to the mid-50s, as a result of the accretion of sediments on the tidal flats. This was followed by extensive reclamation of mangrove areas in Pittwater during the 1960s and reduced sedimentation rates in Cowan Water. The rate of sedimentation increased in Cowan Water during the 1980s (Recher, pers. obs.), but it is not known if there was an expansion of mangrove areas.

Early residents at Berowra Waters described the water at the ferry crossing in the 1930s and 40s as clear enough to see the bottom. Squid were fished on a sandy bottom in clear water in Porto Bay as recently as the 1940s and 50s. These areas are currently characterised by turbid water and silty substrates, and squid are uncommon.

In addition to the accumulation of muddy silts associated with turbid water, there has been an accretion of clean sand along most foreshores of the lower Hawkesbury (e.g., Dangar Island, Long Island, Porto Bay) since the 1960s (Recher, pers. obs.). Within the estuarine environment, two processes operate (Roy 1980, 1984). The first is the movement by flood tides of the marine tidal delta. This process, according to Roy, is responsible for the formation of beaches at Pearl Beach, Woy Woy and probably around Dangar Island. The second process occurs upstream beyond the tidal delta. In these reaches, the river, rather than marine influences, dominates and floods move sand banks. Roy (pers. comm.) suggests that the full extent of processes affecting river and estuarine substrates is complicated making it difficult to interpret the extent to which human activities influence events. Nonetheless, among other activities the clearing of native vegetation, grazing and farming, alluvial mining, and changes to fire regimes by Europeans are known to have had a significant impact on Australian soils, including increased rates of erosion (see papers in Russell and Isbell 1986). Comparable effects may have accompanied Aboriginal settlement of the catchment and the introduction of Aboriginal fire regimes (Hughes and Sullivan 1981, 1986).

Roy (pers. comm.) has found Holocene shell deposits in Port Stephens which are 20–30 m in thickness and over a kilometre in diameter comprised of mud oysters and other species, including some warm water forms. Some of this shell material has been dated at 1 500 years BP and Roy speculates that estuarine productivity in the past 6 000 years was much higher than during the past 200 years or so. The reasons for this greater productivity are not known, but could be related to temperature differences (i.e., warmer water). We would like to propose the following hypothesis for testing and discussion; that increased erosion and nutrient release following Aboriginal settlement of eastern Australia 10 000–6 000 years BP was responsible for a burst of increased estuarine and near-shore productivity (in an otherwise relatively nutrient poor environment) that was responsible for the estuarine shell deposits reported by Roy and others. It is also possible that changes within river catchments following European settlement (e.g., clearing, deforestation) were rapid and induced changes within the estuaries that led to the loss of estuarine productivity before accurate records of the abundance and distribution of oysters and other shellfish could be made. Recher (1990) and Recher and Lim (1990) have emphasized that changes in terrestrial environments leading to the loss of species usually occurred within 10 to 20 years of a region being settled. The speed of these changes is such that no records or memories of the pre-settlement environment exist. As illustrated by the rapid decline of the mud oyster in New South Wales estuaries (Roughley 1925), equally rapid changes in the distribution and abundance of species can occur in estuaries.

Changes to the Aquatic Fauna

Early accounts of the aquatic fauna of the Hawkesbury-Nepean River, its tributaries and the estuary describe a rich and abundant fauna. As with the terrestrial fauna, attention and comments are focussed on waterfowl, fish and shellfish that were large and edible, and that could be caught.

