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The Capel Wetlands Centre: A survey of its Historical Development, Significance and Research Results

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Information for Contributors

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Intending contributors should contact Prof Majer, c/- the Department of Environmental Biology, GPO Box U1987, Perth, Western Australia 6845 (Tel. 08 9266 7041; Fax. 09 9266 2495). All submitted papers will be considered by the Editorial Board and appropriate referees. Publication costs for papers that are accepted must be met by authors or their employers.

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Abstract

The Capel Wetlands Centre was established in 1985 when a sandmining company resolved to rehabilitate large pits at Capel as an environment for waterbirds instead of as pine plantation and pasture. The Royal Australasian Ornithologists Union was commissioned to manage the rehabilitation and instituted a research programme that aimed to identify management options leading to the development of a self-sustaining ecosystem at the site. Hydrology, water quality, biological resources and rehabilitation techniques were examined. As the Capel Wetlands Centre matured it became a focus for school and university projects and a regional recreational resource within the Living Windows Ecomuseum system. This bulletin summarises the history of the site, the results of the research programme and the potential of the Capel Wetlands Centre as a link in the conservation estate of south-western Australia.

1.0 Introduction

The Capel area in south-western Australia supports numerous sand mining projects, where old beachlines are fractionated into sand, clay and minerals. Ilmenite, zircon and rutile are the main minerals, ilmenite in particular being an important ore of titanium. The original ore body at Capel was very rich, about fifty percent of the material being usable ore. The excavations intersected the water table so that post-mining rehabilitation had to deal with large, deep lakes of permanent water. The Capel Wetlands Centre is the solution to the problem presented by these lakes. Many of the research projects at the Centre have involved staff and students of Environmental Biology at Curtin University of Technology.

2.0 The contributing institutions and personnel

The development of the Capel Wetlands Centre has involved contributions from many organisations and people. The Centre acknowledges with gratitude the efforts of the following:

Associated Minerals Consolidated Ltd., AMC Mineral Sands Ltd., Renison Goldfields Consolidated Ltd., Westralian Sands Ltd. and Iluka Resources Pty. Ltd., including their staff, Rudolf Agnew, John Allan, Denis Brooks, Colin Brown, Gary Crockford, Malcolm Elson, Keith Faulkner, Peter Grigg, Owen Horton, Mark Jefferies, Greg Kaeding, Fiona Nicholls, Caroline Nixon, Trevor Peters, Tony Petersen, Alan Riles, Gunnar Rippon, Peter Robinson, Kim Sawyer, Dick Shore, Ted Taylor, Mick Templman, Paul Tett, P Thomas and Ian Wood.

WA Department of Conservation and Land Management and the WA Lands and Forests Commission, including their staff, Roger Banks, Frank Batini, Anthony Brandis, Charlie Broadbent, Norman Caporn, Bob Chandler, Denis Hilder, Jim Lane, Tony Raven, Ian Rotheram, John Skillan and Greg Voiht.

The Royal Australasian Ornithologists Union and Birds Australia, including members, Stephen Ambrose, David Baker Gabb, Mandy Bamford, Donald Coventry, Stephen Davies, Frank Doyle, Roger Jaensch, Phil Moors and Dick Shore.

The University of Western Australia, including Dave Cale, Jane Chambers, Peter Davies, Don Edward, Arthur McComb, Simon Nield and Lloyd Townley.

The Western Australian Institute of Technology and Curtin University of Technology, including Kylie Ashenbrenner, Michelle Barrett, Belinda Bastow, Kim Burkett, Brian Collins, Christine Gayton, Jacob John, Justin Long, Jonathan Majer and Melanie Ward.

Murdoch University, including Ted Bazen, Kristine Bennetts, Jane Chambers, Sarah Comer, Nicola Fletcher, Howard Gill, D. Gordon, Jacqueline Kellenberger, Arthur McComb, David

Morgan, Ian Potter, Qiu Song and Bill Scott.
Australian Trust for Conservation Volunteers, including Ben Carr, J Clayton, Ed Greenway, Don Huxtable, Sandra Maley and Tony White.
Oldham Boas Ednie Brown, including Tony Ednie Brown, Murray Johns, Stuart Pullybank and Jenny Rayment.
Science Teachers Association of Western Australia, including Malcolm Crosbie, Fred Deshon, Robyn Donnelly, Ray Forma, Shirley Grundy, Rod Thiele and Shelley Yeo.
South West Development Commission, including Stuart Morgan, Janet Payton and Mary Lou Banay.
Regeneration Technology including Kathy Meney, Georgina Reiss and Ingrid Seiler.
Coolilup Pet Memorial Park, including Rob Breedon, Robyn Cuthbert, Graham and Felicity Hanaclone, Kristina Lightfoot, Paul Repton, Ian Robb and Dick Shore.
South Perth Zoological Gardens, including Ricky Burgess, Neil Hamilton and Colin Hyde.

Contributions are detailed in Section 7.0.

3.0 The Capel environment

Capel lies on the Capel River in south-western Australia, midway between the regional centre Bunbury and the tourist centre, Busselton. It grew up as a centre for the farming community at the end of the nineteenth century. At that time the railway connecting Perth to Bunbury and Busselton was not yet built, although a timber line, built privately, took timber from the southern forests to a jetty at Vasse, opened in 1871 (Battye 1924). Transport to the district was by ship and wagon. Farms raised cattle and sheep. As communications improved dairying and horticulture developed, as well as horse breeding, an important industry for the district as long as troop horses were required.

The Capel area was originally a mixed woodland, some parts having good stands of tall tuart *Eucalyptus gomphocephala* trees and other, sandy parts supporting only *Banksia* woodland (Seddon 1972). The soil of swamp edges was peaty and, if drained, was fertile enough for horticulture once the heath vegetation had been cleared. The early settlers obtained land grants "in fee simple" which gave them ownership of all minerals, as well as the surface of the land, whereas later grants retained the mineral rights to the Crown. This difference had an impact on sand mining tenements when they were later established in the district.

Settlement was slow, partly as a result of the distance from Perth and partly as a result of the lack of substantial natural resources. The distance from Perth precluded the large scale production of perishable foods, such as milk, fruit and vegetables. The climate and soil were not suitable for grain production, so that wool, cattle and horses were the mainstay products, in addition to some timber. As means of transport improved, particularly with the opening of the railway, settlement expanded, and after 1950 the tourist business began to expand. The extensive and attractive beaches of Geographe Bay were used initially only by fishermen and those exercising horses. They were inaccessible until motor cars were generally available and roads built to carry them. For many years the Capel district remained a quiet, rural backwater, green fields in winter, with sheep and cattle feeding on hay through the dry summer. Forest reserves were maintained where the tuarts grew and plantations of pine sown on sandy areas too nutrient deficient even to grow pasture.

Geologically the district is part of the Swan Coastal Plain made up of Quaternary deposits, laid down during the Pleistocene and Recent period in the earth's history. The Darling Fault, which runs north from the south west corner of Western Australia for about 1000 km, is the edge of two plates of the earth's mantle, the seaward one sliding under the inland one. The fault line lies about 30 km east of the coast and the Swan Coastal Plain lies between it and the sea. This plain is surfaced by a series of parallel dunes, running north to south. These dunes are based on formations that reflect changes in sea level that in turn were regulated by the thawing and freezing of the polar icecaps during the four ice ages of the Pleistocene. Each successive interglacial rise in sea level was lower than the last and each successive glacial low was lower than the last, so that the oldest dunes are highest and farthest inland. During these rises and falls in sea level mineral sands were deposited on the beach lines and incorporated into the dunes. It is these ore bodies that the south-west mineral sands industries have worked since the mid fifties. The ore bodies are not even. They have been modified by water erosion, by deposition during times of flood and by wind erosion, so the ores occur in pockets (*lenses* in mining terminology) varying in depth and in quality. Much of the sand making up the dunes is calcarious, formed by corals and coralline algae when the seas off the coast were warmer than at present. The alkaline component affects the soils and in turn the vegetation of the Capel area. Indeed the dominant tree, the tuart, is restricted to calcarious soils (Seddon 1972).

The second half of the twentieth century has seen the intensification of agriculture in the Capel district. Dairy farms have increased output, as Friesian cattle began to dominate the herds, bred for high milk production. The Jerseys, Guernseys and Illawarra Shorthorns of earlier days have dwindled and are now hard to find. A dairy factory was established in Capel, on the banks of the Capel River, and other activities began to be fostered by local landholders. A good market in cut flowers led to the establishment of wildflower farms, for such natives as *Banksia* as well as exotic *Proteas*. Vineyards took over from broadacre farming on suitable farms, a development that has proved very successful, leading to a major export industry. Not all vineyards have wineries; some sell their grape crops to larger concerns where the grapes are crushed and the wine produced. Caravan parks and other tourist attractions are appearing at suitable sites, accompanied by a wider range of shops in the town. Buses have replaced trains as the means of public transport, although a freight line still runs into Capel. But Capel remains a rural town. Unlike Bunbury and Busselton it has not attracted government offices, and now that the Bussel Highway bypasses the town, some of the services for passing traffic have also gone.

4.0 Wetland projects in a global context

Around the world wetlands are being destroyed, by drainage, by infilling for development, and by pollution. When they go a microcosum of life goes with them; the plants and animals of the wetlands cannot survive without the environment to which they have evolved. Not only the permanent residents, but also the seasonal visitors, mammals, bird, reptiles, frogs, damsel flies, dragonflies, and many more lose one more breeding site, feeding ground or loafing place. The process of destruction is insidious. A few hectares here, another pond there, but over the years it has added up to an immense decline in the area of wetland available for wild plants and animals. The decline has been particularly marked near big centres of population. For example the Swan Coastal Plain, around Perth, Western Australia, has lost more than two-thirds of the area of its wetlands in the last 175 years (Brooks 1992, 1993).

Biologists have recognised the consequences of these losses for many years. For example, in about 1880, R. J. Howard writing to F. S. Mitchell (Mitchell 1892) commented:

> *From opposite the Naze, seawards, the Ribble (a river in Lancashire, England) had no definite channel forty or fifty years ago; the estuary was all sand and its general level several feet lower than it is at present. Then the number of knots, redshanks, dunlins, godwits and other waders was many times greater than now, but not more than 30 or 40 geese visited the river. Gradually the mud began to accumulate: training walls were put down, and the channel was confined to the north side of the estuary. As the mud increased in depth, and the ground approached its present level and became covered, first with glass-wort (locally known as samphire) afterwards with creeping bent-grass (Agrostis stolonifera), a greater number of geese came; now we have about 200 in an average season from the end of September until the end of April. Since 1863 about 4,000 acres of marshland have been enclosed and cultivated, so that the estuary is practically ruined as a resort for waders, but the geese remain all winter; and as a rule there is no appreciable difference in the numbers which frequent the estuary.*

This quote illustrates two aspects of the changes to wetlands that have been taking place for many years. First the changes reported, digging the channel, the deposition of mud from erosion and the draining and cultivation of large areas of wetland, led to the decline of the waders and shorebirds that traditionally used the estuary. But it also led to an increase in the numbers of birds, geese in this case, that benefited from cultivation. The trouble is that those species benefiting from development are often those that are common and able to adapt to many different environments. The specialist wetland species are less common and are the ones to suffer.

Some people have been able to contribute to reversing the decline in local areas, by establishing reserves in which wetlands are preserved, wetland animals maintained and research on wetlands undertaken. Although these endeavours have initially been on a small, local scale, as time has passed their influence, through people who have visited and worked in them, has spread widely. A good example is the Wildfowl and Wetlands Trust at Slimbridge in Gloucestershire, England. It was established as the Severn Wildlfowl Trust by Peter Scott in 1946 (Boyd 1997). Prior to World War II Peter Scott maintained a small collection of wildfowl at a lighthouse in Norfolk. During the war it was destroyed and all but twelve birds from the collection dispersed. Undeterred he rented land on the Severn River in south-west England and began to rebuild the collection, study the geese that visited the nearby marsh, the Dumbles, each winter, and trap and ring (band) the ducks caught in the duck decoy that he restored. By 1950 the collection included 700 individuals of 119 forms of wildfowl, and the Trust had a membership of over 3,000. Peter Scott was able to fund the early stages of this endeavour from private means and by the sale of his paintings, but as the activities of the Severn Wildfowl Trust increased, grants were received from many charities and government agencies. From its small beginnings it gradually expanded, acquiring some wetlands and arranging protective agreements with the owners of others. In 1998, after fifty-two years, the organisation, still centered on Slimbridge, has seven other centres in the British Isles, a staff of 200 and a membership of over 70,000. Over 750,000 visitors come to its centres each year.

The ARC Wildfowl Centre at Great Linford in Bedfordshire, England, had an origin different from that of the Severn Wildfowl Trust (Giles 1992). It began with the vision of Nigel Gray from The Game Conservancy and Rudolf Agnew of the Amy Roadstone Corporation (ARC). The mining of gravel along the River Ouse near Bedford during the construction of Milton Keynes had created a large wasteland of worked out gravel pits. Gray and Agnew saw the need to rehabilitate these areas and at the same time an opportunity to return to the community recreational wetland areas for sailing, fishing and bird-watching. The Game Conservancy had done some initial work on the rehabilitation of gravel pits as waterbird habitats and ARC commissioned them as project managers to undertake the development needed to make the gravel pits at Great Linford into a productive waterfowl area and to manage the project. The challenge to the Game Conservancy was how to turn a biological desert left after sand and gravel extraction into a high quality wildlife conservation area tailored specifically to the requirements of breeding ducks. After 20 years the questions were answered and both organisations had achieved their goals. In the process some very fine research results had been obtained, showing important interactions between duck breeding success, landscaping, habitat development, fish density and diversity and the quality of the flooded substrate. The ARC Wildfowl Centre at Great Linford is now an important bird-watching area, providing educational facilities for school and university students.

The Shortland Wetlands Centre, near Newcastle, New South Wales, originated in 1984 as a community project (Maddock 1985). Its initiation was stimulated by two events, one environmental, the natural establishment of an egret colony, and one bureaucratic: the local council decided to reopen a former land fill site (rubbish dump) and at the same time the main roads authority published its plans for the main roads of the area. Both proposals impacted on swampland that several local groups hoped could be set aside as a wetland reserve. The land was owned in part by the Marist Brothers, who were willing to sell it, and the release of the two plans generated such lobbying of the business community, local government, state government and environmental organisations that funds were raised to purchase the land, refurbish its football pavilion as a field studies centre and dredge the associated football ground to extend the swampland and create an attractive wetland that could be used for environmental education and recreation. Local industry, especially Broken Hill Pty. Ltd., and service clubs participated enthusiastically, so that with the help of many volunteers led by Max Maddock, $2.3 million was raised in four years and the 65 ha. site developed into a major wildfowl refuge and environmental facility associated with the Hunter River on the New South Wales coastal plain. From the outset planning concentrated on designing a reserve that provided visitors with worthwhile experiences of water birds and other wildlife while at the same time facilitating education and research. Being close to a large city the Shortland Wetlands Centre has deliberately encouraged visitor contact with the waterbirds by providing a viewing tower for the egret colony, a feeding pond and a canoe trail. These features have not detracted from the environmental value of the bulk of the reserve, but have helped to ensure that funds flow in to maintain the Centre and its staff. As well as being an educational resource and reserve, the Centre has become a release point for reintroducing birds that have died out during European settlement.

Herdsman Lake Regional Park, close to the central business district of Perth, Western Australia, has had a long and varied progression towards a conserved wetland (White 1984). Known to the early settlers as The Great Lake, it was selected, after the 1914-18 World War, as a site for soldier settlement. In 1922 a drain was dug to the sea through the sand dunes to the west of the lake, drainage channels cut through the lake bed and the area subdivided into 10 acre (about

4 ha) blocks for dairies and market gardens. The project failed because the peat of the fen was too acid to grow successful crops, and by the middle of the century the government was looking for other uses for the lake's 450 ha. Originally a body of open water, it was now densely covered with the bulrush *Typha* that had spread following drainage and agricultural disturbance. Two suggested uses were as an airport or a land fill (rubbish) site and mining leases were taken out over it as a source of diatomaceous earth. None of these plans proceeded and in 1976, largely through the vision of David Everall of the WA Department of Planning and Urban Development, a concept plan was developed that proposed allowing development of residential housing around the perimeter and the preservation of the central area for wildlife. Companies led by Dallas Dempster had already bought many of the original blocks on the south-west side of the lake, and David Everall negotiated with him to allow development of the urban, upland section of each block provided the companies returned the lower rural section to the Crown. The arrangement allowed them to take sand from the lower part, under mining leases, to provide fill for the housing blocks; at the same time the excavation left a protective moat around the central conservation zone. Arrangements of this kind were finally concluded around the whole lake. Meanwhile three members of the World Wildlife Fund's Conservation Programme Committee, Stephen Davies, David Fischer and Vincent Serventy, inspired by Peter Scott, who visited the lake in 1978, pressed WWF to raise money for a Wildlife Centre on the lake. The strategy was simple. If such a Centre was built in a prominent position on the lake, it would attract an ongoing use for environmental education of school children. This would protect the lake better, through community opinion, than any government decision or regulation, devices always subject to sudden reversal when the winds of political change blow from a different direction. Dallas Demptster's companies assisted materially in this endeavour and the Herdsman Lake Wildlife Centre was opened in 1984, operated by the WA Gould League. By 2000 it was attracting over 7,000 children a year, and is an integral part of the education system of the state. Meanwhile the lake, protected by its encircling moat created by the surrounding developments, remains a wetland wilderness in the heart of Perth, and is now administered as a Regional Park by the WA Department of Conservation and Land Management.

5.0 Early sandmining at Capel

The black sands of Capel and the surrounding district had been known since the early days of settlement. Lieutenant Henry Bunbury, during a short stay in the Swan River Colony from 1836-1837, explored between Pinjarra and Busselton where he reported "Along the beach about Port Leschenault and again on the Vasse Inlet, one finds a quantity of black sand, which, on examination, appears to be a ponderous metallic sand, bright, sparkling and specular, and apparently iron." Although titanium was discovered as an element in 1791 it was, in the nineteenth century, considered rare, so Bunbury's assessment of this heavy substance as iron is not surprising. Titanium's usefulness remained unrealised until the Second World War, when it became widely sought as welding rod flux and, later, for use in paint, replacing lead oxide, and for many other uses. For long the black sand had dirtied the feet of children playing on the beaches of the southwest. Harry Giddons, in the 1930's, seems to have been the first local to bore into the layers of black sand and get the core tested, but the prospect was not followed up. In 1949 heavy minerals were identified at Koombana Bay near Australind and shortly afterwards the Joice brothers, Jimmy and Jack, began prospecting the paddocks at Capel east of the Busselton Road. They had prospecting experience in New Guinea and also knew there was a worldwide shortage of ilmenite, the main ore of titanium. The dairy industry was in the doldrums at the time, with sandy paddocks regarded as of little agricultural value. The Joice's recognised the potential of the mineral deposits on these sandy wastes, raised about £80,000, and established Western Titanium. With their capital they bought the sandy land (many of the titles were old and included the mineral rights), acquired machinery and set to work. The early days of the mine, and the personalities who "put the show on the road" are well described in the book *Just a Horse Ride Away* (Chase and Krantz 1995), from which the following quote is taken:

> *Operations were slow to get under way because no one could set up the machines properly. By 1955 the project was looking shaky; then Collie electrician Dales Pugh suggested they get in touch with fitter and turner, Frank Wovodich. Dales and Frank had worked together at Norseman and Collie and had a mutual respect for each other's expertise. Manager Peter Nairn knew a good team when he saw one and employed both men. By mid 1956 Nairn had added a group of skilled and experienced tradesman including Les Higgins (who lived in Capel), Fred White, plant foreman Jack Avery, Lee Abbey, shift boss Laughton Lowe, Tom Sheffield the carpenter and Lab man Garnett Paul. Each family occupied one of the company houses built for them on the ridge behind the town (the site of an abandoned aboriginal camp).* . . .
>
> *Just before Christmas Jimmy Joice threw the switch to set the plant operating. The wheels turned, and the complicated mechanism cranked and ground away at a huge mountain of sand. The team waited breathlessly for the first consignment. When the machine fell silent, they rushed over to admire the results. At the bottom of the collecting tank was a tiny fistful of fine black dust. 'My God,' muttered Frank. 'Is that it?'. They did a whole lot better in the days ahead.*

In those early days the mining was done by creating a slurry of water and sand to pump up to the concentrator. Later front-end loaders were used to move the sand. In 1982 the first bucket wheel excavator arrived, now in its retirement given pride of place near the Ecocentre at the Capel Wetlands Centre. It had first seen service in Victoria's brown coal mines and then in the sand mines at Jerusalem Creek, New South Wales, from 1969 to 1982, before coming to Capel. For many years the mine was small. It turned the banksia scrub on the sandhills around the plant into a bare moon-like landscape. The neighbouring farmers were concerned when and whether they would get the land back in a useful condition. Rehabilitation, although required under the mining lease, was not a high priority. As mining spread south-westward, along the old beach line, it entered state forest land, where a crop of pine trees had been harvested. The mineral was on the surface, so the trees were cleared and the topsoil mined - none was retained for future rehabilitation. It was not until the mine path crossed Hithergreen Road that 15 cm of topsoil began to be set aside to put back after mining.

The ilmenite ore bodies were irregular, some very rich, others of low quality. Where the ore was very rich large amounts of material were removed, so much that where the mine pits intersected the water table, large lakes formed and did not dry up even in summer. These lakes were useful to the mine because the process needed large quantities of water. The lakes provided a ready water resource and also a ready dumping ground for water that had been through the processing plant. So they were both pumped from and drained into. But they also posed a problem in rehabilitation because they would support neither pasture nor pines, the logical completion criteria for rehabilitation. The pits that now form the lakes of the Capel Wetlands Centre were dug between 1975 and 1979 (Figure 1). From 1977 until 1983 such rehabilitation as took place aimed to re-establish pasture on the dry land and plant trees around the lakes to mellow their stark appearance (Brooks 1991). Water plants, particularly fringing vegetation became established and some waterbirds began to use the 44 ha of water in the lakes. In 1984 Rudolf Agnew, then Chairman and CEO of Consolidated Goldfields PLC, suggested that the mining company, now Associated Minerals Consolidated (AMC), a subsidiary of Renison Goldfields Consolidated (RGC) which was itself part of the Consolidated Goldfields PLC, should undertake a project like the ARC Wildfowl Centre at Great Linford, England. The Great Linford project was recognised by his company as having considerable public relations value. The General Manager of RGC came to Peter Cassidy, then head of AMC, who in turn asked his Environmental Manager, Denis Brooks, to set the project up at Capel. Denis began the task by commissioning the Royal Australasian Ornithologists Union (RAOU) to make a feasibility study of the conversion of the lakes into a waterbird refuge

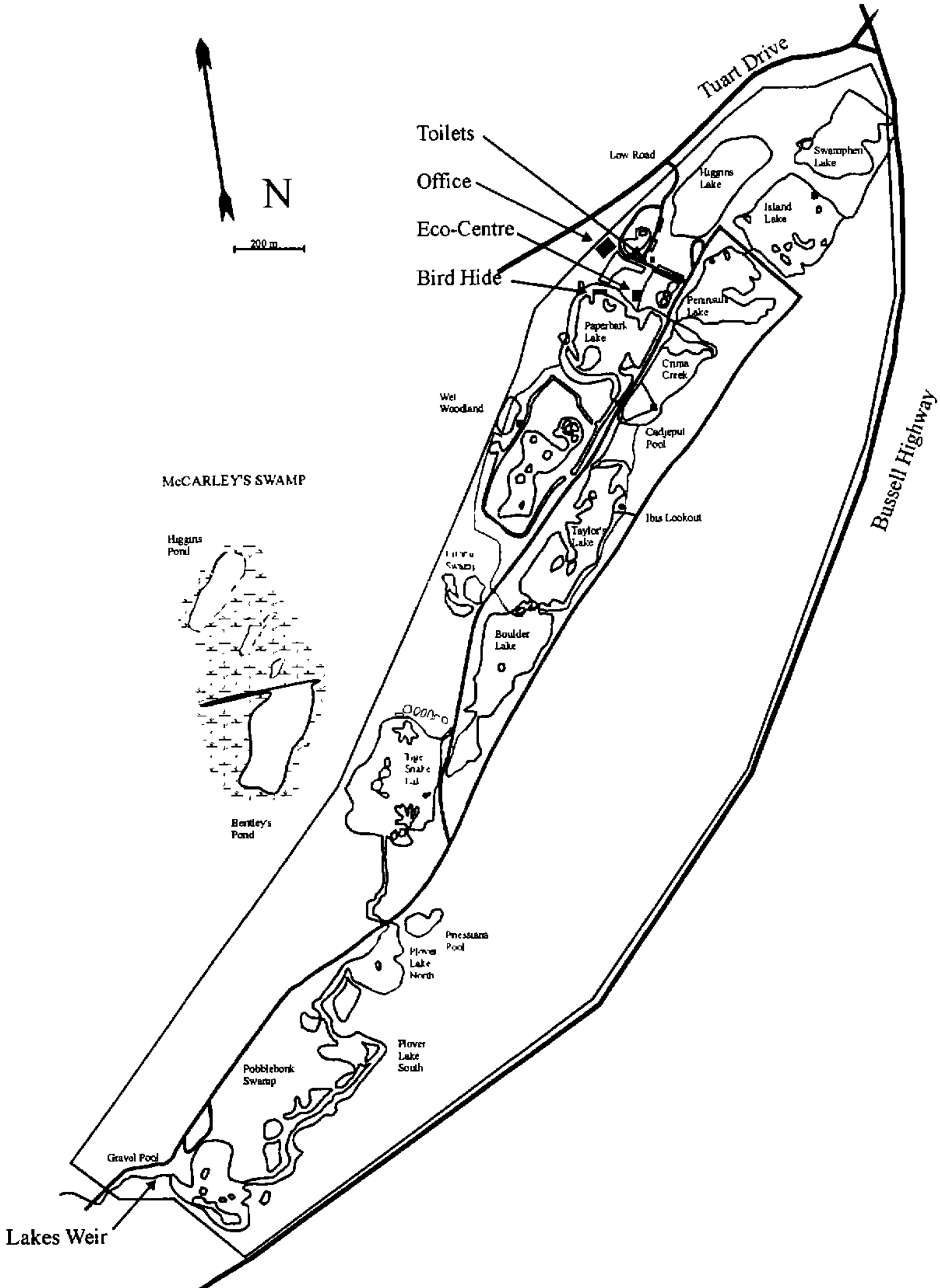


Figure 1. Map of the Capel Wetlands Centre, showing the lakes and the position of the public facilities in 2000.