When Governor Phillip's party explored Brisbane Water and Broken Bay in March 1788 they referred to the abundance of pelicans and other birds and caught a great quantity of mullet off Dangar Island (which they called Mullet Island) (HRNSWe; Bradley 1969). Aboriginals were found "in great numbers" and virtually every cove up the north arm of Broken Bay (i.e., Brisbane Water) was occupied. A year later, Phillip's party caught large quantities of fish in Broken Bay and on Dangar Island they again caught a "vast quantity of excellent mullet and other fish" (Hunter 1793). In June 1789, Tench and Ardnell explored the Nepean near present day Penrith (Tench 1793) and reported vast flocks of wild ducks (HRNSWf). Phillip also found large numbers of ducks and some swans in the Upper Hawkesbury on his 1789 voyage up the river (Atkins 1792, p. 70). In 1792 Atkins led a party to the Nepean that found quantities of large fish in a lagoon. During his explorations of the Nattai, Barrallier observed that the river was "teeming with fish of various kinds, and especially black bream weighing from "4 lb to 6 lb" (probably the southern bream *Acanthopagrus butcheri*, but silver bream *A. australis* also occur in the Hawkesbury River). Large ("12 lb") eels (on the basis of size and locality these were probably the long-finned eel *Anguilla reinhardti*, but the smaller short-finned eel *A. australis* also occurs in the catchment) were caught (Atkins 1792, p. 67; Borrallier, p. 761). Freshwater mussels were also found. Exploration of the Blue Mountains in 1813 by Evans, Blaxland, Wentworth and Lawson found abundant fish in the Coxs and Grose Rivers (Lawson 1817–24, Mackanes 1978, Part 1, Wentworth 1813–17).

The accounts of abundant wildlife and fish continued; in 1818 "plenty of wild fowl" on the Goulburn Plains (Cambage 1920); in 1819

Plate 14. Laughtondale, Wisemans Ferry, 1993. The persistence of agricultural activities on the fertile alluvial flats has continued to the present day and contributed to the steady loss of wildlife in the catchment. Photo by Lisa Iley.

Plate 15. Laughtondale, Wisemans Ferry, 1993. The steepness of parts of the Hawkesbury River system and the non-arable nature of the soils have allowed parts of the native vegetation to persist with only minor intrusions such as the houses on the foreshores. Such steep and infertile country does not contain habitats for all terrestrial species and their population continues to decline. Photo by Lisa Iley.

French botanists found the Nepean well stocked with fish (Quoy in Mackaness 1978); in 1826 "the fish are so abundant . . . mostly mullet"; in 1833 the Hawkesbury ". . . is absolutely swarming with wild fowl" (Matthew, in Harvard 1943, p. 127; Swancott, in Powell 1988, p. 54).

When it is considered that the most abundant Aboriginal populations were almost certainly located along the rivers and estuary, and that their middens were large enough to be mined for shell to make lime (Sydney Gazette, 6th April, 1806), the Hawkesbury-Nepean, its tributaries and the estuaries of Broken Bay, Pittwater and Brisbane Water were highly productive of all manner of water birds, fish and shellfish. Interestingly, the descriptions of abundant waterfowl and fish in the catchment cease by about 1840 and are replaced in the 1870s by expressions of concern for the disappearance of wildlife (Atkinson 1978). The aquatic life associated with the clear water and clean substrates found at the time of European colonization differed from that occurring in the 1990s. Freshwater crayfish (spiny crayfish) (*Euastacus* spp.) were abundant in the larger creeks feeding into the Hawkesbury-Nepean, including Crosslands in Berowra Waters. Musgrave (1925) collected a new species of freshwater shrimp *Atya striolata*, as well as specimens of *Paratya australiensis*, near Nortons Basin on the Nepean River. This was also the first record of the genus *Atya* from Australia. The modern status of these shrimp is unknown.

Freshwater mussels remain abundant in the catchment (Ponder, pers. comm.), but may not have been significant as a food item for Aboriginal people. According to Attenbrow (pers. comm.) there are no middens of freshwater bivalves in the Hawkesbury-Nepean catchment comparable to those found in western New South Wales. There were probably extensive beds of cockles, clams, and mud whelks such as persisted at Careel Bay (Hutchings and Recher 1974) until overfished in the 1980s (Recher pers. obs.). Crabs, prawns, squid and fish were abundant, as were sharks (there was a shark fishery in Porto Bay during the 1930s); marine turtles (in Broken Bay), porpoises (into the Upper Hawkesbury), whales (Broken Bay), and a wide variety of water birds (pelicans, cormorants, terns, herons, ducks). The change to this fauna is one of progressive decline and local extinction for many species.

Recently some species that had declined in numbers have become more abundant. For example, a number of species of ducks have habituated to people along the lower Hawkesbury, perhaps because they are no longer hunted and perhaps because people encourage them with food. The ducks that are most abundant near people are the black duck *Anas superciliosa*, grey teal *A. gibberifrons* and chestnut teal *A. castanea*. The introduced mallard *A. platyrhynchos* and muscovy duck *Cairina moschata* are also common, as are black duck/mallard hybrids (Recher unpubl.).

Interpreting the Impact of Europeans on the Aquatic Environment

The effect of European settlement on the aquatic fauna of the Hawkesbury-Nepean catchment is a consequence of the development of agriculture, industry (including mining) and urbanization. Hamilton writing in 1892 identified three principal causes for the decline of Australia's biota; habitat destruction and fragmentation, the introduction of exotic animals, and the introduction of exotic plants. Hamilton was referring to the terrestrial biota, but parallels can be drawn with the aquatic biota. There are four principal causes for the decline of the aquatic biota in the Hawkesbury-Nepean catchment;

1. *habitat destruction, fragmentation and modification* as a result (among others) of increased rates of siltation, changes to the volume and pattern of stream flow and flooding, the construction of dams, weirs and bridges, urbanization, foreshore erosion from vegetation clearing and recreation boating, and the effects on bottom substrates of commercial trawl fishing;
2. *changes in water chemistry* as a result of decreased fresh water flows into the estuary, increased nutrient levels, and pollution from agricultural, industrial and domestic (including recreational boating) wastes;
3. *introduction of exotic plants and animals*;
4. *exploitation of fish and shellfish*

It is clear from early descriptions of the Hawkesbury-Nepean River and geological history that erosion and deposition were normal features of the catchment and its waterways. As the land uplifted, the river and its tributaries cut deep gorges through the sandstone. This material formed the alluvial flats, shoals and shallows encountered on Governor Phillip's first explorations in 1788 and 1789. At least in the estuary of the lower Hawkesbury, Broken Bay, Pittwater and Brisbane Water, water depths and the location and shapes of shoals and bars in 1993 do not appear to differ from those described in early explorations or shown in photographs from the 19th century (e.g., of the flats off Dangar Island). This is in contrast to events further up river and in tributaries such as the Macdonald River, where significant shallowing seems to have followed European settlement. Although Roy (pers. comm.) points out that it is difficult to separate human effects from natural geomorphological processes, the extensive clearing of vegetation on the flood plain and along watercourses affected bank stability (Rosen 1992a) and water flow. By the mid-1870s navigation in the Macdonald, Upper Hawkesbury and Nepean was significantly impaired.

The sand impeding navigation could have been derived from many sources; erosion of agricultural lands, sediments washed from construction and mine sites, increased surface erosion in wooded landscapes as a consequence of less frequent but more intense fires, and the mobilization of alluvial material accompanying foreshore collapse and scouring as a consequence of land clearing. Increased erosion would also lead to increased turbidity and siltation as organic material and clay contained in the eroding parent material was released.

Erosion following land clearing for agriculture was a problem by the 1820s (Atkinson 1826) and well-established by the 1830s (Rosen 1992a). In the 1870s floods on the Upper Hawkesbury caused significant shallowing and widening of the river and river trade to Windsor and St Albans was affected (Henry 1977). There was significant erosion and runoff into the river associated with the construction of the railway through the Blue Mountains from the 1859s until the end of the 1870s (Rosen 1992a). Continued problems with erosion, siltation and shallowing of the Hawkesbury-Nepean are illustrated by the interview with Mr. Jim Drinnan, a farmer in the Camden area. Drinnan comments that when his family moved to the area in 1958 there were still deep holes in the river, but these filled with sand in the 1960 flood. He also comments how freshwater flow in the Nepean had been stopped by construction of the Cataract, Cordeaux and Nepean Dams and how quickly weirs built to provide water to farmers silted up. Long-time resident of the Upper Hawkesbury, Frank Laughton, considers that the river has shallowed significantly since the 1940s.