6.0 The origin of the Capel Wetlands Centre

Roger Jaensch, then South-West Waterbird Projects Officer with the RAOU, undertook the feasibility study and reported to the company in 1985. He identified potential for the lakes in enhancement of the environment to make the site attractive to more birds than at present, in research opportunities, in education and in public use. He also suggested two special projects that could operate in conjunction with the wetland, a captive waterfowl collection and the preservation of an adjacent natural wetland, Ludlow (McCarley's) Swamp.

The report (Jaensch 1986) was detailed in its recommendations and provided the first concept plan for the Centre, drawing on Jaensch's own experience of such facilities interstate and overseas. Reading it now it is impressive to see how many of the strengths and weaknesses of the site were identified. In particular the report raised the issue of the need for water quality much better than existed in 1984, the need for shallows where submerged aquatics were abundant, the need for seasonally flooded woodland and the safety concerns raised by the unstable nature of the bottoms of some of the lakes. The report recommended extensive earthworks and the planting of both upland and wetland areas, but pointed out that much time would elapse before the wetlands achieved their full potential.

The company accepted the report. Rudolf Agnew visited the site again and in discussion with Max Roberts, Chairman of RGC, and Campbell Anderson, RGC's Managing Director, decided to go ahead with the project. Through Rudolf Agnew's influence the AMC Wetlands Centre received, in October 1987, a five year funding commitment with one third of its initial budget from The Goldfields Trust, one third from Consolidated Goldfields and one third from AMC. Although the land was crown land, held by the company under a mining lease, that lease allowed AMC to carry out the work. The Western Australian Department of Mines accepted the proposal that the rehabilitation conditions of the lease could be discharged by creating a wetland rather than regenerating a pasture or pine forest. Denis Brooks, the AMC Manager - Environmental Affairs, took the lead in implementing the proposal, forming an Advisory Committee of Management, for what then became the AMC Wetlands Centre, Capel, to access the expertise of those people in Perth with responsibility for management or research on wetlands or waterbirds. The Advisory Committee was charged with overseeing the rehabilitation of the wetlands and given a budget establishing funds for research, development, public relations and management within which to operate.

The Committee of Management held a preliminary meeting on September 30, 1986 with representatives of AMC, the RAOU, the University of Western Australia, WAIT (later Curtin

University of Technology) and the WA Department of Conservation and Land Management. The Committee set out the objectives of the project as:

1. To develop self-sustaining wetland ecosystems for the conservation of waterbirds in lakes created by mining at Capel.
2. To facilitate research into wetland ecosystems including their development and management.
3. To develop the potential and facilities for public education and recreation at the Wetlands.
4. To develop and demonstrate rehabilitation technology for wetlands created by human activity.

It immediately initiated a programme of baseline research that identified the present state of the lakes, their flora and fauna, and indicated directions in which change was needed. Although the rehabilitation staff at AMC Capel, in particular Ted Taylor and Malclom Elson, had done such work at the lakes as could be fitted into their other duties, it became clear in 1987 that the project needed an on-site management presence. The RAOU agreed to act as Project Managers and appointed Mandy Bamford as the Capel Wetlands Centre first Project Officer. She started work in November 1987, although she had been visiting the site since 1986 to count the waterbirds on a monthly basis. She developed the second Concept Plan for the Centre and landscaping of the site began in earnest. When she resigned in 1989, Frank Doyle took over as Manager, and has run the Capel Wetlands Centre ever since.

It was clear that extensive works would be needed and the Management Committee negotiated with the Company for the commitment to a five year development plan, the first of three that have now been executed. Throughout these developments planning has been guided by the results of the research programme initiated in 1986 and each five year strategic plan continually reviewed in order to keep it focused on studies that would assist management.

One difficulty that needs to be faced in long-term projects of this nature, whether operated by governments or by commercial interests, involves unpredictable changes at the directorate level of management. Renison Goldfields Consolidated (RGC) was formed in 1981. In 1989 Consolidated Goldfields was taken over by Hansons, and AMC became the sandmining division of Renison Goldfields Consolidated (RGC), later becoming RGC Mineral Sands Ltd.. Then in 1998 RGC and Westralian Sands merged and became Iluka Resources. Throughout these changes, which had immense effects on the companies and their staff, the Capel Wetlands Centre has survived and each successive directorate has given generous support. Thus RGC Mineral Sands increased their annual support for the second five years to $200,000. In this respect the Wetlands have been very fortunate, able to maintain continuity when all around them was being reorganised. Such continuity is essential for the success of long-term projects dependant on biological processes and succession. The value of the vision and support of the commercial interests should be fully recognised.

7. 0 The participants

The participants are listed in section 1.0, and some are mentioned in earlier sections. Below are details of the involvement of the various groups in the project and a summary of their activities over the last fifteen years

7.1 *Associated Minerals Consolidated Ltd., AMC Mineral Sands Ltd., Renison Goldfields Consolidated Ltd. RGC Mineral Sands Ltd., Westralian Sands Ltd. and Iluka Resources*

The Capel Wetlands Centre was conceived by Rudolf Agnew when he saw the permanence of the lakes created by sand-mining at Capel. He recognised the opportunity to create wetlands attractive to waterbirds there along the lines of the ARC Wildfowl Centre at Great Linford in Bedfordshire, England. Rudolf Agnew instructed Peter Cassidy to initiate the project. Cassidy delegated to Denis Brooks the responsibility for managing the rehabilitation of the mined land which Denis saw as adding to the State's wetland estate so that the company made a contribution to conservation beyond its statutory obligation to rehabilitate the mine site. The directorate of the company, then Associated Minerals Consolidated, and the principal of the parent company, Consolidated Goldfields, supported this concept, so that, from the first, it had backing at senior levels. Throughout the next fifteen years the successive operations managers at the Capel site, Colin Brown, Alan Riles, Mick Templemen and Peter Grigg, have each taken a lively interest in the progress of the project and given it considerable support. This would not have been possible without the endorsement of the directors and executives, notably Rudolf Agnew, Mark Bethwaite, Tony Coton, Peter Cassidy, Trevor Peters, Peter Robinson and Keith Faulkner. The Capel site's rehabilitation staff, Malcolm Elson and Mark Jefferies, also viewed the project enthusiastically, so that the Centre benefited by many projects spun-off from the main rehabilitation thrust on the mine. In addition, the company provided housing for the project officers, as well as giving them office space, secretarial assistance and housing for volunteers. Throughout the life of the Centre senior company staff have always taken the project seriously and encouraged the Management Committee in its endeavours.

The company has benefited by the publicity the Centre has received. In 1990, using the rehabilitation at Capel as one of its components, the company won the inaugural State and the National Landcare Awards in the Business category. The Capel site has also featured in many public relations releases, including a television clip and illustrated journal articles. The Mineral

Sands Industry Tours routinely include the Centre, the participants making many appreciative remarks about the company's efforts at creating a south-west wetland.

7.2 *Conservation and Land Management (CALM)*

A substantial part of the mined land is managed by the WA Department of CALM on behalf of the Lands and Forests Commission. The WA Department of Forests grew pines on this land until the 1970's when the trees were harvested ahead of the mine path. Although much rehabilitation is possible dunng the tenancy of a mining lease, in the long term, the conversion of the CALM land to a wetland available for public access needed CALM's active co-operation. CALM has therefore been involved from the outset. A succession of CALM officers has participated in Management Committee meetings and members of the Lands and Forests Commission have also attended. Despite the cooperation of these officers, serious obstacles stand in the way of many developments that would benefit the establishment of public facilities on the CALM land. These difficulties are not in the attitudes of the officers but in the nature of the vesting of the land. Many activities and developments could not be undertaken without a change in the vesting, a process that requires the passage of legislation through State Parliament, an undertaking with an uncertain timeframe. CALM also has other interests in the area, the Ludlow Forest and the Vasse-Wonerup Estuary, so that the Regional officers have only limited time to devote to the Wetlands, which they see as having a lower priority within their brief of nature conservation, than the undisturbed nature reserves. Nonetheless CALM have been helpful in many ways, not least in undertaking construction work such as bridges and viewing points at the Centre, and in making planning advice available to the Management Committee.

7.3 *Lands and Forests Commission*

The authority in which the land is vested that is managed by the WA Department of Conservation and Land Management.

7.4 *Royal Australasian Ornithologists Union (RAOU), Birds Australia*

The RAOU's involvement began soon after Denis Brooks, implementing the company's vision, formulated the concept of creating a wetland for waterbirds out of the old mine pits at Capel, when he sought advice on the feasibility of the scheme from the RAOU's waterbird project officer, Roger Jaensch. Following the presentation and acceptance of his report Denis contacted the then RAOU Director, Stephen Davies, and invited him to join the Management Committee. Stephen was succeeded as Director by Phil Moors, David Baker Gabb and Donald Coventry, all of whom have contributed to the Management Committee. Stephen remained on the committee after his retirement from the RAOU, and has provided continuity for the project when most other founding members have had to move on to other responsibilities. As the project developed the RAOU was asked to become the project manager and has had a project officer on the site since 1987. It has contributed ornithological expertise to the planning, development and operation of the Capel Wetlands Centre, provided volunteers for siteworks, and undertaken research on birds. The involvement of its project officers, Mandy Bamford and Frank Doyle have been the lifeblood of the Centre's day to day operations.

7.5 *The University of Western Australia*

As soon as the Capel Wetlands Centre was formally commissioned by the company Denis Brooks approached his university contacts, with the intention of establishing baseline information about the biology of the Centre that could be used for comparison with developments in later years. Arthur McComb, then co-director of the Centre for Water Research, and Don Edward, leader of the Aquatic Research Laboratory in the Department of Zoology, joined the Management Committee at its first meeting and initiated water quality, aquatic flora and aquatic invertebrate research work on the site that has been maintained ever since. Arthur McComb took up an appointment as Professor of Environmental Science at Murdoch University, bringing that university into the research team. Several research students, graduate assistants and research workers from the University of Western Australia have contributed studies over the years.

7.6 *Western Australian Institute of Technology, Curtin University of Technology*

Professor Brian Collins of the School of Environmental Biology joined the Management Committee at the outset and a number of his colleagues and their research students have worked at the Capel Wetlands Centre ever since. Jacob John's work on the diatoms and algae has been particularly extensive and he has provided an almost continuous stream of research students.

7.7 *Murdoch University*

When Arthur McComb moved to Murdoch University in 1989 he brought with him many of his research team, including Jane Chambers, so that their research at Capel added Murdoch to that of the other universities contributing to the research effort on water quality and aquatic plants. Murdoch's contribution continued to grow, with the addition of fish studies in 1993 by Ian Potter, Howard Gill, Simon Hambledon and David Morgan and hydrology studies in 1997 by Bill Scott and Jacqueline Kellenberger.

7.8 *Ecological consultants*

The Capel Wetlands Centre has retained consultants in various capacities. Two of the longest serving are Drs. Michael Bamford and Stephen Davies, who have provided advice and participation on many issues, ranging from the painting of a mural on the wall of the nursery to strategic planning matters.

7.9 *Australian Trust for Conservation Volunteers (ATCV)*

Almost since the rehabilitation siteworks and planting began in 1987 volunteers from a community group, the ATCV, have visited the Capel Wetlands Centre and contributed their time and labour to the development programme. The work has ranged from planting to spreading hay in the lakes, building bridges and a variety of habitat enhancement activities. Their involvement is continuing.

7.10 *Oldham Boas Ednie Brown*

In 1990 Tony Ednie Brown of Oldham Boas Ednie Brown was commissioned to prepare a landscape plan for the Capel Wetlands Centre, based on the Concept Plan of 1988 but with special attention to future public use, the layout of footpaths, design of bird hides and structure and control of visitation to the Centre by the public. His team reported to the Management Committee in November 1990 and supervised the layout of the landscape plan during subsequent years.

7.11 *Science Teachers' Association of Western Australia*

In mid 1992 Frank Doyle held discussions with STAWA with a view to the initiation of an education programme at the Centre. The outcome of these discussions was a three year proposal for the preparation of a resource book for classes visiting the Centre. Robyn Donnelly from Busselton came to work on the book and start professional development courses for teachers planning to use the site. The involvement of STAWA continues and has effected the publication of a very successful primary and secondary resource book, *Sand to Ducks* (Donnelly 1995), for school children. Upwards of 2,000 children now visit the Centre each year. This innovation has led to the construction of a bird hide large enough to hold a complete class, an Ecocentre that acts as a classroom and an outdoor amphitheatre where classes can be held in good weather. The programme has been outlined by Donnelly and Thiele (1997).

7.12 *South West Development Commission (SWDC)*

In June 1994 the Management Committee decided to make contact with SWDC with a view to joining the South-west Ecomuseum project and thereby obtaining funds for the construction of a shelter that could serve as a classroom for visiting classes of schoolchildren and other groups. The association with the Ecomuseum continues and provides continual advertising for the Centre through the Living Windows programme and the brochures distributed by SWDC and the Ecomuseum managers.

7.13 *Regeneration Technology*

The lack of establishment of submerged marophytes in the lakes of the Capel Wetlands Centre has long been of concern to the Management Committee. Regeneration Technology, a firm of consultants who specialize in the propagation of water plants, was invited to examine the problem after Kathy Meney visited the site in March 1995. The work, developing methods of propagating the aquatic plants into the Centre's lakes, concluded in 1999.

7.14 *Coolilup Pet Memorial Park*

During 1996 an approach was made to the Management Committee for the establishment of a pet cemetery within the grounds of the Centre. The approach was made by a group of veterinarians from Busselton, on the basis of a petition signed by 350 local residents and represents a tangible link between the Capel Wetlands Centre and the local community. A site was selected at the eastern end of the Centre and approval given for the development. Each pet is interred in a separate grave within a semi-formal garden and a wooden or stone marker provided. A small but steady number of burials have taken place since the cemetery opened, providing additional income for the Centre.

7.15 *South Perth Zoological Gardens*

Another important development was discussion between Neil Hamilton, Curator of Birds at the Zoo, and Michael Bamford that indicated an interest by the Perth Zoo in cooperating with the Centre and using the Capel site as a release point for surplus native stock. A formal meeting with the Director of the Zoo, Ricky Burgess, in October 1996, led to the Zoo joining the Management Committee, and was followed by a visit to the Centre by Perth Zoo staff in November 1996.

8.0 Research at the Capel Wetlands Centre

Research has always been seen as an essential and integral part of the development of the Capel Wetlands Centre. From its outset the project has devoted a substantial proportion of its budget to supporting research on the ecosystem of the Centre, and been repaid by the provision of information that has improved and assisted management in many ways. The bias for research has always been to help management, but the Centre has welcomed participation of students from Perth's universities and their work has contributed much to our overall knowledge of the Centre and the biological processes that its wetlands support. This section summarises the results of the research work so far accomplished at the Capel Wetlands Centre.

8.1 *Waterbirds*

8.1.1. *Abundance*

The concept of rehabilitation of the mine pits at Capel as a wetland for waterbirds arose because the lakes "looked right" for waterbirds. The first question to examine was did waterbirds use them already? Monthly counts of waterbirds at the Capel Wetlands Centre began in November 1984 by volunteers from Birds Australia. Jaensch (1986) reported that the 13 surveys from November 1984 to October 1985 identified 23 species of waterbirds using the lakes. The largest number of waterbirds seen on any one survey of the 53 ha ponds was 383 birds. His report compares the observations at the Capel Wetlands Centre with the status of waterbirds on four other wetlands in the region, the Vasse Estuary, the Broadwater, the Nine Mile Lake and the Wellard Clay-pits. The lakes at the Capel Wetlands Centre held fewer species than the Vasse Estuary and the Broadwater, a result that Jaensch attributed to the great diversity of habitat available on these two wetlands compared with the Capel Wetlands Centre, as well as the large size of the Vasse Estuary. He noted that the Capel Wetlands Centre compared closely with the small Nine Mile Lake and the Wellard Clay-pits. Most waterbirds were using the Capel Wetlands Centre lakes in the summer and early autumn and breeding was confined to one species, the Pacific Black Duck. The oldest lakes, Swamphen, Island, Peninsula and the lakes east of the processing plant (now filled with tailings) held most birds. In the second year of counting (1985-6) Bamford and Jaensch (1987) reported lower numbers of species and individuals than in the previous year, but with the same species, Pacific Black Duck and White-faced Heron most common; two species bred. Three lakes, Island Lake and Gravel Pool, at opposite ends of the chain of lakes, and the nearest lake to the east of the mine office were most favoured. Bamford and Jaensch interpret this to show that the lakes rehabilitated for the longest time are most attractive to waterbirds and suggest that counting over many years may be needed to identify the factors that cause differences from year to year. The two year's data indicated the species most likely to use the Capel Wetlands Centre and pointed to deficiencies in the characteristics of the lake that might be remedied by habitat enhancement and then attract other species. In particular coots were low in numbers, suggesting that submerged aquatics, on which they feed, were in short supply. Few Darters and grebes were seen, suggesting that the aquatic macroinvertebrates and small fish were lacking in numbers. These surveys set the pattern for regular counts of waterbirds to monitor the progress of rehabilitation as well as providing pointers to the aspects of the environment about which information was lacking. Research programmes were initiated in subsequent years to fill the gaps.

The next waterbird report (Bamford and Davies 1991) covered December 1986 to August 1989, a period when extensive earthworks and habitat enhancement was done on the site, as well as much tree planting. The number of waterbird species recorded at the Centre rose from 24 in 1986 to 45 in 1989, thought to result partly from the presence of a resident observer and partly from an increase in attractiveness of the site to waterbirds as a result of development works. The study identified five species, Australasian Grebe, Black Swan, Australian Sheldduck, Pacific Black Duck and Musk Duck, whose counts showed a trend of increasing numbers, indicating that development was making the Centre more attractive for them than it had been. Conversely one species, the Black-fronted Dotterel, declined steadily, indicating the reverse. This report recognises the value of such indicator species in monitoring the success of rehabilitation, and the trends shown by them and four other species, Purple Swamphen, Little Pied Cormorant, White-faced Heron and Australian Wood Duck, whose numbers fluctuated rather than increasing or decreasing, have been watched closely in subsequent years. An innovation of this report was the incorporation of counts from the nearby natural wetland, McCarley's Swamp. It is difficult to measure the amount of water at either the Centre or McCarley's, because it varies seasonally, not always in correlation. Therefore comparison of birds/ha of wetland is not possible. Nevertheless the figures for the two environments can be used as indices to show trends that can be compared between the sites. Each subsequent annual report on waterbird usage at the Capel Wetlands Centre (Doyle 1992, 1993a and b, 1994, 1996, 1997a and b, 2000a and b and Doyle and Carter 1998) has included information about McCarley's Swamp, from which Table 1 is derived. The diversity of waterbird species has consistently been higher at McCarley's than on the Wetland's lakes, but the Centre appears to be more attractive to some species than others when compared with the natural wetland. The numbers of Pacific Black Duck at the Centre is always within the same order of magnitude as at McCarley's, although usually lower. Counts of White-faced Heron, Little Pied Cormorant, Australasian Grebe and Musk Duck have usually been higher at the Centre than at McCarley's. On the other hand McCarleys Swamp always supports large numbers of Grey Teal, Australasian Shelduck and Eurasian Coot whereas the Centre consistently has small numbers (Table 1).

A conclusion from these figures is that the Centre does well for White-faced Herons, Little Pied Cormorant, Australasian Grebe and Musk Duck, is somewhat attractive to Pacific Black Ducks, but has little attraction for Australian Shelduck, Grey Teal and Eurasian Coot. Waterbirds are attracted to wetlands that provide food, shelter and nesting sites. It is useful to examine the developments that have been undertaken at the Centre over the years and consider their role in providing resources for these waterbirds.

At the start of the Capel Wetlands Centre project the lakes were deep water bodies with little shelter or fringing vegetation, other than around Swamphen, Island and Peninsula Lakes. Deep water is attractive to Musk Ducks, especially if there is fringing shelter close to open water (Marchant and Higgins 1990). Some of the lakes at the Centre now have extensive beds of *Typha* whereas there is none at McCarley's, which is a paperbark woodland with only two open pools. The lakes at the Centre are up to 5m deep while the pools at McCarley's are seldom more than 1m deep. So in these respects the Centre provides the requirements of Musk Ducks better than the natural wetland. Because Musk Ducks breed successfully at the Centre the lakes must provide adequate food, probably in the form of freshwater crayfish and large invertebrates. The addition of brush, hay and logs to the lakes from 1990 was designed to provide shelter for such invertebrates and, along with the improved water quality from 1989, should have helped to enhance the resources for the Musk Duck. Table 1 shows that its numbers increased in 1990 compared with earlier years and have remained at the increased level.

Much of the White-faced Heron's recorded food is crustacean (Marchant and Higgins 1990). Frogs are seldom mentioned and tadpoles not at all. Nevertheless observations at the Centre and elsewhere indicate that the heron is often found fishing in pools where there are numbers of tadpoles. Such soft bodied food would be digested rapidly, and may be overlooked in conventional diet analyses. Be that as it may, the heron is common at the Centre, often in higher numbers than at McCarley's, possibly as a result of the installation of numerous "frog hollows" (Figure 18) around the Centre. Other developments that should have attracted the herons, aside from the extensive shore lines and permanent water, are the battering of steep banks to increase the amount of shallow water. On several lakes peninsulas have been built out into them by taking sand from the uplands and pushing it out into the water. These developments not only increase the open shoreline, which are favoured hunting grounds for the heron, but create shallow water fringes (Doyle 1992). The numbers of herons did not increase at the Centre to the same extent as the Musk Duck, but they have remained steady after 1990 when the major earthworks were completed. No White-faced Herons have been known to nest at the Centre. Their nests are solitary, in tall trees sometimes hundreds of metres from the nearest water. It may be that the trees at the Centre are not yet tall enough, nor the foliage dense enough to provide the shelter that they favour for nesting. Numbers are highest in the late summer and autumn, when many wetlands are dry, and the permanence of the lakes may be the principal attraction.

Table 1. The mean numbers of each species seen on each survey of the Capel Wetlands Centre lakes and Bentley's Pond on McCarley's Swamp, 1987-1997. (*n* = 18 for 1987;*n* = 12 for 1988;*n* = 23 for 1989;*n* = 44 for 1990; *n* = 47/48 from 1991, except McCarleys where more than 30 counts were made each year) (from the work of Doyle and Carter 1998)

Species and Lake	87	88	89	90	91	92	93	94	95	96	97	98
Pacific Black Duck												
Wetlands	22	18	11	23	68	61	23	18	47	19	20	32
McCarleys	15	13	23	41	43	69	53	34	25	29.6	33	
White-faced Heron												
Wetlands	3.5	1.3	1.4	2.2	4.3	4.2	4.1	3	2.5	3	2.8	2.6
McCarleys	4	2	4.4	3.6	1	1.8	4.3	2.9	1.8	0.5	3.6	
Little Pied Cormorant												
Wetlands	0.8	0.9	1.6	4.0	4.5	6.5	4.9	3.7	3.3	4.6	7.1	8.1
McCarley's	0.2	0.7	0.6	0.4	0.2	5.4	0.5	0.8	0.1	0.6	0.6	
Australasian Grebe												
Wetlands	0.5	0	2.5	2.1	12	14	9.0	10	6.4	5.0	3.6	11
McCarley's	5.4	8.8	12	6.9	5.2	0.2	5.8	1.4	0.6	3.6	2.6	
Musk Duck												
Wetlands	1.8	2.1	1.7	5.5	8.5	10	7.7	8.4	8.1	6.5	5.1	6.6
McCarleys	3	0.9	4.2	2.6	3.6	3.2	3.1	2.8	1.4	3.4	3.1	
Australasian Shelduck												
Wetlands -Day	2.2	2.5	4.5	8	6.8	5	3.3	2.4	7.9	2.9	1	1.4
Wetlands - Night									21	11.4	9.8	11
McCarleys	40	11	31	10	19	61	16	13	16	44.5	50	
Grey Teal												
Wetlands	0.4	0.3	0.3	0.2	16	1.3	0.4	1.4	3.6	0.8	0.5	
McCarleys	74	49	50	38	92	40	51	93	80	143	81	
Eurasian Coot												
Wetlands	0	0	0.6	0	3.6	0.6	0.1	1.1	0.6	7.5	0.3	
McCarleys	0.2	2	1.5	17	27	11	19	62	33	14.3	6.2	

Like the Musk Duck, the Little Pied Cormorant favours deep water in which it can dive and fish. The figures for the Centre in 1987 and 1988 are comparable with those from McCarley's but thereafter the Centre has consistently higher mean counts than McCarley's. Water quality improved in the Centre in 1989 and this may have assisted the cormorant by helping the production of its prey, mainly fish and large crustaceans such as crayfish (Marchant and Higgins 1990). Little Pied Cormorants also need perches on which to stand and dry out their wings. From 1987 large dead trees have been placed on the edges of the lakes and the cormorants use these regularly as perches between bouts of fishing. No nesting has yet taken place at the Centre.

The Australasian Grebe feeds on aquatic insects and their larvae (Marchant and Higgins 1990). The counts of this species have been higher at the Centre than at McCarley's for most years since 1991. Unlike the Little Pied Cormorant its occurrence is seasonal, in summer and autumn rather than throughout the year. It favours deep water and for this reason the Centre would have been attractive to it once the water quality improved and the production of prey species increased. It breeds at the Centre, although often unsuccessfully, its floating nest susceptible to disturbance by passing swamphens (Doyle 1992) and flooding by unexpected changes in water level.

Pacific Black Ducks are distributed throughout the Centre. They take 70% plant material and 30% animals, filtering their food from shallow water, sometimes while upended (Marchant and Higgins 1990). Since the start of the Centre, project developments have built sandbanks and islands, increasing the amount of shallow water, benefiting the Pacific Black Ducks. The construction of islands in particular provides protection from the wind, so that whichever way it blows, the ducks can find sheltered loafing spots. The numbers of Pacific Black Duck increase substantially when hay is put into the lakes and this effect accounts for the high numbers in 1991 and 1992, when much hay was added (Doyle 1993b). The ducks are attracted at once, harvesting the seeds from the hay, accessible once they are in water and can be filtered out. Later the hay generates an increase in the algal mat which the ducks feed amongst, if not on. In 1995 McCarley's Swamp dried up in the autumn and many more Pacific Black Ducks than usual came to the Centre. In other ways the Centre is still less than an optimal environment for these birds. Many Pacific Black Ducks already breed at the Centre but some lakes still lack the fringing shelter that the ducks favour for nesting. As the uplands are revegetated more shelter in which they can nest should be available. Probably because the water quality is still not optimal, the Centre lacks an abundance of floating aquatic plants, an important food source for ducklings. The lakes also contain many fish, especially the introduced *Gambusia holbrookii*. Studies at Great Linford have shown fish to compete with ducklings for aquatic invertebrates and they may also do so significantly at the Centre. There is therefore potential for improvements to the Centre to make them more attractive to Pacific Black Ducks.

The Australian Shelduck is a grazing bird, feeding on lawns, pastures and aquatic plants in shallow water. It favours large open bodies of water and it is somewhat surprising that it not seen more often on the large lakes of the Centre. The figures for the daytime counts in Table 1 do not tell the full story, because numbers come to the Centre at night. Night counts of waterbirds began in 1995 and show higher numbers of Australasian Shelduck at the Centre at night than during the day. In 1995, when McCarley's dried up, the mean night count at the Centre were higher than the mean day count on McCarley's, but in the other two years it did not reach such a high figure at the Centre. The reasons for the attractiveness of the Centre to shelducks at night has not yet been explained. It may be that there is less disturbance by night than by day. As the uplands are rehabilitated and as lawn areas increase, shelducks may be attracted in larger numbers.

The Grey Teal sometimes gathers in large numbers on McCarley's but is rare at the Centre a few hundred metres away. It favours large, shallow, productive inland wetlands, and the very productivity of McCarley's compared with the Wetlands probably explains its absence from the site. Teal are strongly attracted to recently flooded land and if, in the future, it is possible to control the water levels effectively, the Centre may be able to attract more teal than at present by occasionally flooding vegetated areas. If this manipulation could be accompanied by the growth of semi-aquatic grasses around the lake edges, the teal may be attracted to feed on the seed heads once the grassland is well established. Like the Pacific Black Duck their numbers were highest at the Centre when hay was added to some lakes and when McCarley's dried out in 1995.

The Eurasian Coot is herbivorous, feeding on aquatic plants by diving and sometimes feeding on grass growing at the lake edges. In recent years moderate numbers of them have stayed on Island Lake for some months each year, but not in numbers comparable with those at McCarley's. Island Lake has gradually developed a flora of rooted aquatics and the spread of these through the Centre Lakes should encourage more Eurasian Coots to visit than do so at present. The numbers of coots at the Centre were barely affected by the addition of hay in 1991 and 1992, and not at all by the drying out of McCarley's in 1995. Throughout Australia the breeding of this species is erratic, seemingly suitable sites being passed by while other unlikely sites are used; coots have not yet bred at the Centre, although they breed regularly at McCarley's Swamp.

This review indicates that, while the Centre has not yet achieved the diversity of species typical of McCarley's, it is very attractive to some species, especially since the water quality improved as a result of changes made by the Company to its discharge water quality. The diversity of species using the Centre has gradually improved, so that by 1997 it does not fall far short of McCarley's, when considered over a full year (Figure 2; from Doyle and Carter 1998[Fig 4]). More effort needs to be put into establishing rooted and floating aquatic plants, which would attract the herbivorous coot, shelduck, swan and teal in larger numbers than at present. Such vegetation should also encourage more species to breed; the Black Swan for example, is known to breed well on lakes where there is plenty of floating vegetation with which it can build its nest. At present it breeds only on Swamphen Lake, a lake densely vegetated with bulrush *Typha*.

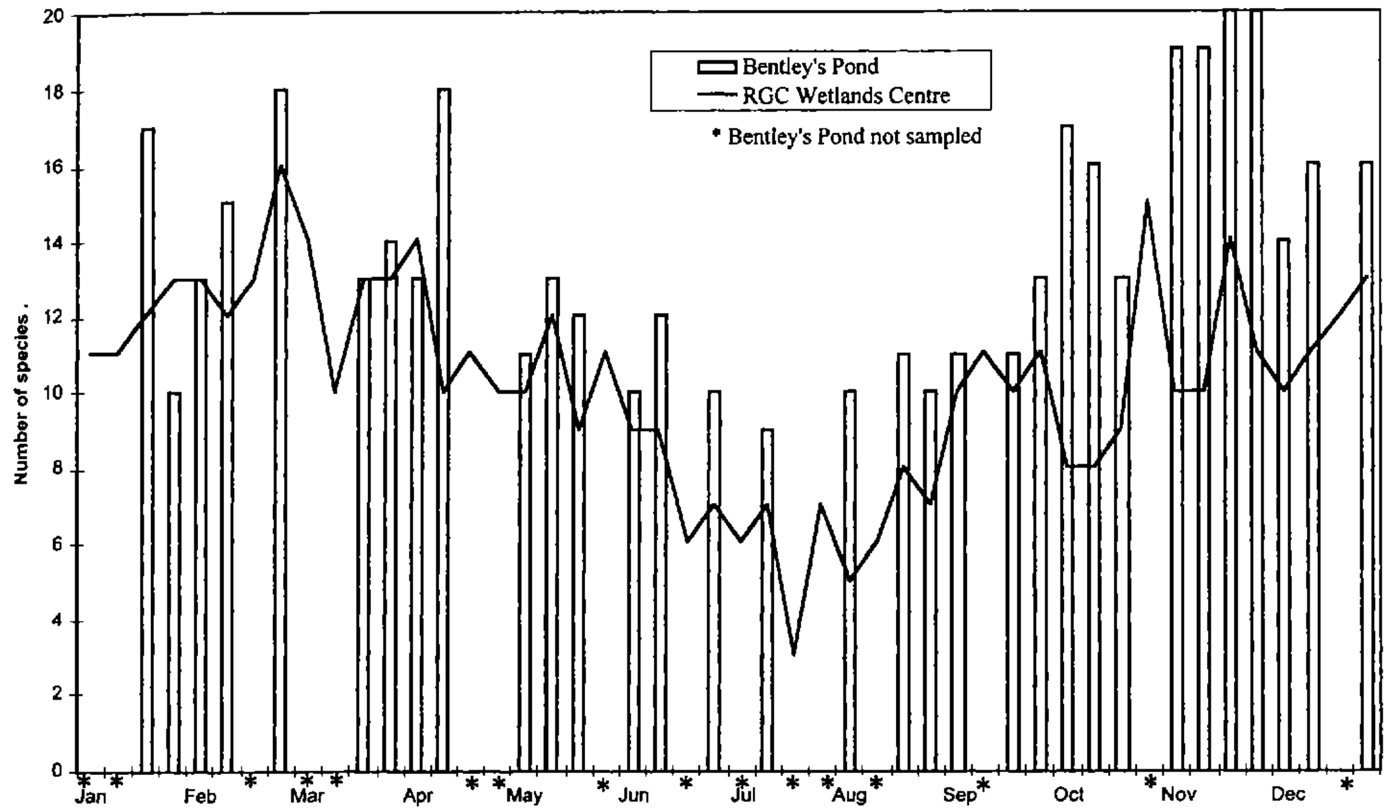


Figure 2. Seasonal waterbird diversity – Capel Wetlands Centre lakes and McCarley's Swamp (Bentley's Pond) in 1997 (from Doyle and Carter 1998).

8.1.2 *Hay additions*

In 1991 an experimental addition of hay was put into portions of six lakes (Doyle 1993a and b). This work followed reports from the ARC Wildfowl Centre at Great Linford (Street and Titmus 1982, Street 1983) that the addition of straw during rehabilitation of wetlands improved the production of invertebrates and therefore the prey available for waterfowl. Each treatment site at the Wetlands had a matching control site. The distribution of the experimental and control sites are shown in Table 2. The bales of meadow hay were opened before being spread on the water and were held within the experimental sites by barrages made of a line of bales strung on a single line of fencing wire held in position by steel posts in the banks. The hay sank during the first week. Waterfowl were counted each week at experimental and control sites (Table 3). Critical analysis is not needed to see the difference between the experimental and control sites. Waterbirds, especially Pacific Black Duck, began to concentrate on the hay within a few days, apparently feeding on floating seeds which could be filtered out of the water. The difference between experimental and control sites persisted for at least ten weeks and Table 1 shows that numbers of Pacific Black Ducks were higher in 1991 and 1992, both years in which hay was added to the lakes than for any other year except 1995, when McCarley's dried out. From 1991 through 1997 total waterbird numbers at the Centre were higher than before the addition of hay, but declined gradually, reaching the 1990 level in 1997. It may be that the long term effect of hay addition will last six years, but it is a treatment that will be worth repeating from time to time. The effects of the hay additions on invertebrates and water nutrient is discussed in later sections.

Table 2. The locations of the control and experimental sites in the hay additions of autumn 1991.

Sites of hay additions	Control sites
North corner of Island Lake	South corner of Island Lake
South-east side of Paperbark Lake	North corner of Paperbark Lake
South bay on west side of Taylor's Lake	North bay on west side of Taylor's Lake
South-east corner of Tiger Snake Lake	South end of Boulder Lake
South-west bay of Pobblebonk Swamp	South-east corner of N. Plover Lake
North end of Gravel Pool	North end of Nitella Pond

Table 3. Regular population of waterbirds on hay additions and control sites in summer and autumn of 1991 and 1992 (mean of three highest counts).

Lake	1991 +hay	1991 -hay	1992 +hay	1992 -hay
Island	97	3	37	1
Paperbark	145	8	46	46
Taylor's	68	7	35	3
Tiger Snake	18	2	43	2
Plover	42	1	10	1
Gravel	99	12	9	7

8.1.3. *Breeding success*

At the outset of the Centre project it was realised that the breeding success of waterbirds was a significant measure of the project's success (Bamford 1987). Twelve waterbird species have bred at the Centre, they are listed in Table 4 together with the number of years in which they were recorded breeding.

Table 4. Species of waterbirds breeding at the Capel Wetlands Centre 1985-1998.

Species	No. of years in which breeding recorded
Australasian Grebe	2
Black Swan	8
Australian Wood Duck	1
Australian Shelduck	9
Musk Duck	8
Pacific Black Duck	14
Grey Teal	6
Buff-banded Rail	1
Purple Swamphen	10
Black-fronted Dotterel	10
Clamorous Reed Warbler	2
Little Grassbird	1

Bamford (1987) pointed out that the success of the project in generating an environment suitable for waterbirds can be measured by their breeding success. Two measures are available; the number of species breeding (which has increased steadily since the project started) and the survival of offspring to independence. Figure 3 compares the survival of Pacific Black Ducklings at the Centre in 1987 with the national figure, derived from the Birds Australia Nest Record Scheme. The percentage survival of these ducklings has improved over the years and in 1997 of 36 eggs known to have been laid, 22 hatched and 10 ducklings reached independence, 45% compared with 9% in 1987. The implication is that breeding conditions are better for the Pacific Black Duck at the Centre now than in 1987, presumably because food and shelter for the nest and brood have improved. More improvements are needed to attract other species, particularly colonial nesters, to the Centre, but the evidence is that rehabilitation is moving in the right direction.

Each species has specific requirements (Nicholls and Davies 1990). For some species these are well known, The Black-fronted Dotterel requires bare ground, provided at the Centre by newly created spits and islands, and even by the extensive system of gravel pathways. The Purple Swamphen requires emergent vegetation at the fringe of a lake, as does the Buff-breasted Rail. So does the Musk Duck provided that the emergent vegetation is close to a deep water feeding ground for that species. Grey Teal, Australian Shelduck and Australian Wood Duck nest in hollow trees, but whereas the Grey Teal chooses dead trees the Australian Wood Duck usually nests in hollows in living trees, and the Australian Shelduck, although it will nest in dead trees, also nests in burrows, often those of rabbits. The Australasian Grebe needs vegetation with which to build its floating nest, and a small tuft of emergent vegetation to which the nest can be attached. As with the Musk Duck it must have easy access to deep water for fishing. The Black Swan needs large quantities of vegetation with which to build its nest, and also favours lakes where large rush beds give it isolation; so far it has only nested on the completely overgrown Swamphen Lake. The Clamorous Reed Warbler and the Little Grassbird are probably underrepresented in Table 4 because the softness of the bottoms of the lakes at the Centre make it difficult to find their nests. They need extensive beds of emergent vegetation; and have been present and almost certainly breeding throughout the project. Some of the species which do not breed have other requirements. Many colonial nesters, herons, egrets, spoonbills, ibises and cormorants, favour flooded woodlands, an environment we are attempting to grow at the Centre but one not yet mature enough to attract these species.

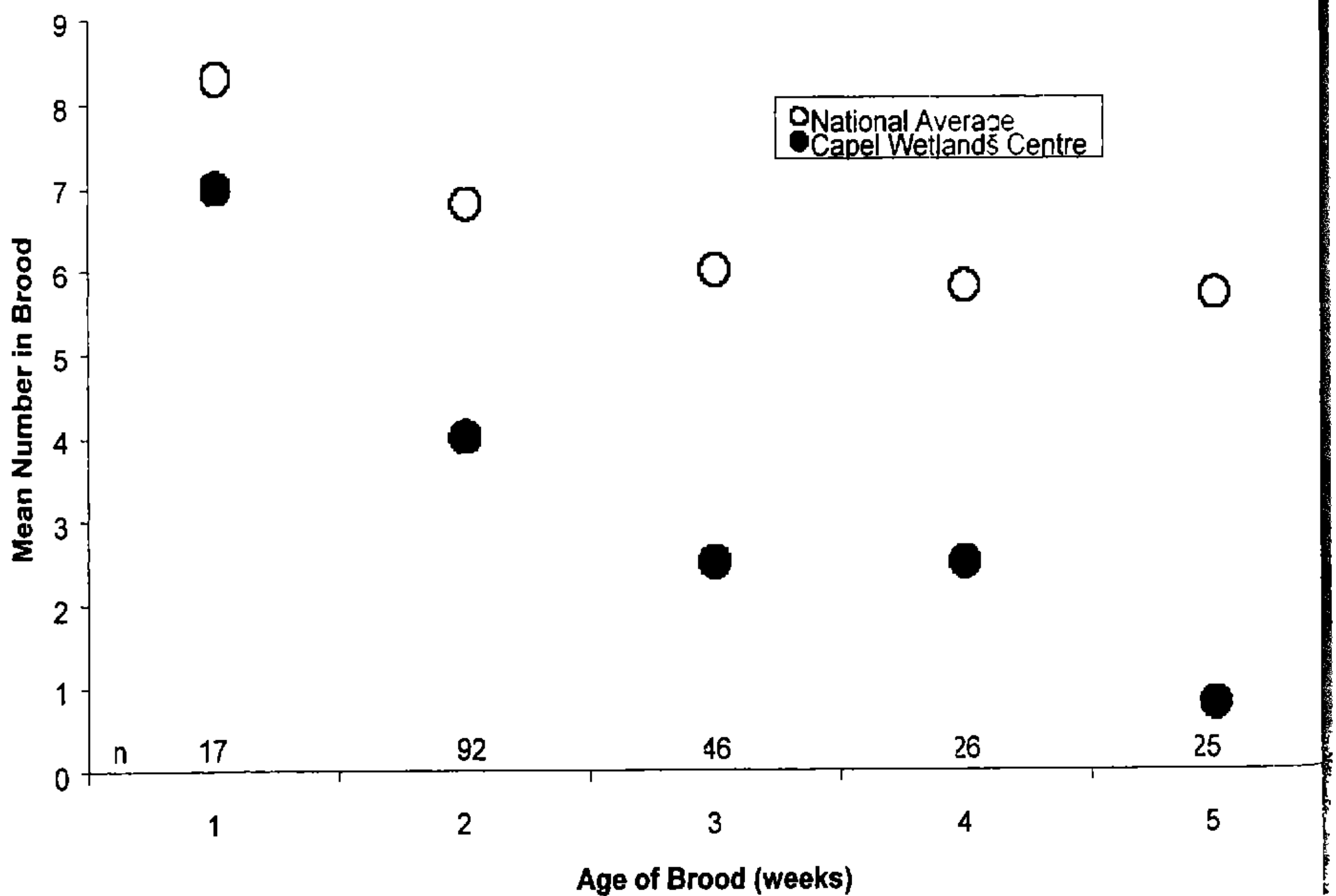


Figure 3. Mean number of ducklings in surviving broods of Pacific Black Duck recorded in the RAOU Nest Record Scheme (open circles) and at the Capel Wetlands Centre lakes (closed circles). N values refer to the RAOU Nest Record Scheme data (from Bamford 1987).

8.1.4 *Banding of waterbirds*

Waterbirds have been trapped and banded at the Capel Wetlands Centre since 1987, mostly in the summer when shortage of water elsewhere concentrates the birds at the Centre. Table 5 gives the total numbers banded and recaptured to 1999.

Table 5. The results of banding waterbirds at the Capel Wetlands Centre.

Species	Banded	Recaptured	Max Distance
Black Swan	1	0	
Australian Shelduck	264	55	1 km
Australian Wood Duck	62	4	
Pacific Black Duck	771	219	20km
Grey Teal	8	3	1 km
Musk Duck	1	0	
White-faced Heron	2	0	
Eurasian Coot	16	11	0.5 km
Purple Swamphen	43	18	0.2 km
Black-fronted Dotterel	15	0	
Totals	1182	310	

Banding took place on McCarley's Swamp as well as at the Centre and showed very frequent movement of individuals between the two areas. The high rate of recapture, 26% overall, indicates a high degree of residency by the birds. Of the 771 Pacific Black Ducks banded, 216 were caught in 1992, the year after the main hay additions. The birds concentrated on the areas where hay had been spread and were then much easier to catch than in other years. The farthest distance so far recorded is of a Pacific Black Duck seen feeding on a lawn in Busselton, W.A. (20 km from the banding site). Some birds have survived for many years; the oldest bird recovered is an Australian Shelduck found freshly dead after 9 years.

8.1.5 *Banding of bushbirds*

From the inception of the Capel Wetlands Centre the uplands have been seen as an integral part of the rehabilitation. The run-off from them feeds plants at the Centre which provide shelter for birds around the lakes, as well as for those that nest a little distance from water. In addition to these features, related to the wetlands themselves, the uplands can provide environments suitable for a range of bushbirds. Plantings have therefore included many species of plants that provide nectar and attract insects on which bushbirds feed. The total number of bushbird species recorded for the Centre has risen from 40 in 1987 to 70 in 1999 and include such interesting birds as the Regent Parrot, Elegent Parrot, Spotted Nightjar, White-breasted Robin and the Red-eared Firetail. Much banding of bushbirds has taken place at the Centre, often as part of the programme for school visits. Between 1987 and 1999, 4942 individuals had been banded of 43 species, with retraps totaling 1040 (21%), again showing that many of these species are resident or return regularly to the Capel Wetlands Centre (Doyle 1995 and pers. comm.). By 1994 some interesting longevity records had been obtained (Table 6).

Table 6. The longevity of bushbirds at the Capel Wetlands Centre

Species	Longevity So Far	No. Times Recaptured
Splendid Fairy-wren	4 years, 5 months	7
White-browed Scrubwren	3 years, 10 months	6
Inland Thornbill	2 years, 10 months	4
Western Spinebill	3 years, 9 months	6
Silvereye	3 years, 1 month	1

In addition to banding at the Capel Wetlands Centre itself, banding was also undertaken on the adjacent Ludlow River, approximately a kilometer away. At least five species were found to move between the river and the Centre, and to be caught at various places at the Centre (Doyle 1995).

Using the methods of the Australian Birds Count (ABC), Frank Doyle (1995) has recorded the status of bushbirds at the Capel Wetlands Centre since 1990. The six areas are shown in Figure 4 and include three grassland areas and three woodland areas. The results for these sites were compared with three sites in tuart *Eucalyptus gomphocephala* woodland and three sites in jarrah *E. marginata*/marri *Corymbia calophylla* woodland outside the Centre. The results showed the grassland sites to be poor in birds, but that the numbers recorded on the other three types of site were comparable. Although honeyeaters dominated the species at the Centre, other species were also present. If more woodland is planted at the Centre the numbers and diversity of bushbirds should gradually increase.