A major change in the Hawkesbury-Nepean following European settlement appears to be increased turbidity affecting light penetration of the water and a greatly increased rate of silt deposition. The effects of these on the aquatic biota have been substantial and particularly severe in the Hawkesbury estuary. Sea grass beds on the lower Hawkesbury are sparse and restricted to very shallow water in the mid-low tide range where sufficient light penetrates during hightide and exposure to the sun and air at low tide is minimal. Evidence of light as a limiting factor comes from the Dangar Island shoals where seagrasses expand during prolonged droughts and water clarity improves, as for example occurred during the 1981–82 drought and since 1991 (Recher, pers. obs.). Large quantities of bivalve and gastropod shells exposed during dredging operations on the Dangar shoals and at Brooklyn (Recher, pers. obs.) and in middens suggest that seagrass communities were more extensive earlier in the Holocene. Extensive seagrass beds remain in Brisbane Water, Patonga Creek and Pittwater, where the water is clear and siltation rates are low. If our interpretation is correct, then it can be concluded that the fauna dependent upon seagrasses has also declined in abundance on the lower Hawkesbury, although the most dramatic declines may have preceded European settlement. The timing of the loss of these estuarine communities (i.e., those dominated by the mud oyster) needs to be determined.

The pattern of water movement in the lower Hawkesbury, Cowan Water, Broken Bay, Patonga Creek, Pittwater and Brisbane Water is that river water with its high silt load flows to the sea along the north shore of Broken Bay from Juno Point past Lion Island. Brisbane Water receives mainly ocean water flowing past Box Head. Ocean water flows into Pittwater and Cowan Water along the south shore past Barrenjoey and West Head. Although these waters mix, the result is that Cowan Water, the southern shore of Broken Bay and Pittwater sustain a different and more maritime biota than the Hawkesbury River and the northern shore of Broken Bay. Patonga Creek largely escapes river influences.

Jones (1987, 1990) found different macrobenthic organisms in the Hawkesbury River from those reported for Careel Bay in Pittwater by Hutchings and Recher (1974). Nonetheless Cowan Water, Brisbane Water and Pittwater are affected by the same sorts of human activities in their catchments as is the Hawkesbury-Nepean and its tributaries. Blacker (1977) reported increased sedimentation in Pittwater and Cowan Creek from 1940 to the mid-50s and attributed this to erosion on developing urban areas and/or following wildfire in bushland. Following a period of stability, since 1980 Cowan Water has been adversely affected by sediments from residential development and road construction, and by nutrient enriched runoff from residential areas (Recher, pers. obs.). In semi-enclosed bodies of water, such as Brisbane Water, Berowra Waters and Cowan Water, increased nutrient loads have a major impact on water quality and aquatic ecosystems.

Europeans have had other effects on the environment and biota of the estuary. Subtidal mining of Holocene shell deposits that took place in Broken Bay in the 19th century to produce lime (Roughley 1922) may have removed seagrass beds and destabilized substrates. The extensive rock oyster industry which developed in the lower Hawkesbury and Brisbane Waters during the 19th century also affects the estuarine biota. The posts, racks and poles used to mark leases and grow oysters provide a substrate for marine plants and animals which would otherwise be less abundant. Marinas and moorings probably have similar effects. The racks and poles used in oyster cultivation slow water flow which, accompanied by the faecal deposits of the oysters, increase silt deposition locally. These effects are minor relative to the more substantial and extensive impacts of changed water regimes, reduced amounts of fresh water entering the estuary, siltation and shallowing, and changed water chemistry in the river system. There is also an impact of trawl fishing on the river and estuarine biota. Prawn and squid trawlers continually disturb and change bottom sediments and adversely affect maritime environments (see Hutchings 1990). There is also a significant by-catch, but there are no published data on the impact of trawling in the Hawkesbury River and Broken Bay on either benthic habitats or the biota. An evaluation of the relative impacts of commercial and recreation fishing on fish stocks needs to consider these possible habitat changes, and the bycatch, in addition to the fish caught and marketed.

The annual catch of 15 000 kg of squid (*Loliga chinensis* species complex, *Loliolus noctiluca*), 70 000 kg of mullet (*Mugil* spp.) and more than 115 000 kg of other fish, and 150 000 kg of prawns in addition to those taken by recreational fishers (see Pollard and Grownf 1993) must affect marine and estuarine food chains. Food for fish and aquatic birds and mammals is reduced. Conversely fishing provides an additional food resource for cormorants (mainly the big black cormorant *Phalacrocorax carbo*), pelicans *Pelecanus conspicillatus*, silver gulls *Larus novaehollandiae*, whistling kites *Haliastur sphenurus* and white-breasted sea eagles *Haliaeetus leucogaster*. Cormorants, pelicans and gulls congregate behind trawlers as nets are pulled in and unwanted fish discarded. Estuarine catfish (*Cnidogalinus macrocephalus*) killed and discarded by recreational fishers are an additional and important food source for kites and eagles (Recher, unpubl.).

There is a large resident population of eagles and kites on Broken Bay and along the lower Hawkesbury (Recher, unpubl.). During the 1992/93 breeding season, pairs of both species on the lower Hawkesbury raised two or more young suggesting an abundant food supply. Almost certainly the breeding success and large populations of both of these species is sustained by the by-catch from commercial and recreation fishers. Following the flooding and subsequent drying of Lake Eyre during the mid-1970s, pelicans appeared on the lower Hawkesbury and in Broken Bay and Brisbane Waters in large numbers (>100 at Brooklyn and Dangar Island alone). Although many of these birds failed to survive, a small resident population has been sustained since then by the by-catch from commercial trawlers and fish heads discarded at cleaning tables by recreation fishers (Recher, pers. obs.). These pelicans also forage for themselves. Big black cormorant populations have also increased since the mid-1970s.

A significant change to the aquatic environment has been the reduction of freshwater flows and changed patterns of flooding following the construction of impoundments and the diversion of water to domestic and industrial uses. However, there is no evidence that this has led to greater salt water intrusion than would occur normally in drought (assuming the catchment has had a history of alternating wet and dry periods leading to relatively rapid and extreme changes in the flow of fresh water into the estuary). Return of fresh water in the form of treated sewage may moderate these effects in the Nepean and Upper Hawkesbury.

It is not clear what changes in the amplitude or pattern of flooding have had on aquatic fauna. Like inland ecosystems, where patterns of flooding and drying are important in stimulating breeding and providing food for young fish and birds, at least some of the biota in the Hawkesbury-Nepean catchment are stimulated by flooding to initiate or complete their reproductive cycle (Harris 1984a,b, 1988). The reduced incidence of flooding and loss of wetlands along the Upper Hawkesbury and Nepean Rivers has reduced the habitat available for wading birds and waterfowl, but the recommendations were not implemented (Recher, unpubl.).

Weirs and dams interfere with the migration of fish and other aquatic animals. As flooding triggers breeding and migratory behaviour in many Australian freshwater fish (e.g., Harris 1988), the alteration of hydrographic patterns caused by extensive catchment impoundments may substantially affect the aquatic biota of the Hawkesbury-Nepean catchment. Harris (1988) in his detailed study of the demography of Australian bass *Macquaria novemaculata* showed that initial cohort abundance indicated that recruitment and subsequent year class strength were positively related to the levels of flooding in the spawning months. A number of fish species in the catchment are diadromous and move between freshwater and marine environments to breed. For example, Australian bass and both long- and short-finned eels are catadromous moving from fresh to estuarine or marine waters to spawn (Allen 1989). Prawns and a number of estuarine fish move into the upper reaches of the estuary and often occur in freshwater. The extent of available habitat for these organisms has been reduced by dams on the Upper parts of the catchment. Another change affecting the freshwater biota in the catchment has been the introduction of exotic fish. Carp, goldfish and mosquito fish *Gambusia holbrooki* in the warmer lower reaches and trout in the colder Upper waters are among the most successful of these introductions. It is well established that trout adversely affect native fish and invertebrates throughout Australia (Fletcher 1986; McKay 1989; Tilsey 1976). Native Australian fish from other catchments were also introduced. During the 19th century, Murray cod *Maccullochella peeli* were introduced into the Wollondilly River and the Mulwaree Ponds near Goulburn (Anon. c. 1904).