In the meantime it seemed advantageous to increase the diversity of honeyeaters. Red Wattlebirds and Brown Honeyeaters are at the Centre in abundance, but the small species are scarce, although the numbers of New Holland Honeyeaters increased after 1991. In 1996/97 Sarah Comer undertook a comparative study of the abundance of honeyeaters at the Capel Wetlands Centre and the nearby undisturbed native bushland on the Capel Nature Reserve. She also examined the plants fed upon by the honeyeaters at each site. She found (Comer 1997) that the diversity of honeyeaters on the two sites was comparable, but that Red Wattlebirds and New Holland Honeyeaters dominated the honeyeater assemblage at the Capel Wetlands Centre, whereas the small honeyeaters, the Western Spinebill and the White-naped Honeyeater, were rare at the Capel Wetlands Centre. On the other hand, the small Brown Honeyeater was equally abundant at both sites. She suggested that the structure of the vegetation at the Capel Wetlands Centre helped to enable the aggressive species, Red Wattlebird and New Holland Honeyeater, to dominate the assemblage to the disadvantage of the small species. Nectar-bearing plants are concentrated around the lakes at the Capel Wetlands Centre, whereas they are dispersed through the vegetation at the Capel Nature Reserve. As a result it is easy for the aggressive species to "protect" the concentrated food resources at the Capel Wetlands Centre. On the Capel Nature Reserve the small species are able to gather nectar from the dispersed plants, which cannot all be "protected" by the aggressive species. An analysis of pollen loads from the honeyeaters at the two sites showed that samples from the Capel Nature Reserve contained more pollen of *Banksia* than those from the Capel Wetlands Centre, where *Banksia* is relatively rare. The Capel Nature Reserve was close to a commercial *Banksia* farm, and birds were seen visiting that to obtain nectar. The management implications of the results of this study are that, to encourage a diversity of honeyeaters to visit and remain at the Capel Wetlands Centre, nectar-bearing plants should be planted widely throughout the site, particularly away from the lakes. These could be Proteaceous or Epacridaceous species, such as were used by the birds on the Capel Nature Reserve, where they especially favoured *Banksia attenuata* and *Banksia ilicifolia*. The advantage of attracting a diversity of honeyeaters to the Capel Wetlands Centre is that they are conspicuous birds and would therefore make the site more attractive to visiting birdwatchers as well as assisting in pollination of the native species and thereby promoting natural regeneration.

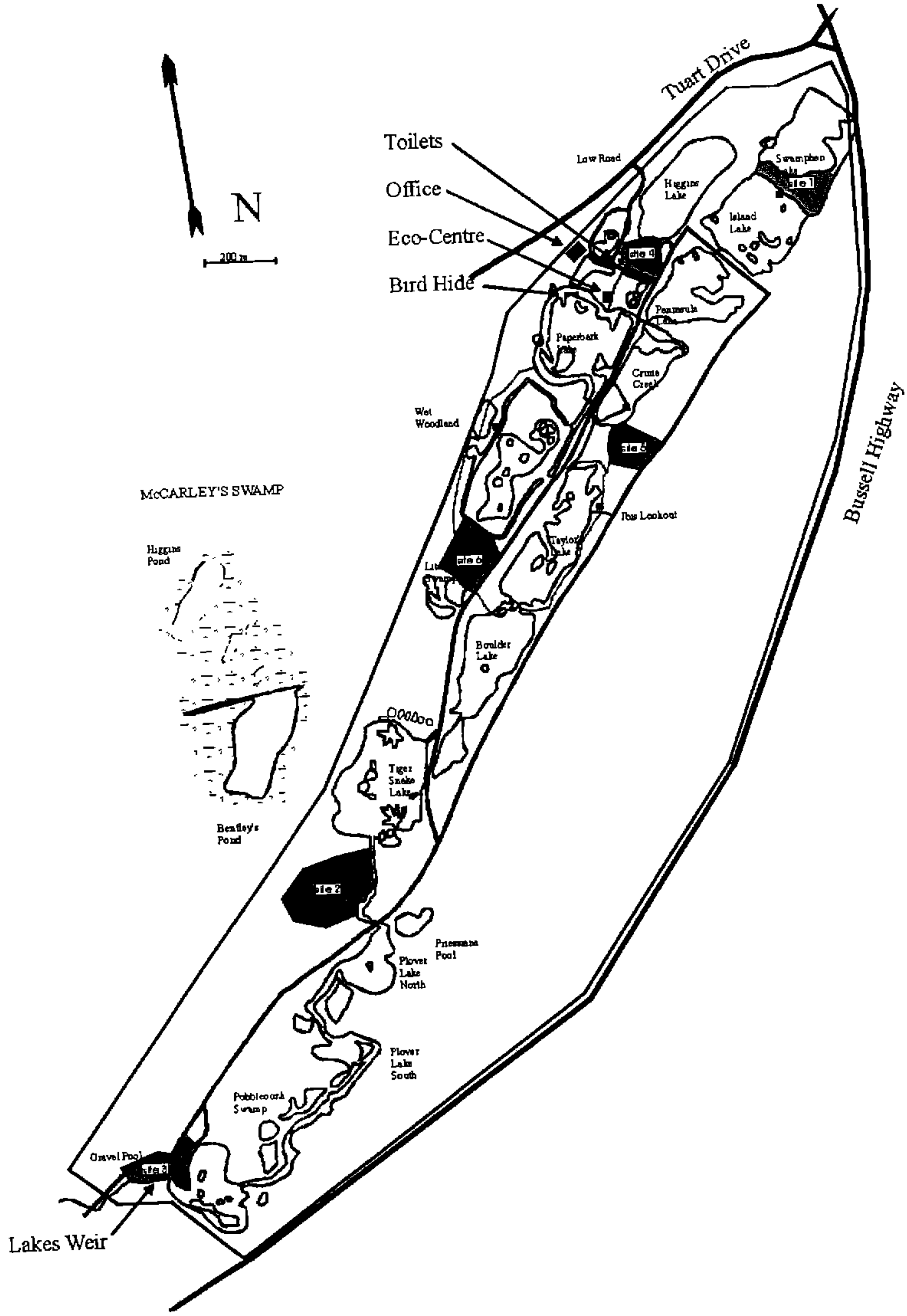


Figure 4: Map of the Capel Wetlands Centre showing the sites at which Australian Bird Count (ABC) observations were made.

8.2 *Water*

8.2.1 *Groundwater levels*

The Capel Wetlands Centre lakes have resulted from the of mineral extractions intersecting the ground water table. Their exposure was a consequence of the large volume of mineral ore removed during the sand-mining operation. Initially the lakes were used as reservoirs from which water was extracted to service the processing plant, and the water from the plant was discharged into the lakes again, so that they acted as a biological filter. Since 1987 the mining operation has pumped water for the processing plant from deep bores, no longer using water from the lakes. But throughout the life of the processing plant (it closed in 1999) the water has been discharged through the lakes. Early in the development of the Capel Wetlands Centre it was realised that it was essential to estimate what would happen to the water levels in the lakes when water no longer flowed into them from the processing plant. Accordingly Neild and Townley (consulting hydrologists) were asked to estimate what would happen to the groundwater table (on which the lakes ultimately depend) when the processing plant ceased operation. They collected such data as were available and applied them to the model AQUIFEM-N in order to estimate the long-term levels of the lakes (Neild and Townley 1987). This study suggested that the groundwater flux across the lake system was about 3,100 cubic metres a day. When the processing plant was operational the discharge at the end of the lake chain was about 270,000 cubic metres a year, and the input of processing water into the groundwater was about 770,000 cubic metres a year. Their estimate of the residence time of water in the lakes gave a range of between 0.18 and 0.90 years. Applying the model to these characteristics of the lake and groundwater system indicated that the cessation of water input from the processing plant would result in a drop in water level of 3m in Swamphen and Island Lakes and of between 0.5 to 1m in Paperbark, Taylors, Boulder, Plover and Gravel. The situation in Peninsula Lake is equivocal; it is about a metre lower than Island, but above the levels of Paperbark and Taylors. In order to keep the levels of Swamphen and Island reasonable the study estimated the about 1000 cubic metres a day would need to be pumped into them.

The option of pumping to maintain water levels has never been finally ruled out, but since the results of their study became available, it has been recognised that while Swamphen and Island may eventually become ephemeral lakes, the other lakes should remain, provided no substantial change impacts on the groundwater table. Neild and Towley (1987) also pointed to the advantage of diverting all the processing water past the lakes, so that, when the plant finally closed, the lake system would already have adapted to the ultimate water levels. In 1997 a diversion drain was dug that took the water from the plant past the upper lakes and emptied it into Taylor's Lake, thus partly achieving their suggestion. An additional factor, not realised during their study, is that in some years, the Ludlow River floods to such an extent that it flows back into the lake system at least as far up it as Paperbark Lake, thus providing a massive input of surface water not taken into account in the model.

8.2.2 *Water quality*

In addition to questions of sustainability of the water bodies, research was initiated into the quality of the water in the lakes. Gordon and Chambers (1987) made a baseline study of the water ecology and vegetation of the lakes in March, April and May 1987. Their assessment of the vegetation will be discussed later. The results of the water ecology work provided the base from which management of the Capel Wetland Centre Lakes could begin. They showed that the pH of Island Lake varied greatly and was often low, about pH 3 (Figure 5). The other principal findings are summarised in Table 7, taken from Table 5 of their paper.

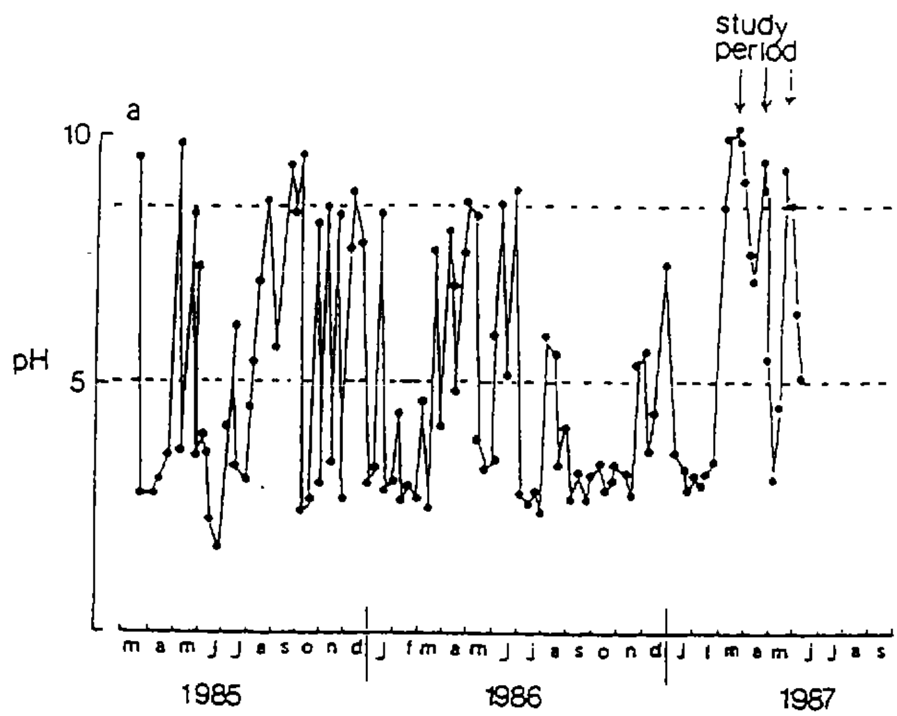


Figure 5. Long-term weekly records of pH in the inflow to Island Lake. The dashed lines enclose the pH limits usually acceptable to plant growth (from Gordon and Chambers 1987).

Table 7. Summary of water quality data[1], Capel Wetlands Centre. Figures shown are means ± standard error (S.E.) and ranges of surface (S) and bottom (B) water samples from the lakes. All concentrations are $\mu g\ litre^{-1}$ (from Gordon and Chambers 1987).

		Swamphen Lake		Island Lake - Gravel Pool		Ponds 9-12		Bentley's Pond	
Variable	Depth	Mean ± S.E.	(range)	Mean ± S.E.	(range)	Mean ± S.E.	(range)	Mean ± S.E.	(range)
Total P	S	49 ± 31	(14-111)	14 ± 2	(4-64)	163 ± 89	(22 - 418)	721 ± 87	(623 - 968)
	B	41 ± 11	(10 -68)	31 ± 5	(6 - 120)				
PO_4-P	S	5 ± 1	(3 - 7)	6 ± 2	(2 - 24)	49 ± 21	(17 - 99)	529 ± 42	(461 - 612)
	B	22 ± 12	(7 - 46)	21 ± 13	(1 - 87)				
NO_3-N	S	110 ± 60	(10 - 220)	142 ± 30	(4 - 495)	86 ± 51	(6 - 223)	9 ± 5	(1 - 18)
	B	124 ± 61	(11 - 223)	135 ± 30	(4 - 493)				
NH_4-N	S	29710 ± 3470	(22300 - 35350)	47700 ± 1440	(34000 - 82700)	313 ± 87	(102 - 500)	533 ± 272	(95 - 1050)
	B	31910 ± 4260	(24050 - 38750)	47100 ± 1640	(33200 - 57600)				
Organic P	S	43 ± 32	(8 - 108)	8 ± 3	(0 -36)	114 ± 70	(5 - 319)	178 ± 109	(11 - 407)
	B	20 ± 6	(3 - 62)	7 ± 3	(0 - 117)				
Organic N	S	17604 ± 4071	(9564 - 25303)	16995 ± 2250	(420 - 45179)	3615 ± 840	(2535 -5909)	12927 ± 3560	(6100 - 18642)
	B	18497 ± 6430	(6883 - 29052)	19900 ± 2680	(316 - 47440)				
Silicate	S	1020 ± 540	(420 - 2100)	428 ± 69	(60 - 1300)	5625 ± 426	(4400 - 6100)	2000 ± 1600	(70 - 5200)
	B	790 ± 303	(310 - 1350)	362 ± 74	(40 - 1500)				
Chlorophyll a	S	2.2 ± 1.0	(0.01 - 4.3)	6.6 ± 1.0	(0.01 - 21.4)	11.2 ± 7.7	(1.7 - 34.2)	34.3 ± 11.0	(14.5 - 74.8)
	B	4.7 ± 2.0		6.4 ± 1.3	(0.01 -24.2)				

1 Means and ranges are from March, April and May field sampling combined. March values are from 3 sites per lake; April and May values are from one site per lake; May samples from Swamphen, Island, Taylor's, Gravel and Higgin's only.

2 Ponds 9 - 12 S + B integrated samples; April only.

3 Very shallow; S + B integrated; Higgin's Pond.

The water quality of the Capel Wetlands Centre lakes was markedly different from that of the control wetland, Higgin's Pond. The lakes of the Centre generally displayed low pH, low concentrations of inorganic and organic phosphorous and high concentrations of inorganic nitrogen; the opposite was true of Higgin's Pond. All the lakes were well oxygenated and without temperature or oxygen stratification at the times sampled. Comparison of mid-day and pre-dawn oxygen content in Swamphen and Island Lakes suggested that diurnal changes in the water were small. The nutrient status of the lakes was found to increase with increasing age. Higgin's Pond was the most eutrophic, followed by ponds 9-12, Swamphen Lake, and finally the other lakes. Comparison of nutrient and chlorophyll concentrations of the lakes with trophic tables suggested that Higgin's Pond was eutrophic/polytrophic. The lakes, other than Swamphen, were mesotrophic with respect to phosphorus and chlorophyll but were clearly eutrophic with respect to nitrogen. The oldest lakes, 9-12, were eutrophic. All the Capel Wetlands Centre lakes, which at the time were directly linked to the effluent channel from the processing plant, had very high concentrations of ammonia, derived directly from the effluent channel. Swamphen Lake, not linked to the effluent channel, also had these high concentrations of ammonia, which may have come from leakage from the channel through the loose sand between the channel and the lake.

Four problems in water quality of the Capel Wetlands Centre lakes were therefore apparent, which reduced the value of the lakes as a wetland for birdlife and limited the productivity of the system. They were all linked to the existing water quality of the input stream.

1. Variable and often very low pH.
2. Excessive ammonia.
3. Low phosphorus levels.
4. High inputs of iron, manganese and other compounds.

Low pH reduced growth through interference with plant and animal cell function, potentially reduced the availability of inorganic carbon in the water, and limited the capacity of the system to exchange nutrients and build up a bank of organic matter through suppression of re-dox reactions (nitrification, denitrification, phosphorus release from sediments). A large background pool of ammonium would potentially provide toxic levels of free ammonia when pH is raised and produced high inorganic N:P ratios, far exceeding natural systems. Low phosphorus levels limited plant productivity and led to phosphorus limitation, particularly under the existing conditions of high inorganic nitrogen concentrations. High levels of iron and manganese increased the potential for phosphorus-complexing in the sediment, reducing the availability of phosphorus for plant growth and thereby reducing productivity.

The organic phosphorous contents of the sediments of the Capel Wetlands Centre lakes were well below those of the natural Higgin's Pond. In contrast the ammonia content was high in the lakes compared with Higgin's Pond. The ammonia of sediments was highest in the superficial algal ooze compared with the underlying sediments in Island and Taylor's Lakes.

Given these results it was clear that high priority had to be given to improving the water quality in the Capel Wetlands Centre lakes if they were to become productive enough to support a substantial population of wetland birds. As a first step the company agreed to increase the pH of the input of water from the processing plant. From 1987 the pH of this water was increased to the point where most of the lakes recorded a steady pH value of 6 or above (Figure 6). The increased number of species using the lakes after that time has already been noted. Several further studies were commissioned in 1988 aimed at establishing the best management techniques for redressing the imbalances in the water quality of the lakes, so that they would become more productive than at the start of the project.

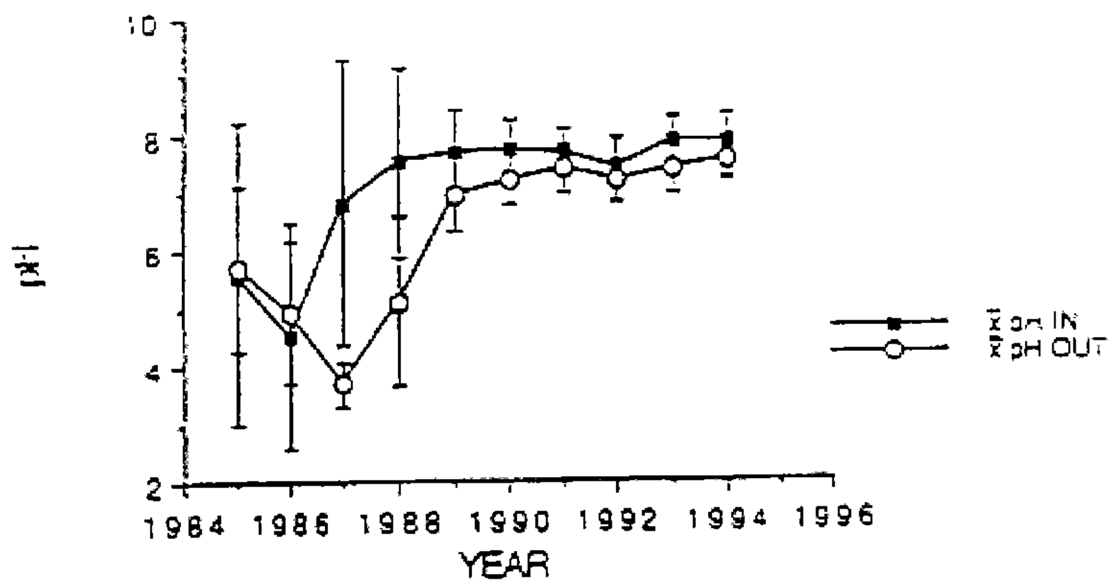


Figure 6. Average pH and standard deviation of inflow and outflow water of the Capel Wetlands Centre from 1985-1994. Averages are from samples taken weekly throughout the year (from Chambers and McComb 1996)

In these experiments Chambers and McComb (1996) used intact cores of sediment and water taken directly from Paperbark Lake and examined the effects of various manipulations in the laboratory. The first experiment assessed the effect of raising the pH of the water on the chemistry of the lakes. The results showed that the lake system had a strong buffering capacity, that an increase in pH had no effect on nitrogen and phosphorus concentrations and that no loss of ammonia through volatilization occurred. This indicated that increasing the pH of the Capel Wetlands Centre lakes would require the addition of a large quantity of base over a long period of time. In fact, as Figure 6 shows, the company maintained the input of base at the outlet of the plant and the pH did gradually increase to a more or less neutral level after three years.

The second experiment investigated the fate and effects of adding different concentrations of phosphorus to the lakes. Addition of phosphorus, resulting in initial concentrations of greater than 500 μg P l^{-1}in the water column, resulted in increased phytoplankton biomass. Phosphorus added to the water was rapidly removed, effectively in 30 minutes, from the soluble phosphorus pool and bound to iron and manganese compounds. The bound phosphorus was releasable and resulted in an equilibrium concentration of 10-30 μg P l^{-1} in the water column, irrespective of the amount of phosphorus added. During phytplankton blooms up to 15% of the total nitrogen pool was removed from the water column, indicating that a significant quantity of ammonium-nitrogen could be removed through algal uptake.

In the third experiment, algal bioassays were used to examine the relationship between phosphorus and algal productivity, in the absence of the sediment component. In this experiment, addition of phosphorus increased phytoplankton growth at concentrations greater than 50 μg P l^{-1} and increased it further from 500 to 5,000 μg P l^{-1}, indicating the substantial efficacy of the sediment in reducing the availability of phosphorus in the water column.

The fourth experiment investigated the phosphorus uptake capacity of the sediments, utilising slurries of water and sediment. The sediments in the lakes had a high phosphorus binding capacity, with a maximum absorption of 15.7 g P m^{-2} (in a 1 mm thick layer of sediment). This compares with the sediment concentration at that time of approximately 0.14 g P m^{-2} . The bond was fairly weak and phosphorus was probably accessible through equilibrium reactions between the water and sediment. At very low phosphorus concentrations of the water column, small quantities of phosphorus would be released by the sediment but this would be insufficient to support significant algal biomass.

As a fifth experiment, a respiratory carbon source was added to darkened wetland microsystems to drive the sediments anoxic, thus preventing phosphorus bonding to iron and manganese, and promoting phosphorus release from the sediments. Bacterial blooms immediately utilised released phosphorus and it was precipitated back to the sediment in particulate form. A greater proportion of the phosphorus was removed from the water column in this way, than would occur through aerobic bonding to iron in the sediment. There was insufficient phosphorus in the sediment to cause a concurrent increase in the phosphorus concentration of the water column, over and above the requirements of the bacteria.

The bacterial uptake of phosphorus might allow increased algal growth in the long term, following decay of the bacterial bloom, so in the sixth experiment carbon was added to see if greater and/or more persistent algal growth might result from the bacterially-mediated phosphorus release. The addition of carbon resulted in bacterially-mediated phosphorus release and the added phosphorus supplied sufficient for algal blooms to occur, subsequent to the bacterial bloom. Aeration inhibited this process, resulting in a lower availability of bacterially-mediated phosphorus and hence a lower algal biomass. When carbon, but no phosphorus, was added, the system was too phosphorus limited to support significant algal growth.

When carbon was not added, algal blooms occurred later, but were of greater duration and chlorophyll concentration, under aerated and mixed conditions. The mixing was the driving force for this process, promoting phosphorus release to the phosphorus-depleted water column and maintaining its availability under the experimental conditions. The process was thought likely to be less effective under the throughflow conditions experienced in the field.

As a result of these experiments it was clear that the ecosystem was seriously deficient in phosphorus, partly because much of it was bound in the sediments. The addition of phosphorus needed to be in a form that maximised its long term use in the water column. Management that reduced the influence of the sediment on the phosphorus dynamics of the water column, such as blanketting the sediments with another substrate, was also recommended. The addition of carbon was shown to be beneficial, but it, too, needed to be in a slow-release form. The addition of straw, which might create local anaerobic conditions in the sediment (and hence promote phosphorus release from it) without leading to bacterial blooms, was thought to be the best strategy. These ideas led to a series of field experiments investigating the effects of the addition of superphosphate and straw to whole lakes, on the water quality and the macroinvertebrates of the lakes. Before reviewing these experiments it is useful to describe the baseline work on algae and macroinvertebrates.

8.3 *Algae*

8.3.1 *Baseline surveys*

The first survey of algae in the Capel Wetlands Centre lakes was undertaken in May 1987 (John 1988). This survey covered the phytoplankton, benthic flora and filamentous green algae on Swamphen, Island and Taylor's Lakes, the phytoplankton and benthic flora of North Plover Lake and Higgin's Pond (part of the natural McCarley's Swamp), and the filamentous green algae of Paperbark Lake. The survey recorded 66 taxa of algae, five blue green algae (cyanobacteria), two desmids, two dinoflagellates, three filamentous green algae and 54 diatoms. Most of the algae were collected in the benthic sample; only the two dinoflagellates *Peridinium* and *Glenodinium*, were observed as blooms in the phytoplankton. A full list of the taxa identified is given in the Appendix. Benthic diatoms dominated all the sites, but Table 8 shows that different taxa were dominant at the various sites.

Table 8. Dominant taxa of algae in each lake at the Capel Wetlands Centre in 1987

Lake	No. of Taxa	Dominants
Swamphen Lake	25	*Nitzschia obtusa, N. palea, Brachysira vitrea**, B. serians#*
Island Lake	8	*Nitzschia palea, Brachysira vitrea**
Taylor's Lake	20	*Nitzschia palea, Brachysira vitrea**, B. serians#*
North Plover Lake	19	*Brachysira vitrea**, B. serians#*
Higgin's Pond	62	*Eunotia curvata, Pinnularia viridis*

**Brachysira vitrea* called *Anomoeoneis exilis* in John (1988).
#Brachysira serians called *Anomoeoneis serians* in John (1988).