In the Nepean, Upper Hawkesbury and various lagoons, the introduction of European carp has had a major impact. From interviews with long-time residents it appears that carp and/or goldfish have been in the river system since the 1920s or earlier (interview with Russell Mitchell in Rosen 1992b), but have only become abundant since the 1970s (Rosen 1992b). Carp were first introduced to Tasmania and in 1876 were introduced into Victorian streams (Roughly 1966). They would have been brought to New South Wales soon after that. Wherever they are introduced (e.g., North America, the Murray-Darling system in Australia), carp have a characteristic impact on aquatic ecosystems (see papers in Pollard 1989). Firstly, the way they feed disturbs bottom sediments and increases turbidity. Secondly, rooted aquatic plants (e.g., ribbon weed) are uprooted. Populations of native fish and other aquatic animals then decline. Fred Smith of Wilberforce linked the increase in carp with the destruction of ribbon weed and the decrease in the numbers of black swans at Bushells Lagoon (in Rosen 1992b). Ribbon weed is a major food of swans. What triggered the carp population to suddenly surge in abundance is not known for certain, but the rapid increase in numbers during the 1970s occurred as increased amounts of domestic wastes with high nutrient loads were being discharged into the Nepean and Upper Hawkesbury. It is not unreasonable to suggest that higher nutrient levels stimulated the growth of food for carp, and that this food was rich in nitrogen capable of initiating and sustaining rapid population growth. If correct, control of carp in the Hawkesbury-Nepean will require the reduction of the amounts of nutrients entering the catchment's waterways. In a sense, the carp is an animal version of blue-green algae.

Introduced aquatic plants, such as water hyacinth *Eichhornia crassipes*, in the catchment have also had an impact on aquatic ecosystems. Adams (pers. comm.) correctly points out that introduced plants have significantly changed the vegetative structure and floristic composition of wetlands.

Two introduced gastropods, *Potamopyrgus artipalum* and *Physa acuta*, are abundant in the catchment and are possible competitors with native species (Ponder, pers. comm.).

The discharge of domestic, industrial and agricultural wastes into the Hawkesbury-Nepean and its tributaries has had a major impact on water quality and aquatic ecosystems. The first instances of water pollution were reported in the 1840s when people complained of dead dogs being thrown into the river and smells emanating from the Hawkesbury, probably from the discharge of industrial wastes (*The Hawkesbury Courier and Agricultural Advertiser, 3 April 1845; 11 December, 1845).* Mining and processing of coal, gold, clay, iron, copper and shale oil in the 1860s and 1870s in the Blue Mountains and on the Southern Tablelands did not conform to modern environmental standards. Mine sites were left without rehabilitation and wastes were discharged into local streams (Rosen 1992a). Much as now, river pollution was publicly debated in *The Hawkesbury Chronicle and Farmers' Advocate* during the 1880s with little apparent success in either preventing or correcting pollution problems. Tanning factories, meat processing plants, and cheese factories were established on the Southern Tablelands in the 1890s and invariably discharged waste into local streams. The abattoir at Riverstone discharged the wastes from processing 500 000 sheep and 2 500 cattle annually into South Creek (Bowd 1973). Since the 1960s major changes in water quality and chemistry in the Hawkesbury-Nepean have been associated with increased levels of nitrogen and phosphorous from domestic, agricultural and urban sources. These issues have been the subject of continuing public discussion and controversy.

The impact of pollutants and changed water chemistry on the fauna of the Hawkesbury-Nepean catchment has not been documented. Like most of the terrestrial fauna, there are no quantitative surveys of the aquatic biota prior to European settlement. However, some of the effects are obvious. The increased nutrient levels have led to algal blooms, including toxic blue-green algae, and decreased water quality, while the decay of organic material reduces the amount of available oxygen. Uniformly there has been a decline in the abundance and diversity of aquatic organisms in the areas most affected. Fish and shellfish have been reported as deformed and sick and since 1987 it has been necessary to purify oysters from the Hawkesbury. Five out of 100 bream caught in the lower Hawkesbury during 1992 were deformed, but this also appears to be a problem in other estuaries on the New South Wales coast (Recher, unpubl.).

Interviews with long-time residents of the Nepean and Upper Hawkesbury Rivers indicate some of the changes in the fish fauna that have occurred since the 1920s and 30s. Bruce Ferguson of Camden said that the freshwater herring *Potamalosa richmondia* were abundant in the Upper Nepean and easily caught (see also Musgrave 1925), but have not been seen since the 1960s. According to Pollard (pers. comm.), herring are still abundant in the lower Nepean. Further down river, Chester Smith commented on the disappearance of fortescues (the bullrout *Notesthes robusta*) from the Upper Hawkesbury. According to most of the interviewees who commented, other species, such as Australian bass, eels, and estuarine species, are still present, but should not be eaten above Sackville. Frank Laughton pointed out that "diseased" or ulcerated fish have been caught in the river since at least the 1940s and that this is not a modern phenomenon. Laughton also attributes the decline in the numbers of prawns caught in the river to over-fishing, an observation made by others fishing the Hawkesbury. The prawn catch in the Hawkesbury system has also increased from approximately 60 000 kg in the mid-1970s (Dunstan 1976) to about 150 000 kg in the 1990s (NSW State Fisheries report on the ABC, 9 January 1993). The increased catch does not indicate that Laughton and others are mistaken, as fishing effort has increased substantially in that time. According to Dunstan (1976), 60 trawlers worked the river in the mid-70s. The number of trawlers fishing in 1992 was 71 (NSW State Fisheries report on the ABC, 9 January 1993) and many of these were larger, more powerful boats than those operated in the 1970s (Pollard and Grownf 1993).

Berowra Waters

Berowra Waters illustrates the problems faced by the aquatic biota of the Hawkesbury-Nepean with development of the catchment. Berowra Waters is an arm of the Hawkesbury opening south from the main channel at Fishermans Point and extending to the Crosslands area below Hornsby. A number of small, often ephemeral, creeks feed into Berowra Waters with Fish Pond Creek feeding into the top end. Because of shallows near its entrance, tidal flushing is limited. As recently as the 1940s, the water of Berowra Waters was clear and noted for the abundance of fish and crabs. Spiny crayfish could be caught in Fish Pond Creek and at Crosslands. With the development in Hornsby Shire since the 1960s, increasingly large amounts of nutrient enriched stormwater enter Berowra Waters. The complete list of wastes entering Berowra Waters is unknown, but includes nutrients derived from garden and agricultural fertilizers, silt from residential development, seepage from septic tanks, illegal discharges of sewage from pump-outs, animal wastes (mainly domestic pets), detergents (e.g., as used in washing cars, and boats). In addition, boats are a source of petrol, oil and heavy metal (e.g., tributyl tin from anti-fouling paints) contamination. The construction of the sewage treatment works at West Hornsby, which discharges into Berowra Waters, increased the nutrient load despite reducing illegal septic disposal. Moreover, the effluent discharged from the plant is heavily chlorinated. Gardens and households are also a source of toxic chemicals including pesticides.

As a consequence of these activities, water quality in Berowra Waters has deteriorated. Tidal flushing is inadequate and high nutrient loads stimulate algal growth; not uncommonly, storm surges are followed by dinoflagelate blooms (often manifested as a red tide).

Phytoplankton and suspended matter have greatly increased turbidity and it has not been possible to see the bottom at the ferry crossing since the mid-60s (Recher, pers. obs.), if not earlier. Dense growths of a green alga, *Enteromorpha*, are now common during the cooler months along the high tide line. *Enteromorpha* is an indicator of increased nutrient levels and reduced salinity. It has become increasingly abundant along the lower Hawkesbury in the last decade, possibly reflecting sustained nutrient enriched freshwater seepage from domestic sources (Recher, pers. obs.). Berowra Waters still has crabs and fish, but it is likely that many species have declined in abundance. These would be the organisms dependent on clear water (e.g., various plants) or which might be especially sensitive to pesticides (e.g., many crustacea and filter-feeding bivalve molluscs). Because of the discharge from the treatment works (which is planned to increase over the next decade) and continued residential development in Berowra Waters' catchment, water quality will continue to decline and the incidence of algal blooms increase.

AN OVERVIEW OF THE IMPACT OF EUROPEAN SETTLEMENT ON THE FAUNA AND PREDICTIONS FOR THE FUTURE

There are parallels in the historical changes in the terrestrial and aquatic faunas of the Hawkesbury-Nepean catchment. In both systems there has been a decline in the abundance of the fauna with local extinctions. Some terrestrial mammals and birds have become regionally extinct, but there is no evidence of regional extinctions in the aquatic fauna. Probably the level of extinction is higher than recorded, but with limited information on fish, frogs, reptiles and the invertebrate biota within the catchment, the number of extinct or endangered species cannot be accurately determined. Changes in the terrestrial fauna are primarily a consequence of habitat clearing and fragmentation, changed fire regimes and the introduction of exotic species. Clearing of native vegetation has also been a significant factor in the decline of the aquatic biota through increased rates of erosion and siltation. More frequent fires, including hazard reduction burning, accelerates erosion and siltation. The aquatic environment is further stressed by reductions in the flow of freshwater by its diversion for human use, habitat fragmentation in the construction of dams and weirs, increased turbidity, changed water chemistry, over-fishing, and the introduction of exotic species.