The natural Higgin's Pond was richest in species and was the only eutrophic water body sampled. All the others were oligotrophic. The diatom assemblages in the Capel Wetlands Centre lakes reflected the low pH and high ammonia status of the lakes. Swamphen Lake most closely approached the natural wetland, but Island Lake, which at that time received the water from the processing plant, had very few species, and was poorer than lakes lower down the system, suggesting that conditions for algae may improve as the water passes through the lakes.

8 3.2 *The search for indicator species*

This initial survey of algae was followed between 1988 and 1993 by a series of surveys aimed at determining indicator species for water of different qualities. The results are summarised in John (1993a and b) and John and Helleren 1998). Over these years the pH of the water in the lakes of the Capel Wetlands Centre rose from about 3 to about 7. This was accompanied by a change in the dominance of the species of algae in the lakes. By 1993 the lakes were dominated by periphytic, alkaliphilous diatoms, preferring water bodies of high conductivity, such as *Chaeoceros muelleri, Cymbella minuta* and *Cylotella meneghiniana*, that had always been common in the natural Higgin's Pond. Planktonic diatom blooms replaced dinoflagellate blooms. Desmids, such as *Pediastrum* sp. and *Chamydomonas* sp., became common and the filamentous green algae *Spirogyra* and *Oedogonium* appeared in the most alkaline lakes. In Nitella Pond (called lake 8a2 in the publication), where the pH was above 8 and the conductivity low (i.e. the water fresh) three species of Charophytes (one *Nitella* sp. and two *Chara* sp.) formed a thick meadow. These changes could be directly related to changes in water quality and enabled the identification of indicator species. The growing shoots of the *Nitella* sp. in Nitella Pond were surrounded by copious mucilage, which harbored a thriving community of diatoms, blue green algae and desmids. The mucilage is composed of mucopolysaccarides containing alkaline phosphatase, which is thought to acquire resources for the plant by extra cellular catalysis (Raven 1992). Organic phosphorus, carbonic acid and Fe^{3+} may be converted into carbon dioxide, inorganic phosphorus and Fe^{2+} by alkaline phosphatase activities, making these chemicals easier for the plant to absorb. The thick boundary of mucilage minimises the loss of converted nutrients into the surrounding water column. In addition the mucilage trapped iron and manganese, so that this species, and one of the *Chara* sp., may assist in improving the water quality by removing heavy metal ions from the water column. The most common species of algae are listed in Appendix, which indicates the changes in their relative abundance as the wetlands have developed.

In a further study John and Gayton (1994) compared the diatom communities in the mucilage sheath of *Nitella hyalina* from Nitella Pond (incorrectly called Plover Lake in the publication), an alkaline lake, with that in the mucilage sheath of *Nitella hyalina* from Lake Leschenaultia, a circumneutral or slightly acidic lake. They showed that the diatom communities from the mucilage sheath was essentially the same in the two lakes, even though the diatom communities in the free water and sediment of the two lakes differed. They pointed out that the diatom community from the mucilage sheath of *Nitella hyalina* could therefore not be used to assess the quality of water in the lakes. The diatom community was characteristic of the microhabitat of the mucilage sheath, rather than of the surrounding water. Table 9 compares the diatom flora from the *Nitella hyalina* mucilage sheaths of the two lakes, indicating the dominant species and the species unique to each lake.

Further work on the charophytes of the Capel Wetlands Centre (Ward *et al.* 1997) was directed at a comparison between Nitella Pond and a nearby farm dam (Bentley's Dam) with the aim of determining the conditions under which charophytes could be introduced to other lakes in the Capel Wetlands Centre. Both Nitella Pond and Bentley's Dam were characterised by low conductivity (low levels of mineral ions) and a high pH. These characteristics of the water correlated with large masses of charophytes, which have been shown to be able to take up mineral ions, thereby reducing conductivity. Other lakes in the Capel Wetlands Centre had a somewhat higher pH and high levels of mineral ions. Attempts were made to establish charophytes in Cadjeput Pool, North and South Plover Lakes, but these were not successful. It was thought that, although the charophytes are able to store high levels of mineral ions in their thalli, the levels of mineral ion in these three lakes was so high, taken with the low phosphate status, that it prevented establishment. The study also showed that the charophytes could compete successfully with other aquatic macrophytes, such as *Potamogeton* and *Typha*, in Nitella Pond. In addition it demonstrated that the vigorous growth of charophytes enabled much higher densities of invertebrates to survive than did so in other lakes in the Capel Wetlands Centre where the charophytes did not grow, probably because the dense aquatic vegetation offered the invertebrates shelter and food. It would clearly be advantageous to establish charophytes in lakes throughout the system, but the study was unable to suggest ways to effect this.

Table 9. The species of diatoms found in the mucilage sheath surrounding the growing points of the charophyte *Nitella hyalina* in two Western Australian lakes, one alkaline and one neutral to acidic. Dominant species are marked with an asterisk (*).

Nitella Pond	Lake Leschenaultia
Species common to the two lakes	
Achnanthes minutissima	*Achnanthes minutissima**
*Amphora veneta**	*Amphora veneta*
Brachysira serians	*Brachysira serians*
*Cymbella microcephala**	*Cymbella microcephala*
Eunotia pectinalis	*Eunotia pectinalis**
Gomphonema gracile	*Gomphonema gracile*
Mastogloia elliptica	*Mastogloia elliptica*
Nizschia obtusa	*Nizschia obtusa*
Synedra rumpens	*Synedra rumpens*
Species unique to one lake	
Cymbella cesatii	*Cocconeis placentula**
*Cymbella pusilla**	*Eunotia camelus*
*Mastogloia smithii**	*Eunotia curvata*
Rhopaloida gibba	*Eunotia flexuosa*
*Rhopaloida novae zealandae**	*Frustulia rhomboides*
Stauroneis pachycephala	*Gomphonema acuminatum*

8.4 *Fringing vegetation*

The baseline study by Gordon and Chambers (1987) surveyed the existing aquatic vegetation and recommended strategies for the future development of the wetlands. They found that, like the studies of the algae, the chief limitation to the establishment of higher plants in the lakes were the low pH and low phosphorus concentration. The lack of shallow water also prevented the spread of fringing vegetation. They recommended landscaping the banks and the construction of spits and islands, the shores of which would become shallowly flooded during the rains of winter So far as possible the shore needed to be sandy, rather than compacted gravel, to encourage the growth of the roots of fringing vegetation. Development work along these lines, together with intensive plantings of fringing vegetation, has led to vigorous growth along the shores of most lakes. In another study, funded by the Minerals and Energy Institute of Western Australia, and undertaken in collaboration with Westralian Sands Ltd. and ALCOA (Australia) Ltd., Chambers, Fletcher and McComb (1995) examined ways of propagating rushes and sedges. The results of their work were published in a useful handbook "*A Guide to Emergent Wetland Plants of South-western Australia*" Chambers *et al.* (1995), that describes fourteen common wetland plants of the south-west, how to identify them and how to propagate them. Many of these plants, which have important application in nutrient-stripping and in stabilising the banks of streams, are best propagated by transplantation of rhizomes; for some the research was unable to germinate the seeds of some species at all, while others could be propagated easily from seed. Subsequent, accidental, experience at the Capel Wetlands Centre nursery has shown a possible explanation for these germination failures. Some rush and sedge seeds, planted in germination trays, were carried over from one year to the next. At the end of their second year some of the seeds germinated, suggesting that a dormancy mechanism may have operated to prevent their germination in the first year. Experimental trials, and many commercial nurseries, do not maintain germination trays for longer than three months; only under the persistent husbandry of the Capel Wetlands Centre nursery did the seeds have the chance to show their true requirements.

8.5 *Invertebrates*

Alongside studies of the water and vegetation, scientists from the Aquatic Research Laboratory, Department of Zoology, The University of Western Australia initiated studies of the invertebrates of the Capel Wetlands Centre. In the baseline studies, Cale and Edward (1987) sampled the planktonic, benthic and macrophyte fauna of Swamphen, Island, Paperbark, Taylor's, Boulder, Tiger Snake and North Plover Lakes, Cadjebut and Gravel Pools and Litoria Swamp, during January, February and May 1987. The survey recognised 77 invertebrate taxa within the lakes of the Capel Wetlands Centre; Bentley's Pond and Scott's Dam were also sampled, but added only six taxa to the list (Appendix). The results showed that the lakes of the Capel Wetlands Centre had a high species richness compared with the natural wetlands, Bentley's Pond and Scott's Dam, mainly because some of the lakes had stands of fringing macrophytes. The samples from the macrophytes increased species richness by 25-50% compared with the samples from the plankton and benthos. The lake faunas tended to be dominated by one or two taxa, for example *Tanytarsus* sp. (Chironomidae: Diptera), whereas many taxa were scattered through the lake system, but nowhere common. Less than half the taxa had a relative abundance of more than 1%. Swamphen Lake had the greatest species richness; 57% of all identified taxa were at some time found in it, and Chironomidae were particularly abundant there, but rare in the other lakes. There was a significant positive correlation between species richness and percent-cover of fringing vegetation. The invertebrates of the Capel Wetlands Centre lakes were mostly those typical of oligotrophic lakes, compared with the taxa in the natural wetlands that were those typical of euthrophic lakes. The results of their survey confirmed the assessment made by other researchers, that the lakes of the Capel Wetlands Centre needed much management to make them as productive as natural wetlands. Cale and Edward (1987) emphasised that the addition of stands of macrophytes to the lakes would make a substantial contribution to the productivity of the wetland.

Following this study Cale and Edward (1990a) made a detailed study of one lake in the Capel Wetlands Centre, Boulder Lake. The study ran for a year from December 1987. During this time the pH of the lakes changed from highly acidic to almost neutral, so that, as well as examining seasonal and spatial differences in the invertebrates, the study was able to quantify the changes that the improved water quality made to the fauna. After the pH change the numerical dominance of *Tanytarsus* sp. disappeared. Seasonal diversity of species increased as pH increased, so that additional species, particularly of Chironomidae, Ostracoda, Cladocera and Cyclopoida, appeared in the plankton and the benthos. The differences observed between the two December data sets, December 1987, before the pH was adjusted, and December 1988, indicated that these changes were not seasonal but represented a response to the changed pH of the water.

Total abundance in the benthos decreased as pH approached neutrality. Standing biomass decreased at the same time, but the difference was less than that observed for abundance, because many of the new chironomids were larger than *Tanytarsus* sp. which had previously represented the bulk of the benthic biomass. The zooplankton also changed. The micro-crustacea were favoured by neutral pH whilst the coleopteran plankters that had been abundant, decreased. After the pH change the total abundance of individuals in the plankton of Boulder Lake was much less than that found in natural wetlands, but the species composition was more like that of natural wetlands. The micro-crustacea have shorter generation times than the coleopteran taxa, so that the productivity of the system was expected to increase, to the benefit of the waterbirds that fed on them, as well as to increase the input of organic matter to the lake. Although the seasonal changes of abundance and diversity were masked by the changing pH, it was possible to identify characteristic summer and winter faunas. Extensive sampling showed that the fauna was substantially uniform within the lake, so that future monitoring could be maintained by sampling at two sites instead of the eight used in the initial study. Depth and pH were the only lake variables that explained large amounts of the variance observed in community measures between sites, bearing out the uniformity of the fauna. Compared with a nearby natural wetland the greatest diversity in the fauna at Boulder Lake was in the benthos, whereas it was in the plankton of the natural wetland. The functional nature of the benthic communities changed in response to the altered pH. The abundance of filter feeders increased, compared with the previously dominant collectors and predators. This change was expected to enhance the stability and productivity of the wetlands, through enhanced opportunities for the recycling of energy within the community.

The importance of the fringing macrophytes to the productivity of the invertebrate fauna had been highlighted in the baseline studies (Cale and Edward 1987) so the next study compared two macrophyte stands, *Typha orientalis* and *Isolepis prolifera*, with an unvegetated area of the same lake, Swamphen (Cale and Edward 1990b). Swamphen Lake was chosen because it had a diverse invertebrate fauna and had substantial areas of open water and of the two macrophyte species. Only the benthos was examined because fauna had proved to be more diverse than the plankton in the previous study at Boulder Lake. The results showed that mean species richness, abundance and the standing biomass of macro-invertebrates (those most favoured by waterbirds) were statistically significantly lower in open water than in the vegetated areas. The fauna of the *Typha* and *Isolepis* stands were not statistically significantly different from each other. Standing biomass was nearly an order of magnitude greater in vegetated areas than in open water, reaching $8 g/m^2$ in the *Isolepis* stand, a value comparable with that from studies of other natural wetlands in Australia (Cale and Edward 1990b). The open water sites also differed from the vegetated sites in species composition, and key indicator species could be identified from each area. The aquatic snail *Isidorella* sp. was only found in open water; a damselfly larvae *Xanthagrion erythroneurum*, a chironomid larvae *Dicrotendipes* sp. 18, two Hydrophilid beetles (Hydrophilid sp. 1 and sp. 5) and a cladoceran (Cladocera sp. 3) were only found in the vegetated areas. Sites differed in the abundance of particular organisms. For example three of the five open water sites were the only ones of the 15 sites sampled that lacked a moderate abundance of oligochaete worms, and the other two open sites were the only ones to record an abundance of *Tanytarsus* sp., the organism so common before the improvement of water quality. The results of this study reinforced the usefulness of fringing vegetation, but also indicated that even apparently uniform environments, in this case the open water sites, could support different faunas.

The next invertebrate study compared, over three seasons, the invertebrate faunas of Paperbark and Boulder Lakes with that of the natural wetland, Higgin's Pond (Cale and Edward 1993). The aim of this study was to identify the factors that needed to be investigated to improve the development of the Capel Wetlands Centre to the point where the lakes were as productive as nearby natural wetlands. Samples, both benthic and planktonic, were taken in winter, spring and summer of 1988. The results showed that species richness was highest in Higgin's Pond in all seasons; it was at a maximum in spring/summer in all lakes, with 33 species/site in Higgin's Pond, 20 in Paperbark Lake and 25 in Boulder Lake. The crustacean order Amphipoda, which includes many food organisms of waterbirds, was only collected from Higgin's Pond, although other crustaceans, mostly Ostracods, were collected in the Capel Wetlands Centre lakes. Crustaceans made up 21-33% of the fauna of Higgin's Pond, 10-19% of the fauna of Paperbark Lake, and 10-21% of the fauna of Boulder Lake. Chironomid larvae dominated the fauna in all lakes (Higgin's 27-33%; Paperbark 7-35%; Boulder 13-30%) Although diversity in the benthos remained fairly constant at Boulder Lake, it was greatest in winter at Higgin's Pond and greatest in spring and summer at Paperbark Lake. The biomass in the benthos was greatest in summer in Higgin's Pond and Boulder Lake, and in the spring in Paperbark Lake. For the individual lakes the highest figures were: Higgin's 4.14g/m^2; Paperbark 0.56g/m^2; Boulder 0.74g/m^2. Only in spring was the biomass in Higgin's Pond not the highest of the three lakes, a time when the water in Higgin's Pond was shaded by a dense growth of algae. The biomass of the plankton was always highest in Higgin's Pond with values ranging from 0.47g/kl in summer to 0.71g/kl in spring. The figures for Paperbark Lake (<0.004g/kl) and Boulder Lake (0.004-0.01g/kl) were very low. Although this showed the Capel Wetlands Centre Lakes to be poor in invertebrates compared with the natural Higgin's Pond, in summer large numbers of the dragonfly *Orthetrum caledonicum* in Boulder Lake meant that prey size was larger in Boulder Lake at that time of year than in Higgin's Pond which was then dominated by small ostracods. Size of prey is an important consideration in the development of the optimal feeding strategies of waterbirds. In winter, when the large chironomid larvae of *Chironomus* aff. *alternans* dominated Higgin's Pond, prey size in that wetland was considerably larger than in the other two lakes under study. Cale and Edward (1993) considered that several factors may have led to the natural wetland being more productive than the lakes of the Capel Wetlands Centre The temperature of Higgin's Pond was up to 10^{o}C higher than in the other lakes, because Higgin's Pond was much shallower and the water darker than the lakes of the Capel Wetlands Centre. High temperature leads to high metabolism and therefore high productivity. In addition Higgin's Pond had much organic matter in the sediment and a high concentration of nutrients, compared with the other lakes. Under these conditions the breakdown of organic matter is accelerated so that primary production can be high. These factors are important but the main difference was in the balance of the N:P ratio. It was balanced in Higgin's Pond, but in Paperbark and Boulder Lakes there was very little phosphorus and a great excess of nitrogen (as ammonia) so that nutrients were imbalanced and productivity low.

8.6 *Fish*

In the early stages of the development of the Capel Wetlands Centre the fish fauna was taken for granted. The introduced fish *Gambusia holbrooki* was known to be present, but no attention was paid to the possible presence of native freshwater fish. Even though at the ARC Wildfowl Centre in Great Linford, England, fish had been shown to be significant competitors of young waterfowl (Giles 1992), the Australian freshwater species were thought to be so small as to pose no serious competition, but rather to provide a food source for grebes and cormorants. As rehabilitation progressed it was gradually realised that (as for other native animals) the wetlands provided an opportunity to create suitable environments for native fish, some of which now have relict distributions on the Swan Coastal Plain (Hambleton *et al.* 1996b). Accordingly in 1993 the Murdoch University Fish Research Group was asked to survey the Capel Wetlands Centre for the presence of native fish and to examine the possible impact of the abundant *Gambusia holbrooki* on native fish in the system. The studies (Hambleton *et al.* 1996a and b), undertaken in 1994 and 1995, sampled thirteen lakes within the Capel Wetlands Centre, and the adjacent Ludlow River. Four native fish, the western pygmy perch *Edelia vittata*, the western minnow *Galaxias occidentalis*, the nightfish *Bostockia porosa* and the blue-spot goby *Pseudogogius olorum* were caught in the lakes of the Capel Wetlands Centre. *Gambusia holbrooki* was abundant throughout the system and represented 93% of the 20,690 fish caught during the survey. Of the native fish *Edelia vittata* was most abundant; 922 were caught distributed in all lakes from North Plover Lake southwards. 373 *Galaxias occidentalis* were caught in North Plover Lake, Gravel Pool, Crossing Pool and South Pool. Only 197 *Pseudogobius olorum* were caught, but the trapping method was unsuitable for them; they were the most widely distributed native fish, occurring in Tiger Snake Lake and all lakes to the south of it. Ten *Bostockia porosa* were trapped from Gravel, Crossing and South Pools. These results suggested that the native species were slowly beginning to colonise the lakes as the water quality improved and habitat enhancement increased; for example nightfish were seen in Paperbark Lake in 1999. The fish may be taking advantage of occasional winter flood events when the Ludlow River flows back into the lakes of the Capel Wetlands Centre. The survey results suggested that the native species were breeding in the Capel Wetlands Centre with a seasonal pattern similar to that found in the Collie River. Comparison of the distribution of the native fish with water quality data showed that the catch per unit effort of all fish was inversely related to the concentrations of un-ionised ammonia, nitrate/nitrite and total nitrogen and directly related to the electrical conductivity.

The abundance of *Gambusia holbrooki* in the lakes of the Capel Wetlands Centre suggested that this introduced species might be actively competing with the native species. This was examined in a further series of observations and experiments (Hambleton *et al.* 1996a). Tests for interspecific dietary niche overlap between four species, *G. holbrooki*, *E. vittata*, *G. occidentalis* and *P. olorum* showed no statistically significant overlap between the four species. The diets of the two surface-dwelling fish species, *G. holbrooki* and *G. occidentalis*, contained high proportions of terrestral fauna and dipteran pupae, whereas those of the two benthic species, *P. olorum* and *E. vittata*, consisted of high proportions of dipteran larvae, ostracods, cladocerans and copepods. Fin damage to *E. vittata*, the native species with most fin damage, was significantly greater in lakes in which large numbers of *Gambusia holbrooki* lived. Laboratory experiments showed that fin damage to this native species was directly related to the density of *G. holbrooki* in the tanks, and mortality of *E. vittata* was highest in those tanks in which *G. holbrooki* was present. Despite these results there was no evidence from field work that competition for food resources or agonistic behaviour by *G. holbrooki* had restricted the distribution of native species in the lakes of the Capel Wetlands Centre.

8.7 *Frogs and reptiles*

Early in the project the importance of rebuilding the frog and reptile populations of the Capel Wetlands Centre was recognised as an important task. Frogs and tadpoles, in particular, were thought to be important in the food chain of several waterbirds, especially herons and egrets. Tadpoles, usually considered vegetarian, convert plant protein to animal protein and themselves provide the animal protein as a prey of suitable size for medium sized animals to include in their optimal foraging strategies. Later work at the Capel Wetlands Centre has shown that the assumptions underlying this concept need some qualification. A survey of the frogs and reptiles at the Capel Wetlands Centre was undertaken in 1988 and 1989 (Bamford 1990). The survey involved pit trapping at 12 locations, including a seasonal wetland on the Capel Nature Reserve, 4 km north-east of the Capel Wetlands Centre. In all 408 pitfalls were laid out between September 1988 and August 1989. The trapping established that all species of frogs common in the region were already present atn the Capel Wetlands Centre. However, few species could be found breeding there, and most of the frogs probably migrated onto the area from seasonal wetlands in the surrounding countryside. Only *Crinia insignifera* appeared to breed in the main lakes of the Capel Wetlands Centre and then only in Swamphen Lake, Litoria Swamp and the Wet Woodland. Tadpoles were seen in many seasonal wetlands and pools adjacent to the main lakes, and Bamford (1990) suggested that *Gambusia* might prey significantly on eggs and tadpoles in the main lakes. Despite the lack of breeding at the Capel Wetlands Centre, large populations of many species were found from marked individuals, to be remaining there. Bamford recommended that the suitability of the site for frogs could be increased by the construction of "frog hollows" - small seasonal wetlands near but not connected with the main chain of lakes - and by the modification of shorelines to expand the littoral zone and reduce its slope. The frogs and reptiles recorded at the Capel Wetlands Centre are listed in Appendix 2.

Of the 20 or more species of reptiles that might be expected in the region, only seven were caught at the Capel Wetlands Centre, and all seven appeared to be breeding there. A further four species, including the tortoise *Chelodina oblonga*, were observed on the site, and were probably also breeding there. Numbers were highest close to areas of remnant vegetation, and it was thought that further rehabilitation of the uplands in order to establish connections with surrounding remnant vegetation would benefit the reptile fauna. Only *Menetia greyii* was common, being present at more than half of the locations where pit traps were set. The population structure of this species indicated that it was breeding successfully at the Capel Wetlands Centre.

In further work in 1990, Bamford (1992) showed that the frog hollows, constructed in 1989, had improved the breeding rate of frogs at the Capel Wetlands Centre. Several environmental conditions had changed since the previous survey. An improvement in water quality in the lakes, and the planting of riparian and upland vegetation had improved the environment. On the other hand the initiation of grazing on the railway reserve and the felling of the pine forest, including the regrowth woodland, south and east of Pobblebonk Swamp had deprived the reptiles of remnants from which they had been invading the Capel Wetlands Centre.

Among the frogs, *Crinia glauertii* was more abundant than in the previous year, possibly due to the food and shelter provided by straw around the Wet Woodland and to an increasing density of flooded grasses around most of the lakes. *Heleioporus eyrei*, although poorly represented by immature specimens, was well-represented by adults. These had increased greatly in numbers since 1988/89, suggesting that the immature specimens caught in 1988/89 were the first successful wave of colonizing *H. eyrei*. No new frog species were caught in 1990. Two new reptiles *Lialis burtonis* and *Cryptoblepharus plagiocephalus* were caught on the site, but no improvement in the status of reptiles was evident.