The expansion of Sydney to the west, southwest and north-west has continued to have a major impact on the remnant fauna of the Cumberland Plain, along the shores of the Hawkesbury-Nepean River and its tributaries, and the main transportation corridors through the catchment. These are the faunal communities that were most affected by European settlement of the Hawkesbury-Nepean catchment and where the largest number of local and regional extinctions have occurred. As has happened in southern California in North America, continued deterioration in air quality in the Sydney region will ultimately affect the health of the less disturbed vegetation on the surrounding sandstone country and consequently of the sandstone fauna. These communities will also be affected by increased fire frequencies through broad area hazard reduction burning and/or an increased incidence of accidental and vandal fires. Fauna will continue to be adversely affected by activities, particularly continued land clearing, outside the catchment. Changes outside the catchment will reduce the chance for recolonization within the catchment whenever local populations become extinct.

The impact of Sydney's growth on aquatic environments will depend on four factors; whether there will be further diversions of freshwater from the catchment for human use, the quality of domestic, urban, recreational, industrial and agricultural effluents discharged into streams and rivers, restrictions on commercial and sports fishing, and the extent to which exotic plants and animals already established in the catchment can be controlled and new introductions prevented. Introductions of exotic marine organisms via ballast water and transfers between catchments may be especially difficult to monitor and control (Pollard 1989; Pollard and Hutchings 1990a,b).

Water in the lower Hawkesbury shows heightened phosphate levels (data supplied by Hornsby Shire Council). Consideration therefore needs to be given to the effects of high phosphate loads coming downstream and *in situ* nitrogen fixation by marine algae and phytoplankton. This combination of events may lead to the same kinds of eutrophication problems and algal blooms on the lower Hawkesbury as now occur above Wisemans Ferry and in many inland rivers.

The pattern of historical change in the Hawkesbury-Nepean catchment is one of continuing degradation in environmental quality affecting both fauna and people. The native terrestrial and aquatic fauna in the catchment will continue to decline with urban expansion and better management of human activities within the catchment is urgently required.

None of the historical and current environmental problems and their effects on the fauna of the Hawkesbury-Nepean catchment are beyond human capacity to correct. Extinct species cannot be resurrected, although re-introductions from elsewhere in the species range are an option. However, there are no technical reasons why terrestrial and aquatic ecosystems in the catchment cannot be managed to improve and restore biophysical conditions to create an environment that is healthier and more enjoyable for both humans and other animals.

Control of erosion from residential developments, agriculture and hazard reduction fires, better regulation of recreational boating, and the harvesting of aquatic organisms is required to stabilize or reverse these trends. Further clearing within the catchment is unwise and existing vegetation remnants (including freshwater wetlands) should be protected from development. This is particularly important on the Cumberland Plain and Southern Tablelands where a distinctive fauna is associated with vegetation remnants and the reserve system is inadequate. Similarly provision needs to be made for minimum freshwater flows into the Hawkesbury-Nepean estuary from its tributaries. The construction of new water supply dams or the augmentation of existing facilities will have major effects on the estuary and should not proceed.

Nutrient removal from sewage, control of stormwater runoff, and better management of agricultural chemicals and fertilizer, and mining within the catchment is necessary to maintain aquatic ecosystems and restore water quality. There is an urgent need to fully evaluate the impact that the use of fertilizers on lawns, gardens and recreation areas (e.g., golf courses) has on water quality with the view of restricting availability. It may be necessary to close parts of the Hawkesbury estuary to fishing, perhaps on a rotational basis, to allow habitats and the estuarine biota to recover. Revegetation of foreshores can contribute to the restoration process by filtering runoff, moderating water temperatures and providing habitat for terrestrial animals and should be a priority. Most importantly, urban expansion and population growth within the catchment should be restricted.

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Footnote added in Proof: A reviewer has drawn our attention to an unpublished Honours Thesis entitled "Factors influencing the decline of frogs (Amphibia: Anura) in Western Sydney", by T. J. Ferraro 1992. University of Western Sydney, Hawkesbury. This topic will be covered in the December edition of *Australian Zoologist*.