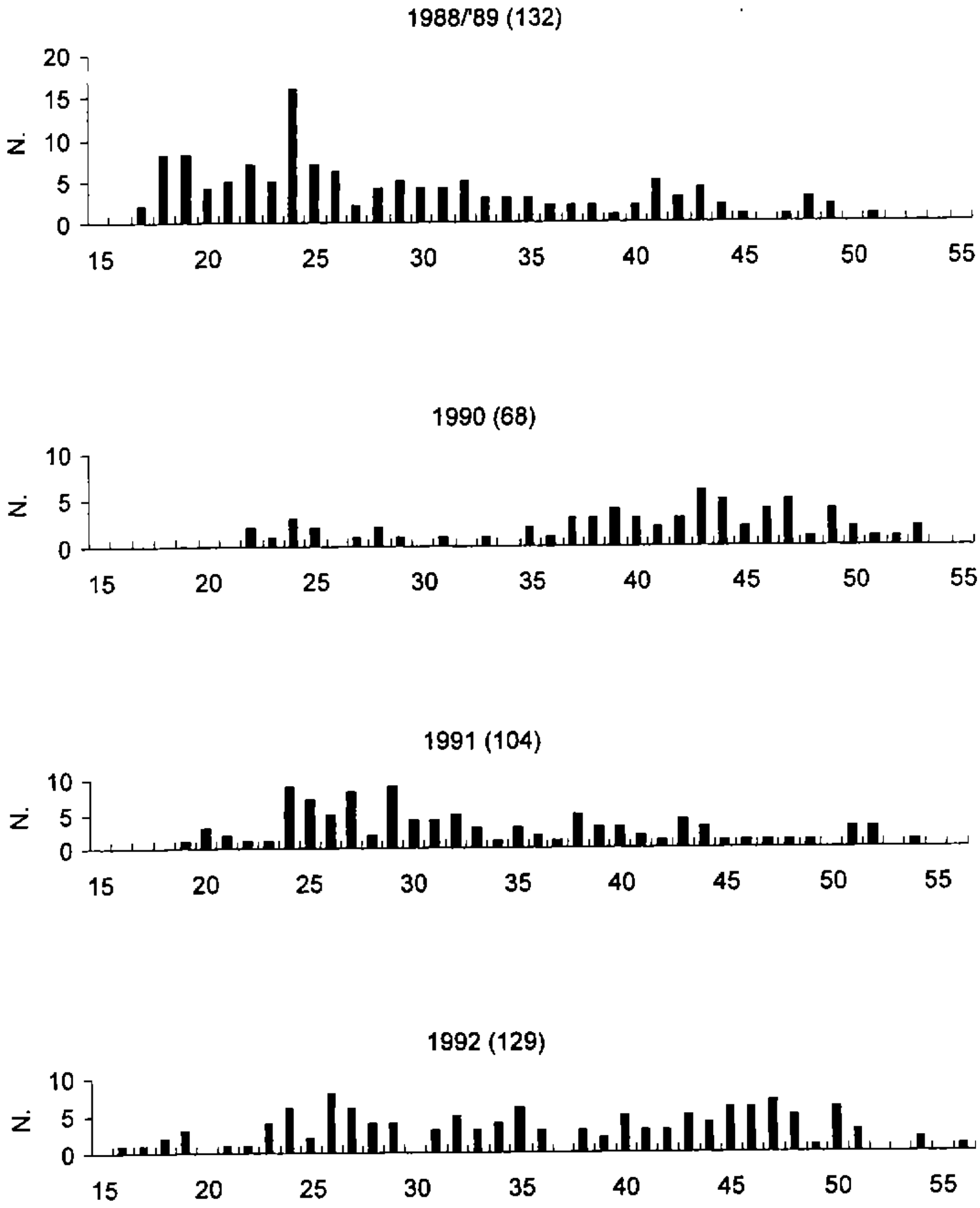


Figure 7a. Snout-vent length distributions in annual samples of *Heleioporus eyrei*. Sampling efforts were not the same in each year and were as follows: 1988/89 - 3,456 trap nights; 1990 - 3,690 trap nights; 1991 - 3,645 trap nights; 1992 - 3,645 trap nights. The sample in each year is given in parenthesis (from Bamford 1993).

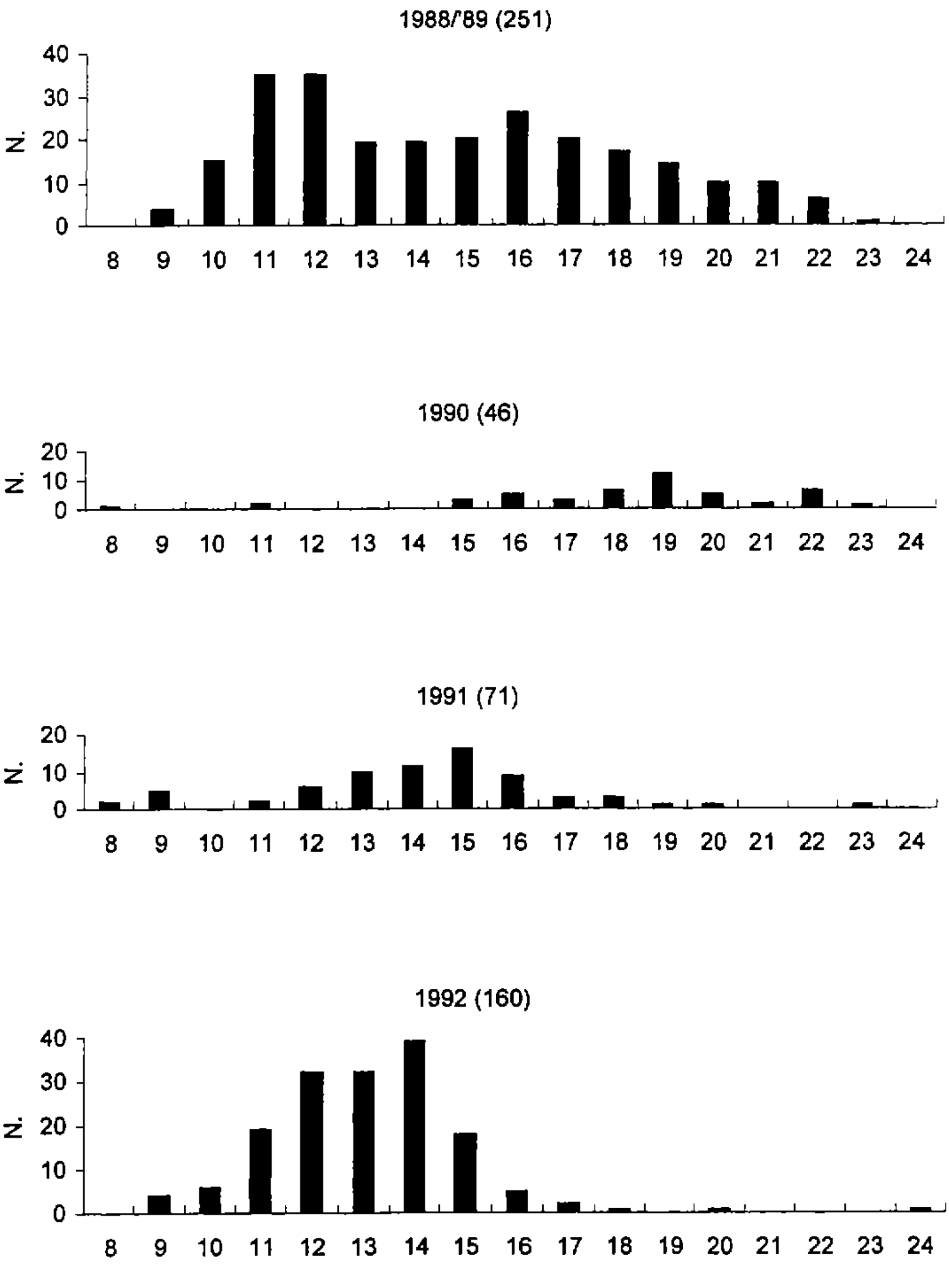


Figure 7b. Snout-vent length distributions in annual samples of *Crinia insignifera*. Sampling efforts were not the same in each year and were as follows: 1988/89 - 3,456 trap nights; 1990 - 3,690 trap nights; 1991 - 3,645 trap nights; 1992 - 3,645 trap nights. The sample in each year is given in parenthesis (from Bamford 1993).

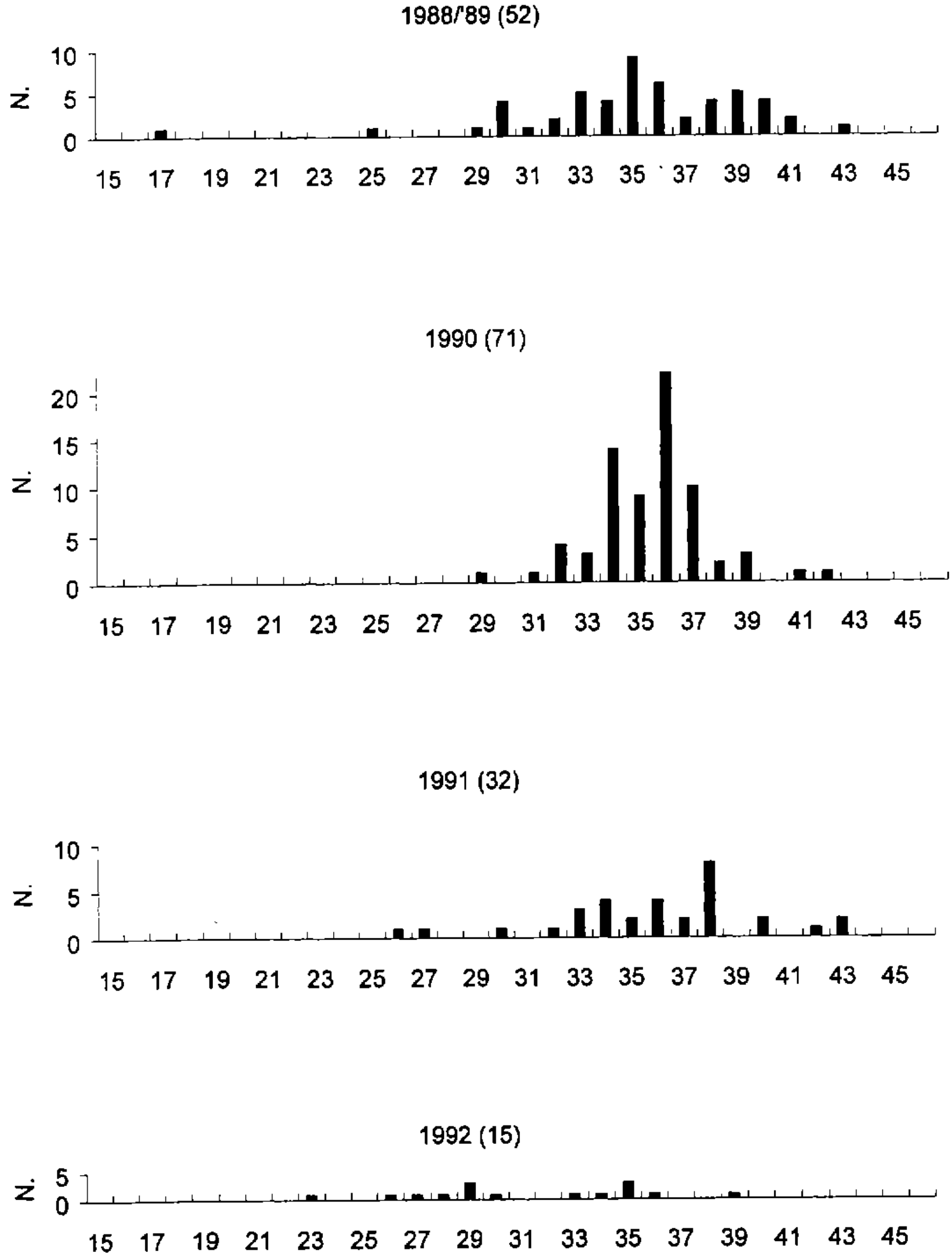


Figure 7c. Snout-vent length distributions in annual samples of *Menetia greyii*. Sampling efforts were not the same in each year and were as follows: 1988/89 - 3,456 trap nights; 1990 - 3,690 trap nights; 1991 - 3,645 trap nights; 1992 - 3,645 trap nights. The sample in each year is given in parenthesis (from Bamford 1993).

In 1991 and 1992 monitoring of the frogs and reptiles continued (Bamford 1993). Figures 7a, b and c (based on snout-vent distributions), illustrate the population structures of the commonest two frogs and commonest reptile over the years of study. Figure 7a, for *Heleioporus eyrei* shows variations in population structure that reflect successful and unsuccessful breeding seasons. Breeding was poor in 1990 due to the failure of early winter rain (Bamford 1992); this resulted in few immature specimens in 1990 and a high proportion (66%) of adults (snout -vent length > 45mm) in that annual sample. In 1991 only 24% of captures were adult, possibly influenced by poor recruitment from 1990. The proportion of adults in 1988/89 was also low (19%); it is not known if this was due to poor recruitment or if it reflected a colonization phase in the frog's population on the site. Population structure in 1992 seemed to be more balanced than in earlier years, with 44% of adults in the sample.

Figure 7b, for *Crinia insignifera* shows that the trends in population structure in the samples of this species were similar to those observed with *H. eyrei* in that little recruitment occurred in 1990, that year's sample being small with 87% adults (snout-vent length > 15mm). In 1988/89 the sample was 44% adult, compared with only 25% and 6% in 1991 and 1992 respectively. This may have been because the unusually favourable weather conditions during sampling in 1988/89 led to exceptional mobility of adults, or the converse may have operated to reduce the proportion in 1991 and 1992.

Figure 7c, showing the population structure in the reptile *Menetia greyii* indicates a scarcity of large specimens in 1992. Samples in 1988/89, 1990 and 1991 contained 94%, 99% and 94% adults (snout-vent length > 29mm) respectively, compared with only 53% in 1992. Bamford (1992) noted that reproduction in this species appears to involve the movement of females to favoured oviposition sites; the scarcity of adults in 1992 may therefore have resulted from a change in such microhabitat usage.

An implication from these figures is that the levels of abundance of these three species did not vary significantly between 1990 and 1992. After the five years of study Bamford (1993) was able to assess the status of the frogs and reptiles at the Capel Wetlands Centre and to indicate where further improvements might be made in the environment for their benefit.

1. Some species of local frogs, notably *Heleioporus eyrei*, *Crinia glauertii*, *C. insignifera*, and *Litoria adelaidensis*, have colonized the area. The other locally common species *Lymnodynastes dorsalis* and *Geocrinia leai* are poorly represented at the Capel Wetlands Centre.

2. Colonization by frogs occurs in spring when recently metamorphosed specimens disperse widely from adjacent natural wetlands. The abundance of frogs did not change between 1988 and 1992, probably because large numbers of frogs were produced in nearby natural wetlands each year. This production and subsequent dispersal is probably the reason for the apparent "success" of frogs in colonizing the area. The poorly represented species had not increased in abundance.

3. Breeding of frogs in the Capel Wetlands Centre occurs mainly in "frog-hollows" and naturally flooded areas outside the main chain of lakes. Exceptions are the densely-vegetated shallows of Swamphen Lake, the Wet Woodland and the northern pool of Litoria Swamp. The latter two sites are free of *Gambusia holbrooki*. *Crinia* spp. bred in newly-created wetlands, including "frog-hollows", in the first season these were flooded. *L. adelaidensis* and *H. eyrei* bred in the Wet Woodland the second season it was flooded. Both these species also bred in Litoria Swamp. Samples of *H. eyrei* collected at Litoria Swamp contained a lower proportion of adults than samples collected at the Wet Woodland, which is close to a natural breeding site. This suggests that colonization of the Capel Wetlands Centre by *H. eyrei* is incomplete.

4. Reptiles are poorly represented, with 11 species recorded but only one *Menetia greyii* widespread. Most small species have only been recorded adjacent to areas of natural or disturbed woodland, such as the railway reserve to the north-west and the pine plantation to the south-east. The status of large species like the Long-necked Tortoise *Chelodina oblonga*, Bobtail *Tiliqua rugosa*, Gould's Goanna *Varanus gouldii*, Tiger Snake *Notectis scutatus* and Dugite *Pseudonaja affinis*, is poorly known. Such species are difficult to sample systematically. Furthermore, as individuals of these species move over large areas, records can be due to animals moving between natural areas and traversing the Capel Wetlands Centre.

5. The distribution of male and female *M. greyii* differs, females dominating samples from grassy sites, males dominating samples from wooded sites. Females may favour open sites for oviposition.

6. Colonization of the Capel Wetlands Centre by reptiles is occurring slowly, if at all. Enhancing upland areas through the addition of rocks and logs may have increased the abundance of *Ctenotus impar* and *Pogona minor*, although the effect was small and, in the case of *P. minor*, apparently temporary. Vegetational structure, complexity and diversity may be important for encouraging the colonization of upland areas by reptiles.

In the ensuing two years studies of frogs and reptiles continued, reworking the established sampling grid, and extending studies to other parts of the Capel Wetlands Centre in an attempt to obtain a full baseline survey (Bamford 1997). Pit traps were laid out in remnant upland vegetation adjacent to an area of unrehabilitated upland, which was also sampled. Nine transects of pit traps were set up in vegetation fringing wetlands, to see how frog and reptile abundance related to the proximity of permanent moisture. Finally systematic searches for reptiles were undertaken in ten 25 sq. m. quadrats of rehabilitated environments which were thoroughly searched by hand for frogs and reptiles.

On the established monitoring grids the patterns of abundance showed that changes in numbers of *Heleioporus eyrei* and *Crinia insignifera* were linked to annual variation in rainfall, being high when rainfall was large and small in dry years (Figures 8 and 9). In dry years breeding was also curtailed, as shown by the population structure. The lizard *Menetia greyii* continued to decline, with little breeding in 1993, 1994 and 1995, but the cause of this decline is unclear (Figure 10). Sampling of the remnant woodland and adjacent sandy sites showed that most reptiles were found on the remnant sites, including two species common there but absent from the rehabilitated areas, *Morethia lineoocellata* and *Lerista distinguenda*. Bamford (1997) thought that these two species may be useful indicators of success in rehabilitation. The common animals *Heleioporus eyrei* and *Menetia greyii* were already at the same levels of abundance on the undisturbed and rehabilitated land.

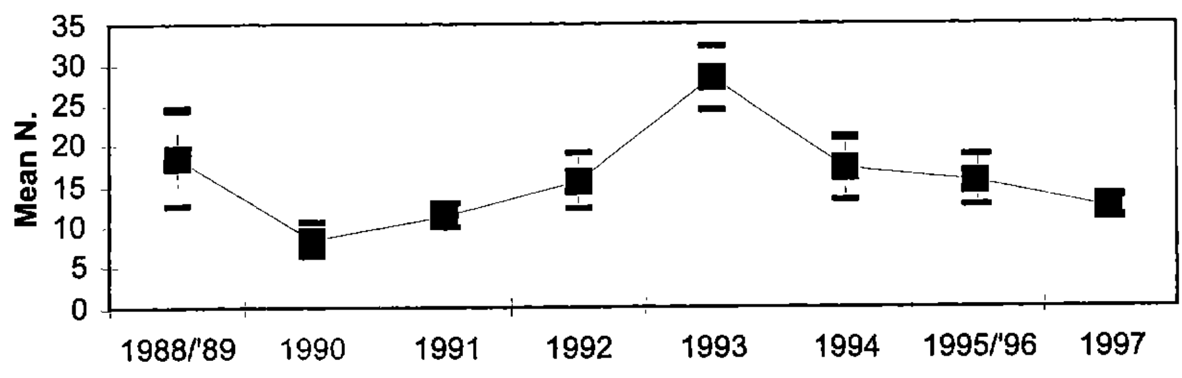


Figure 8. Mean numbers of captures of *Heleioporus eyrei* per year per grid of 24 pitfall traps, based on monitoring grids. Each annual sample consisted of trapping in autumn, spring and early summer, with a total trapping effort of 1080 trap-nights per year (from Bamford 1997).

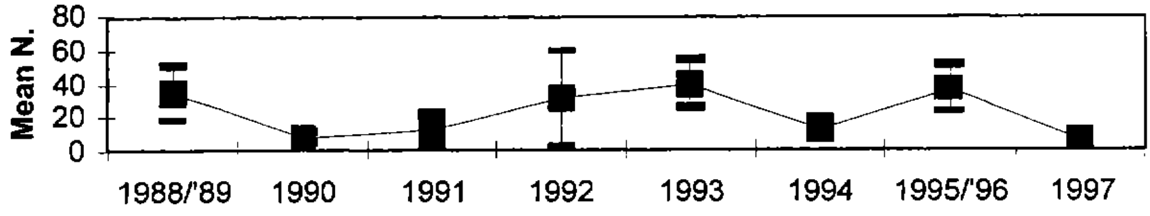


Figure 9. Mean numbers of captures of *Crinia insignifera* per year per grid of 24 pitfall traps, based on monitoring grids. Each annual sample consisted of trapping in autumn, spring and early summer, with a total trapping effort of 1080 trap-nights per year (from Bamford 1997).

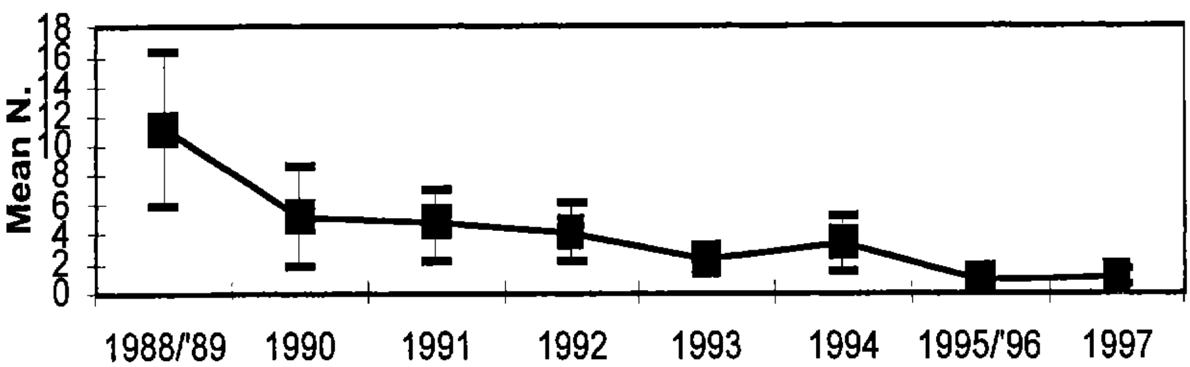


Figure 10. Mean numbers of captures of *Menetia greyii* per year per grid of 24 pitfall traps, based on monitoring grids. Each annual sample consisted of trapping in autumn, spring and early summer, with a total trapping effort of 1080 trap-nights per year (from Bamford 1997).

Around the wetlands *Crinia insignifera* was commoner than on the monitoring grids, which were farther from wetlands, whereas *Heleioporus eyrei* captures were greater on the monitoring grids, reflecting its ability to exploit a wider range of environments than *Crinia insignifera*. Systematic searching revealed that the skink *Hemiergis peronii*, recorded only once in all pitfall sampling from 1988 to 1995, was extremely abundant in damp places close to wetlands, with a density possibly in excess of 600 individuals per hectare. Compared with this the lizard so common in pit traps, *Menetia greyii*, had an estimated density of 31 per hectare. Several marked individual frogs and lizards (four frogs and five lizards) were recaptured, confirming that some species are permanent residents of the wetlands. In the case of the frog *Heleioporus eyrei*, some individuals showed the ability to move hundreds of metres within the Capel Wetlands Centre. The studies from 1993-1995 provided detailed information on the biology of several frog and reptile species and reinforced earlier conclusions that colonization is at present restricted to a few, versatile species of frogs and reptiles.

9.0 Questions relating to the development and management of the Capel Wetlands Centre

9.1 *What happens when the water flow from the plant stops?*

From the outset of the project the water quality of the lakes in the Capel Wetlands Centre has been a matter for concern. The company effected a great improvement in 1987 when they made the waste water from the processing plant alkaline instead of acid, but this waste water, which flowed through the lakes, still contained very high levels of nitrogen, mostly as ammonia, heavy metals and salts. In 1995 the construction of small diversion weirs enabled process water to be diverted past Island Lake and into Peninsula Lake, so that the effects of depriving Island Lake of process water could be observed. In 1997, a new diversion drain was dug that took process water past all the lakes at the upper end of the chain and discharged it into the southern end of Taylor's Lake. The opening of this drain gave the opportunity to examine changes in the chemistry of the lakes after the process water was diverted. The first sample was taken five days before the diversion drain was opened and further samples were taken over the following five weeks (Bennetts 1998).

The study focused on Peninsula Lake and found that a decline in the water level followed the opening of the diversion drain and cessation of the input of water from the processing plant, just as was observed when the water was diverted around Island Lake in 1995; the decline was 0.16 m. Ammonium concentration and total nitrogen concentration declined in Peninsula Lake, from about 45,000 $\mu g/l$ before the diversion to 23,750 $\mu g/l$ on September 15. 1997. Ammonium concentrations rose in Tiger Snake Lake from about 14,000 μg/l before diversion to about 18,800 μg/l on September 15, 1997. Total nitrogen levels fell from about 40,000μg/l before diversion to about 18,000 μg/l on September 15, 1997, while they rose in Tiger Snake Lake. The range of total nitrogen concentrations observed on September 15 in Swamphen, Island and Peninsula Lakes implies that once the inflow of water from the processing plant is removed total nitrogen concentrations will be greatly reduced, with a consequent improvement in water quality and ecosystem health. The concentration of manganese in Peninsula Lake declined from about 3 mg/l before diversion to between 1.5 and 0.3 mg/l on September 15. Iron was already at very low levels, but sulphate concentrations increased in Peninsula and Tiger Snake Lakes after diversion. There was some evidence that the number of invertebrate taxa decreased in Peninsula Lake after diversion of the water from the processing plant, but the study did not continue for long enough to establish diversity at a stable state. The study was not able to assess the full effect of the diversion on the levels of chlorophyll in the lakes. Overall, the study showed that diversion of the water from the processing plant did not result in a sudden, large drop in the water levels in the lakes, but did materially improve the water quality.

9.2 *How far have we improved the ecosystem in ten years?*

An opportunity to examine progress in the improvement of water quality came in 1998 when a study of five lakes was undertaken with the aim of measuring community metabolism, comparing the diversity of the lakes with the baseline data gathered in 1988 and examining species richness and community structure (Davies *et al.* 1999). Community metabolism is an ecosystem attribute describing the carbon-base of a system and the rates of conversion of carbon into food-webs. Low rates were measured in the benthos and water column of all five lakes, Boulder, Paperbark, Taylor's Lakes and Cadjeput and Gravel Pools. Tables 10, 11 and 12 give the results for, respectively, the benthos, the water column and of net daily metabolism. All of these values were within the range of oligotrophic lakes elsewhere in south-western Australia. All the lakes were heterotrophic and therefore net consumers of carbon.

Table 10. Rates of benthic productivity, respiration and net daily metabolism at the Capel Wetlands, September 1998.

Lake	Benthic Gross Primary Production gC/m^2/day	Benthic Respiration/24hrs gC/m^2/day	Benthic Net Daily Metabolism gC/m^2/day
Boulder	0.87	2.01	-1.14
Paperbark	0.99	2.23	-1.24
Cadjeput	1.03	1.67	-0.64
Taylor's	0.77	1.22	-0.45
Gravel	0.58	0.94	-0.36

Table 11. Rates of water column productivity, respiration and net daily metabolism at the Capel Wetland Centre, September 1998.

Lake	Water column Gross Primary Production $gC/m^2/day$	Water column Respiration/ 24hrs $gC/m^2/day$	Water column Net Daily Productivity $gC/m^2/day$
Boulder	0.11	0.08	+0.03
Paperbark	0.23	0.10	+0.13
Cadjeput	0.19	0.12	+0.07
Taylor's	0.03	0.02	+0.01
Gravel	0.09	0.04	+0.05

Table 12. Habitat weighted values of metabolism for the Capel Wetlands Centre sampled in September 1998.

Lake	Net Daily Metabolism $gC/m^2/day$
Boulder	-0.56
Paperbark	-0.56
Cadjeput	-0.29
Taylor's	-0.22
Gravel	-0.16

Fifty-seven taxa of macroinvertebrates were collected from the lakes in 1998, compared with 36 taxa in 1988. The fauna was dominated by cosmopolitan species, in particular detritivores, but there was an increase in the number of taxa that were sensitive to degraded water quality. The main differences between 1988 and 1998 were the presence in 1998 of more mayflies (*Cloeon* sp., *Tasmanocoenis tillyardi*), caddis flies (*Notolina fulva, Oecetis* sp., *Triplectides australis*), gyrinid beetle larvae, oligochaetes and the mollusc *Physa* sp. At the same time bugs (*Anisops* sp., *Agraptocorixa* sp.), the dragonfly *Procordulia affinis*, and sand flies (ceratopogonids), formerly common, were reduced in numbers or absent. The 1998 sweep net samples from the lakes contained a greater diversity of functional feeding groups than the 1987 samples, implying that the functional complexity of macroinvertebrate communities has increased in all lakes since the beginning of the project. New taxa collected in 1998 represented functional feeding guilds that were poorly or not previously represented in the Capel Wetlands Centre lakes. The shredders, the mayflies *Cloeon* sp. and *Tasmanocoenis tillyardi,* are ubiquitous in streams and wetlands of the Swan Coastal Plain but had not previously been collected in Taylor's Lake, Cadjeput Pool or Gravel Pool. These insects play an important role in the processing of large organic detritus such as terrestrial leaves or dead leaves and stems from aquatic macrophytes. There was also an increase in the proportion of scrapers/grazers, mainly due to the increase in abundance of the gastropod *Physa* sp. This was the only snail to occur in the lakes (Cale and Edward (1990b) recorded *Isidorella* sp. in Swamphen Lake in 1989), probably because low pH originally precluded all gastropods from the site by interfering with shell development. The presence of this species in three of the five wetlands sampled suggested that it is likely to become common as water quality improves further. Biodiversity of the lakes of the Capel Wetlands Centre is now comparable with, if somewhat lower than, other urban lakes on the Swan Coastal Plain. The authors strongly recommended that the planting of riparian and upland vegetation be given a priority because the debris from such vegetation would add materially to the carbon store in the lakes, a store that is still so small as to be limiting productivity.

9.3 *Can productivity be improved by adding phosphorus directly?*

In earlier work (Chambers and McComb 1996) the results of manipulating water quality in the laboratory had been examined. The next stage was to extend these observations on a small scale in the field. Studies of the effect of the addition of phosphorus to the water column were carried out in Taylor's Lake in 1989 (Chambers *et al.* 1998a). Phosphorous was added as double superphosphate fertiliser to 16 enclosures subjected to four levels of phosphorus concentration (0, 2.5, 5 and 10 mg l^{-1}) to determine whether the addition of phosphorus would stimulate the productivity of phytoplankton and macroinvertebrates. The sixteen enclosures, $2m^2$ in area, 1.3 m high, were constructed from clear plastic sheeting and sealed at the sediment interface in the littoral zone of Taylor's Lake (approximately 1 m depth). There was no significant difference in phytoplankton productivity in enclosures receiving less than 10 mg P l^{-1}, although high variability in the mesocosms possibly masked increases of phytoplankton within the 2.5-5 mg l^{-1} treatments. Phytoplankton growth responded to the phosphorus concentration of the water rather than to the amount added. Micro-crustacea (Cladocera, Copepoda and Ostracoda) were the only group of macroinvertebrates to respond significantly to the phosphorus addition, and only at P concentrations >10 mg P l^{-1}. The density of benthic chironomids tended to have a higher density at the 5 mg P l^{-1}. This study confirmed the results of the previous one (Chambers and McComb 1996), except that much higher concentrations of phosphorus were required to increase nutrient availability to the aquatic biota. It also highlighted the importance of the benthos in phosphorus dynamics of the system and the high variability of the lake environment. It suggested that these systems would be better driven by benthic productivity than by trying to encourage planktonic productivity. Phytoplankton growth required excessive input of nutrients which may lead to future eutrophication of the lakes of the Capel Wetlands Centre.

The next step in the study of water quality at the Capel Wetlands Centre was to see what would happen when a whole lake was treated with additional phosphorus. Would phosphorus addition to a whole lake system result in long term benefits to primary productivity? Chambers *et al.* (1998b) chose Cadjeput Pool as the lake to test, because it was small. A disadvantage was that a trial with the dye rhodamine showed that the residence time was only 2.5 hours in some places (Figure 11a and b), but up to 9 days away from the main channel (Cale and Edward 1994). They added phosphorus as double superphosphate to it in May 1990 and observations were maintained until December 1991. The aim was to see if the addition of phosphorus would stimulate the growth of algae within the ecosystem of a whole lake, knowing that it would in small enclosures. Sufficient phosphorus was added to provide a concentration of 10 mg P l^{-1} if all the phosphorus dissolved at once. Phytoplankton growth was stimulated within the first two days of phosphorus addition, especially at shallow sites, but the flow-through nature of the lake resulted in the system being flushed and no further phytoplankton blooms occurred for some months (Figure 12). A second phytoplankton bloom occurred when flow through the system was stopped, allowing nutrient release from the sediment to increase the phosphorus concentration in the water column. The addition of phosphorus resulted in a more permanent increase in the productivity of a benthic algal mat (mainly diatoms), until water flow stopped which resulted in its decline. Phytoplankton growth resulted in uptake of approximately 20% of the nitrogen into organic form. Other dynamics of nitrogen loss were masked by the continual inflow of ammonium-rich water. The high phosphorus absorbance capacity of the sediment, and the presence of the benthic algal mat, which took up any nutrient released, limited phytoplankton growth. Sediment phosphorus constituted a source of phosphorus that would be quickly exhausted if the form of phosphorus was easily soluble, due to the flow-through nature and short residence times within the lake. Phosphorus addition was recommended as a mechanism to increase benthic algal mat productivity in shallow areas, but not as a tool to increase phytoplankton growth in flow-through systems such as the deep parts of Cadjeput Pool.

As a complement to these studies Cale and Edward (1991b) compared the macroinvertebrate fauna of Cadjeput Pool before and after the addition of phosphorus. Twelve months after the addition of the phosphorus the number of species in the benthos had increased from 26 before the addition to 39. The biomass of the benthos had increased tenfold, while at one site in the pool the planktonic biomass was more than 100 times greater than before (Figures 13a and b). It was interesting that the nutrient enrichment seemed to have made the environment of the benthos more evenly suitable for invertebrates, whereas before their distribution had been patchy. The number of "collectors" increased after enrichment while the species that were there earlier remained. This suggested that the increase in species was the result of an increased food supply in the form of phytoplankton and other micro-organisms. The community of invertebrates appeared to have a complex well-developed food web and was healthy, with the species present in both plankton and benthos typical of eutrophic wetlands. This study indicated beneficial long-term effects of the addition of phosphorus on the aquatic fauna.

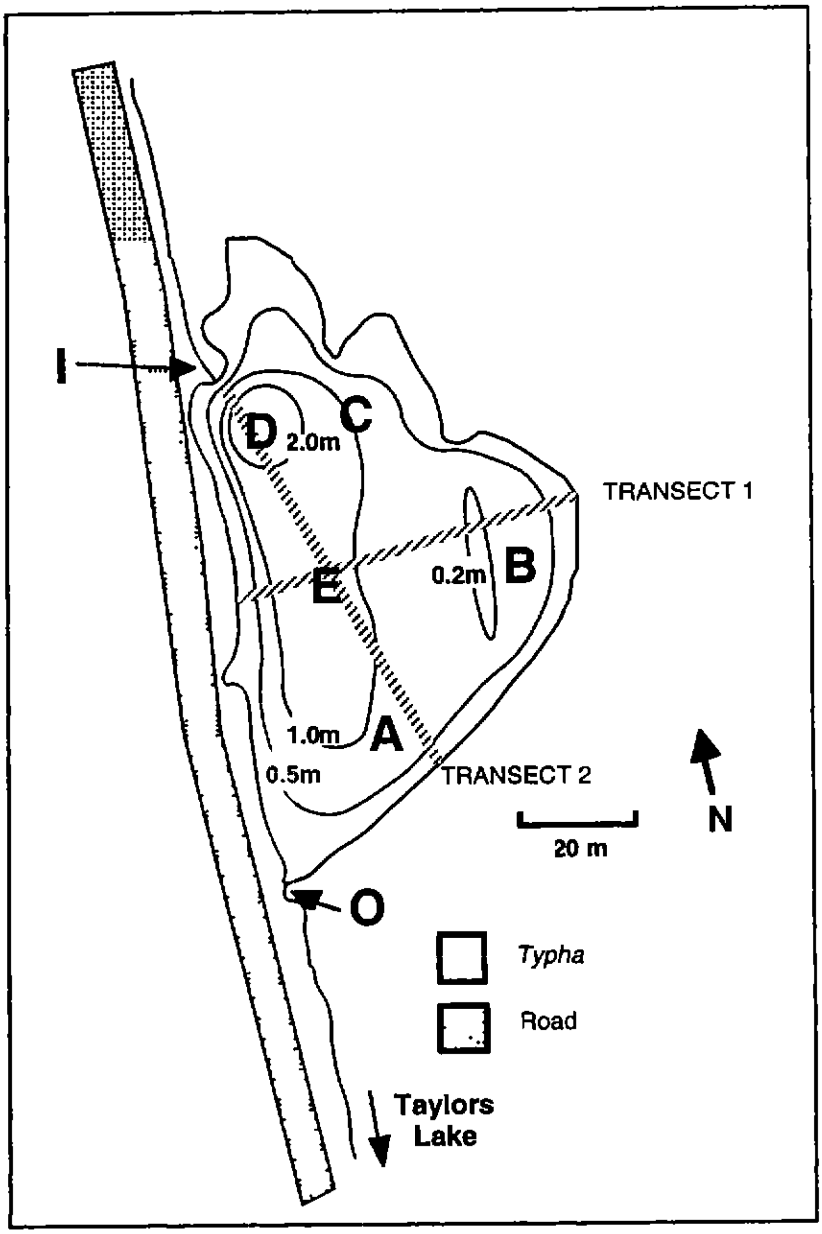


Figure 11a. Bathymetry, location of sites and transects in Cadjeput Pool, Capel Wetlands centre, for the phosphorus addition trial, May 1990 (from Chambers *et al.* 1998b).

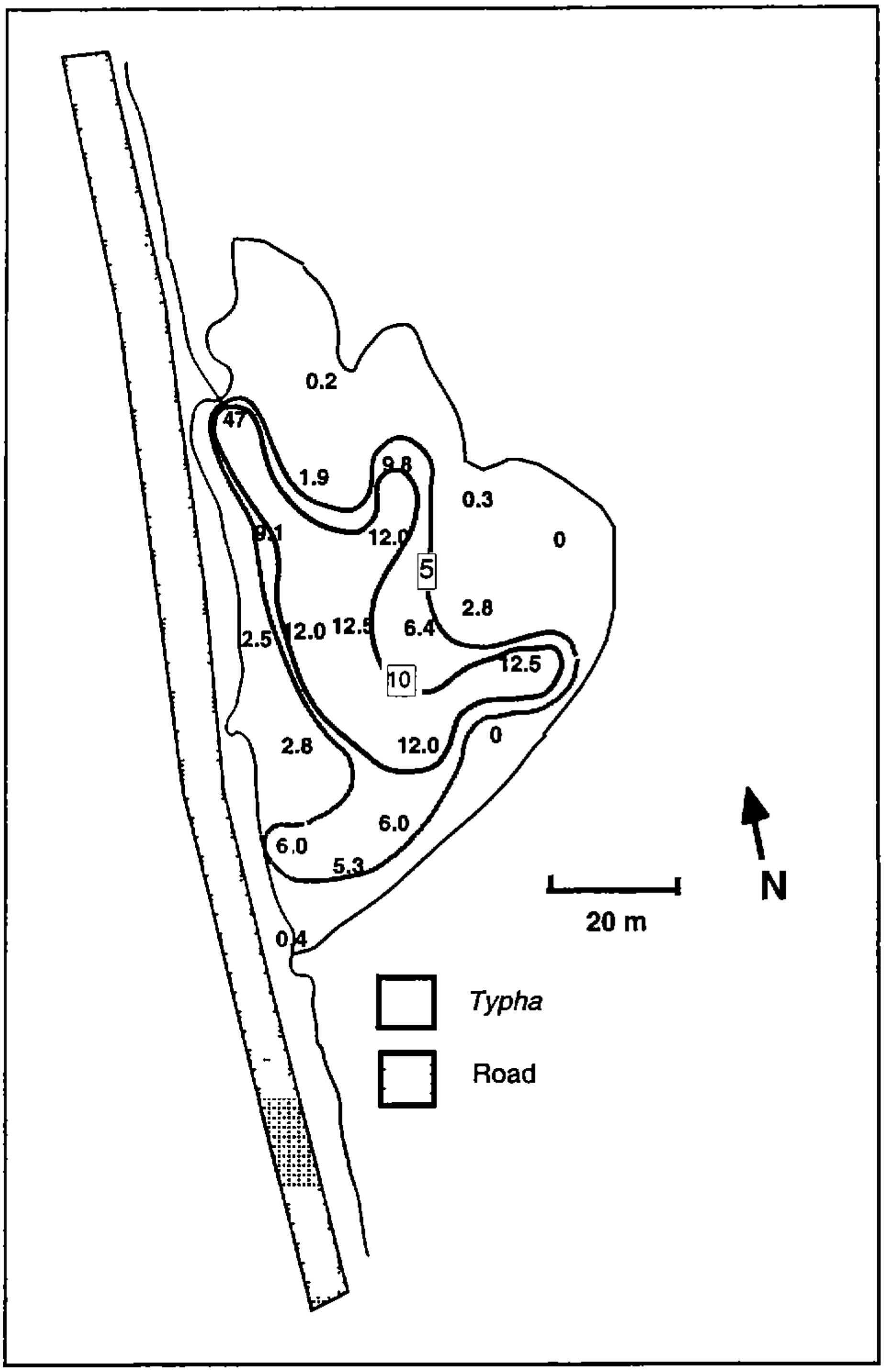
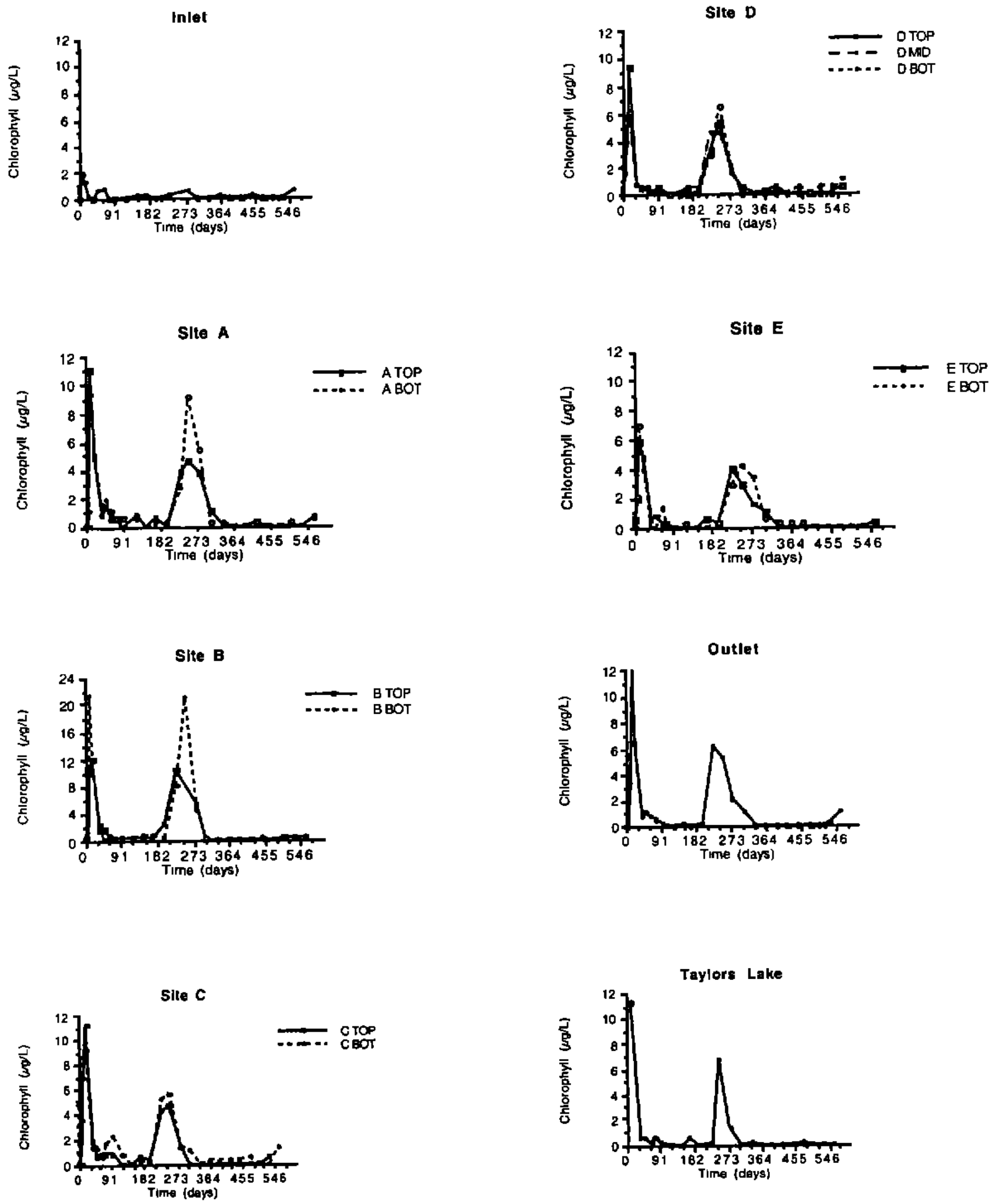


Figure 11b. The distribution of rhodamine dye, indicated by fluorescence values, in Cadjeput Pool, Capel Wetlands Centre, between 1330 and 1730hrs. on May 30, 1990 (from Chambers *et al.* 1998b).



Key to day number:

Day no.	0	91	182	273	364	455	546
Date	15 .5. 90	14.8.90	21.11.90	20.2.91	22.5.91	21.8.91	20.11.91

Figure 12. Changes in chlorophyll concentrations (showing abundance of phytoplankton) of the water for each site in Cadjeput Pool, Capel Wetlands Centre. TOP = surface water, MID = halfway down the water column, BOT = just above the sediment surface. For site locations see Figures 1 and 11a (From Chambers *et al.* 1998b).

9.4 *Hay as a source of carbon and nutrients?*

The results of the experiments of Chambers and McComb (1996) had led to the suggestion that the productivity of the lakes would benefit most from the addition of nutrients and carbon in a form that released these components slowly. Straw was suggested as a possible source, and had been used successfully at the ARC Wildfowl Centre at Great Linford (Street 1979, 1980, Street and Titmus 1982). In 1989 a pilot experiment was undertaken in Gravel Pool in which samples of the macroinvertebrates were taken some time after the straw was added. Twelve months after the addition of the straw it had distributed itself around the benthos of Gravel Pool such that some places were covered with a layer of decomposing straw and others were clear of it. Cale and Edward (1991a) compared samples from sites covered with decomposing straw and those without straw. They found 40 species on the former and 31 on the latter; the mean diversity of the straw covered sites was 2.1 compared with 1.5 on the clear sites and a mean biomass of $0.9 g/m^2$ on the straw covered sites compared with $0.3 g/m^2$ on the clear ones. These improvements were complemented by changes in the pathways by which energy passed through the invertebrate community. Thus "collectors" accounted for 62% of abundance in the straw covered areas but only 47% in the clear areas. On the other hand predators made up 17% in the straw covered areas but 47% in the clear areas, indicating a greater diversity of functional feeding groups in the straw covered areas.

A full scale trial of the addition of hay to a whole lake was undertaken in 1992 (Chambers *et al.* 1998c). In this trial, begun in November 1992, hay was spread over the surface of Cadjeput Pool at a rate of 1.5 kg m^2. The hay became saturated and sank within a week. Measurements of phosphorus, nitrogen and chlorophyll were taken from the lake at the same sites used in the 1990 trial in which phosphorus was added (Figure 13a and b) during the ensuing year. As an extension to the trial small packs of hay and *Typha* were placed in the lake and allowed to decompose. Measurements were taken from samples of these packs over the same period to compare the value of meadow hay with litter from a local wetland plant. The results showed that phytoplankton growth was stimulated within the first two days of the addition of the hay, as it sank through the water column. The bloom, measured as increase in chlorophyll concentration, was especially apparent at shallow sites, but the flow-through nature of the lake resulted in the system being flushed, limiting further blooms, except in deep water (site D; Figure 14). The addition of hay resulted in the initial development of a benthic algal mat followed by an increase in the algae six months after the addition of the hay (Figure 15). The hay in the litter packs decomposed more rapidly and released more phosphorus than did the *Typha* litter, because it was softer and had a high nutrient content. The results of the study suggested that hay should be placed in shallow sites, protected from direct flow, but that in the long term there is no substitute for deriving litter from emergent fringing vegetation, and that the planting of this should be a priority.

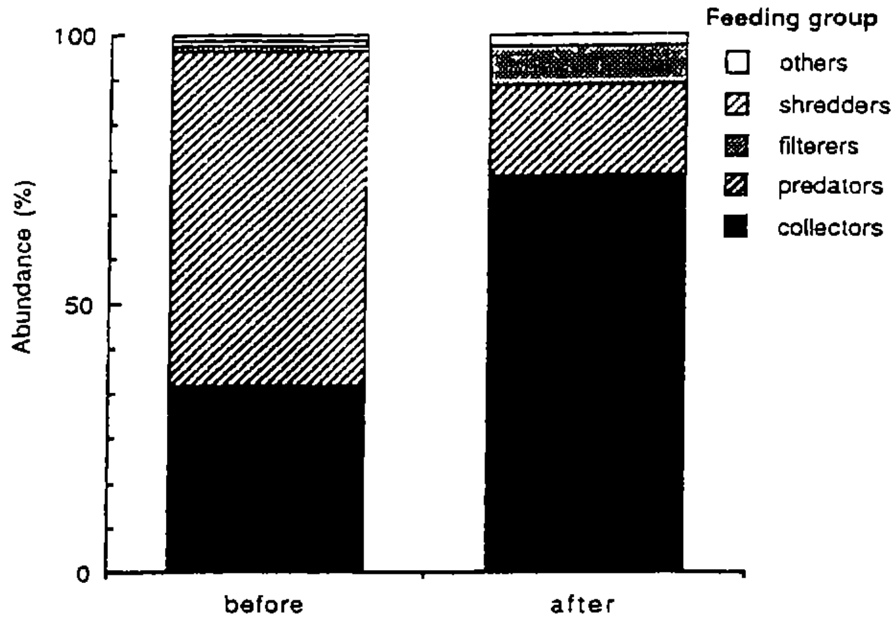


Figure 13a. The proportion of abundance, within the benthos, attributable to each of five functional feeding groups in Cadjeput Pool, Capel Wetlands Centre, twelve months after the addition of phosphorus fertilizer to the pool (from Cale and Edward 1991).

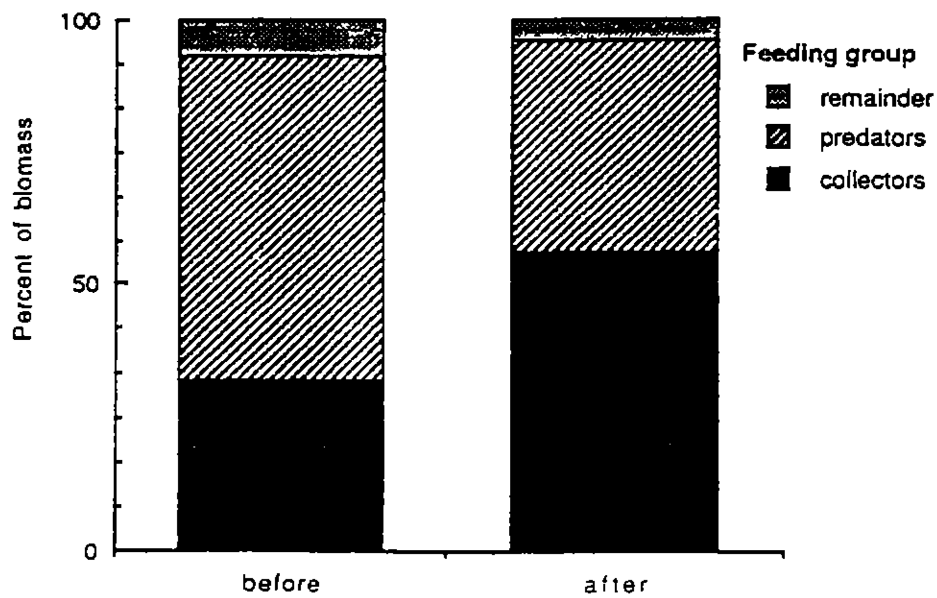
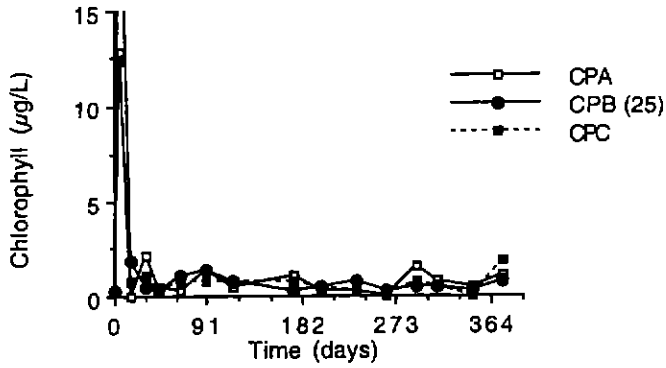
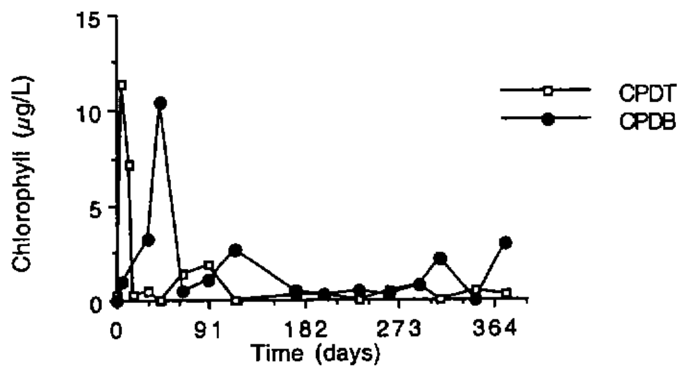
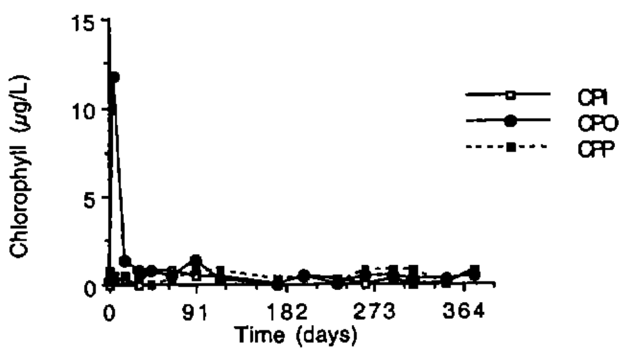


Figure 13b. The proportion of benthic standing biomass attributable to five functional feeding groups in Cadjeput Pool, Capel Wetlands Centre, twelve months after the addition of phosphorus fertilizer to the pool (from Cale and Edward 1991).



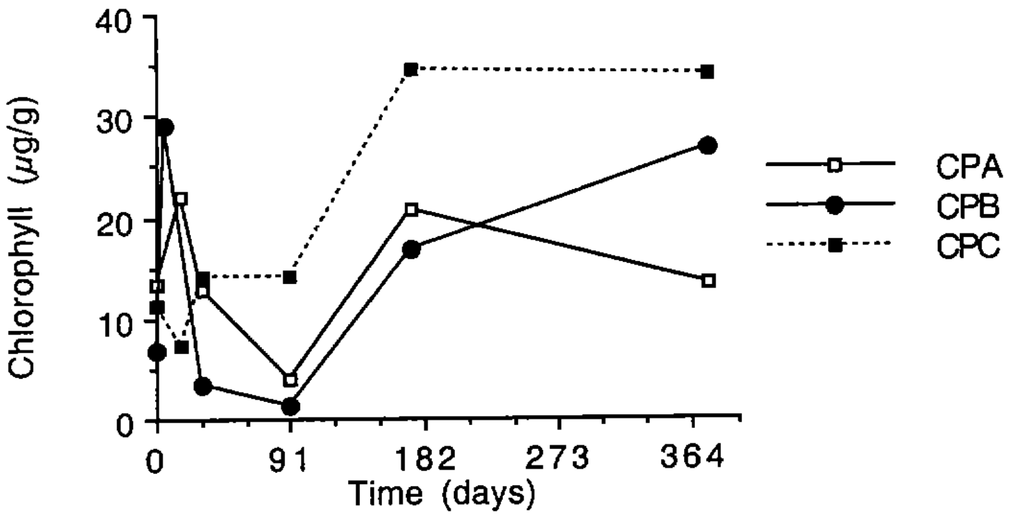


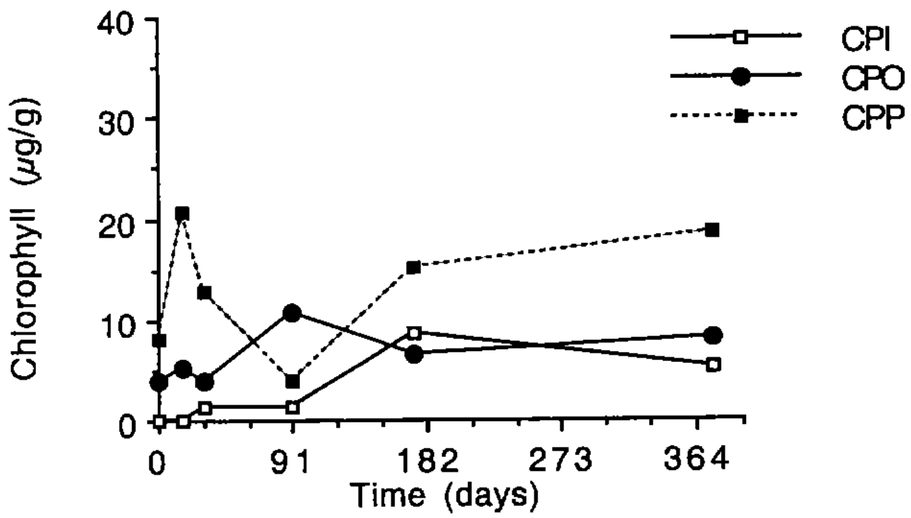


Key to day number:

Day no.	0	91	182	273	364
Date	3.11.92	2.2.93	4.5.93	3.8.93	2.11.93

Figure 14. Changes in chlorophyll concentrations of the water for each site (see Figure 11a) in Cadjeput Pool, Capel Wetlands Centre, after hay additions in November 1992. DT = Top of site D (surface water), Db = Bottom of site D (just above the sediment surface). The number in brackets next to the site code (B) is the chlorophyll concentration of the peak off-scale of Day 2 (from Chambers *et al.* 1998c).





Key to day number:

Day no.	0	91	182	273	364
Date	3.11.92	2.2.93	4.5.93	3.8.93	2.11.93

Figure 15. Changes in chlorophyll concentrations of the sediment for each site (see Figure 11a) in Cadjeput Pool, Capel Wetlands Centre, after hay additions in November 1992 DT = Top of site D (surface water), Db = Bottom of site D (just above the sediment surface). The number in brackets next to the site code (B) is the

At the same time, samples of the invertebrates in the plankton and benthos of Cadjeput Pool were taken to examine the effects of the addition of hay on the fauna (Cale and Edward 1994). The results showed that the macroinvertebrate biomass was not significantly increased on the benthos, probably because the fauna community there was already well developed after the previous experiment with the addition of phosphorus. Seasonal influences were important and in December 1992, one month after the hay was added, some very large biomass values were recorded for individual samples. Only a small number of replicates fell on sites of increased biomass and the variability of biomass was very high so that the mean biomass estimated for the lake was not significantly different from other sampling dates (Figure 16). Several other studies in the Capel Wetlands Centre have shown mid-summer to be the most productive period in the benthos (Cale and Edward 1990, 1993). If the effects of hay addition on invertebrate biomass are realised only in summer, they will only benefit the few waterfowl that still have small young at that time, and so may be less useful as a continuing management practice than they would at first seem. Diversity was increased in both the water column and the benthos after the addition of hay. The results of the study of litter packs showed that, although biomass and total species richness did not differ between hay packs and *Typha* packs, the number of species greater than 3 mm size was higher in the *Typha* packs than in the hay packs. This effect seemed to be the result of larger spaces occurring in the *Typha* packs than in the hay packs, suggesting that litter from plants such as *Typha* may provide a better structure for large macroinvertebrates than litter from meadow hay. The results did not suggest that biomass or total species richness declined with time in the lake over the year covered by the measurements. In this lake at this time the benefits of hay additions to the invertebrate fauna were therefore equivocal.

9.5 *Establishing submerged aquatics?*

The establishment of aquatic macrophytes in the lakes of the Capel Wetlands Centre has long been an important goal of the development programme. Aquatic macrophytes are an important source of carbon for the ecosystem, shelter for aquatic fauna, stabilisers for the unstable substrate and food for many waterbirds. With this in mind Regeneration Technology was asked to examine ways to establish rooted aquatic plants on the clay slimes that covered parts of the bottoms of many lakes. Their report (Regeneration Technology 2000) on experiments in the laboratory and field indicated that only one of the three species examined *Potamogeton ochreatus* was suitable for establishment in the lakes. Propagules (rooted cuttings) of this species readily established at depth in the lakes, and were capable of outgrowing algal mats and slimes which suffocated cuttings of the other species tried, *Triglochin procerum* and *Myriophyllum crispatum*. The best time to introduce propogules into the lakes was during spring, just prior to flowering, when the plants go through a rapid growth phase that allows them to outgrow competitors. The study concluded that the principal limiting factor to the growth of submerged aquatics in the lakes of the Capel Wetlands Centre at present is the water quality, in particular the high level of ammonium, which is about 50 times the normally accepted level at which these plants can detoxify this pollutant.

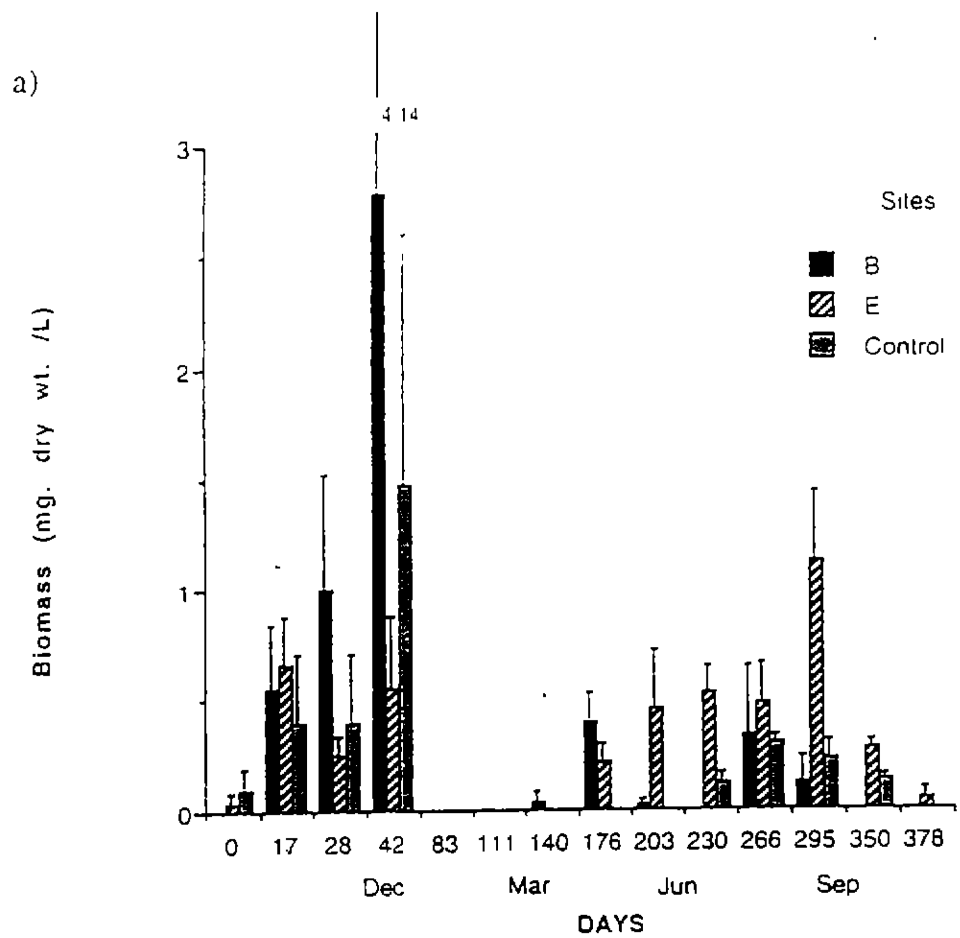


Figure 16. The mean biomass of zooplankton at sites B and E (see Figure 11a) in Cadjeput Pool, and in Peninsula Lake (Control) which lies immediately upstream (from Cale and Edward 1994).

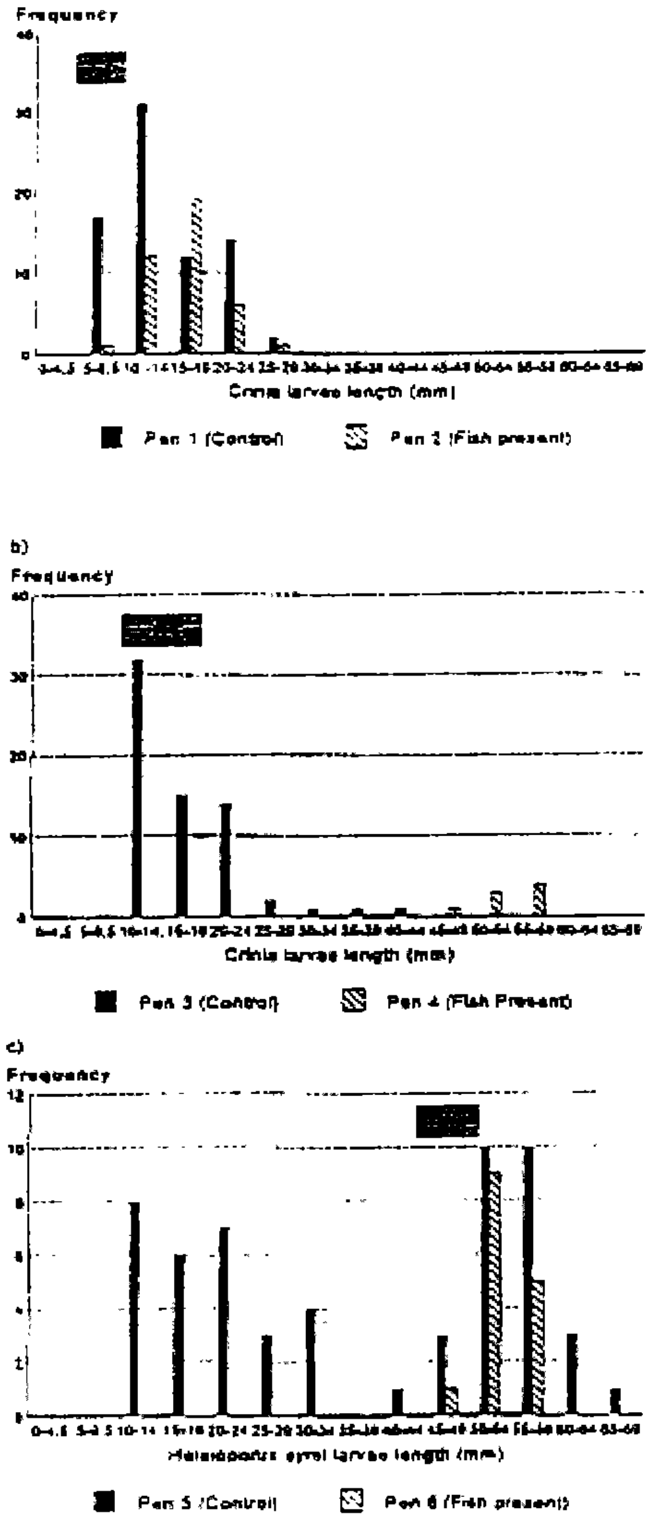


Figure 17. Total length of Anuran larvae in the presence and absence of fish. Data are compared within paired groups; (a) Pens 1 and 2; (b) Pens 3 and 4; (c) Pens 5 and 6. The shaded area indicates the size range at introduction (from Blyth 1994).

9.6 *Are frogs limited by predation of tadpoles?*

During the surveys and monitoring of the frog populations it was thought worthwhile to investigate the interaction between tadpoles and two of their possible predators, *Gambusia* and dragonfly naiads. If the fish were serious predators of frog eggs and tadpoles it would be important to create numerous frog hollows to encourage breeding of frogs on the site. Dragonflies would be a more difficult predator to counteract than the fish, but if they proved to be serious predators too it might be feasible to make frog hollows less attractive to them by ensuring that the hollows were densely vegetated.

Table 13. The number of tadpoles in each pen at the beginning and end of the experiment.

Pen No.	Species	*Gambusia* present	Size mm	Number at start	Number at end
1	*Crinia*	no	5 - 10	50	76
2	*Crinia*	yes	5 - 10	50	39
3	*Crinia*	no	12 -25	50	66
4	*Crinia*	yes	12 - 25	50	8
5	*Heleioporus eyrei*	no	45 - 50	50	56
6	*Heleioporus eyrei*	yes	45 - 50	50	15

In 1993 Blyth (1994) established six enclosures, placed 24 *Gambusia* in each of three of them and tadpoles in them all. One enclosure had *Heleioporus* tadpoles, one small *Crinia* tadpoles and one large *Crinia* tadpoles. The experiment was allowed to run for 45 days and the results at the end are shown in Table 13; Figure 17 indicates the size range of the survivors. At the end of the trial each of the pens containing fish had fewer tadpoles than at the start, whereas each of the pens without fish had more tadpoles than at the start. The latter result can be explained by assuming that frog eggs laid in the pen hatched during the course of the experiment. The results from the pens containing fish were more complex. Pen 4, which initially held large *Crinia* tadpoles, appeared to hold only *Helioporus* tadpoles at the end. Possibly the *Gambusia* had eaten the *Crinia* tadpoles, but *Heleioporus* tadpoles which hatched there during the trial had been able to survive. Some *Crinia* tadpoles in pen 2, which initially held small tadpoles, had been able to survive, perhaps because they could hide under leaves and cover effectively from the fish, whereas the large *Crinia* tadpoles could not. Comparison between pens 5 and 6 was interesting. In the control, pen 5, the lengths of surviving tadpoles had a bimodal distribution, showing that eggs which hatched in that pen during the course of the trial survived. At the end pen 6, which contained fish, had only large tadpoles in it, indicating that the fish had eaten any that hatched during the trial. In addition to mortality, these trials provided evidence that the tadpoles in the pens containing fish suffered fin damage from nibbling by the fish The results made clear the value of frog hollows in protecting tadpoles, and presumably frog eggs, from predation by *Gambusia*. Figure 18 is a diagram of a frog hollow designed by Michael Bamford for the Capel Wetlands Centre.

The study of the interaction of tadpoles and dragonfly naiads (Barrett 1996) explored the situation thoroughly, both in experimental tanks in the laboratory and in enclosures in the field. The laboratory experiments examined the kind of predator-prey relationship that existed between tadpoles and dragonfly naiads, based upon the classifications developed by Cothran and Thorp (1985), Hassell *et al.* (1977) and Rogers (1972). A type 1 functional response of the predator to the prey produces a linear response to an increase in prey density. The number of prey eaten per predator increases constantly with increases in prey density, until a maximum value is reached. A type 2 functional response is a logarithmic response to increases in prey density. The number of prey eaten per predator increases at a decreasing rate for increasing prey densities, until a maximum value is reached. This means that a decreasing proportion of the prey is eaten as the prey density increases. A type 3 functional response is a sigmoid response to increases in prey density. The number of prey eaten per predator initially increases at an increasing rate then increases at a decreasing rate until it asymptotes at a maximum value. This means that an increased proportion of the prey is eaten as prey density increases. Distinguishing the type of functional response displayed by a predator is essential if their contribution to the stability of the population of the prey is to be assessed. By stabilising the population of a prey species a predator can dampen any fluctuations in the density of the prey by a corresponding change in their rate of attack. Only the type 3 functional response will stabilise a prey population. Types 1 and 2 functional responses do not lead to stability of the population of the prey.

The laboratory and field experiments established that the dragonfly naiads showed a type 1 or 2 functional response to tadpoles of *Crinia* sp., implying that they did not control the tadpole population size. In detail the results showed that, when exposed to various densities of prey, large dragonfly naiads of *Aeshna brevistyla* (average head width 8.13±0 23mm) showed a type 1 response and inflicted more mortalities on tadpoles than did small (average head width 5.84±0.21mm) naiads, which showed a type 2 response. When the density of tadpoles was increased the mean proportion of prey removed decreased (type 2). When exposed to a constant density of tadpoles, the naiads with head width ranges of 5-5.9, 6-6.9 and 7-7.9 mm inflicted most mortalities, probably because small naiads could not catch or manipulate the tadpoles, while large ones were concentrating their energy on internal preparations for metamorphosis and emergence rather than on feeding actively. Indeed at this stage the large naiad labium shrinks and the "near adults" do not eat. Small tadpoles were more vulnerable to predation - including fin damage - from all sizes of naiads, indicating that large tadpoles may be too large to be manipulated by naiad mouth widths. Exposure time was found to be significant over the proportion of tadpoles removed. Changing the density of naiads did not significantly influence the proportion of tadpoles surviving to metamorphosis in the field trials, but their size at metamorphosis deceased when naiads were present. Observations showed that tadpoles had some behavioural responses - immobility and adoption of cryptic coloration - that reduced the likelihood of predation by naiads, when the tadpoles were at susceptible stages and sizes. From a management point of view the study indicated that, at the densities present in the frog hollows, *Aeshna brevistyla* naiads were not serious predators of *Crinia* sp. tadpoles.

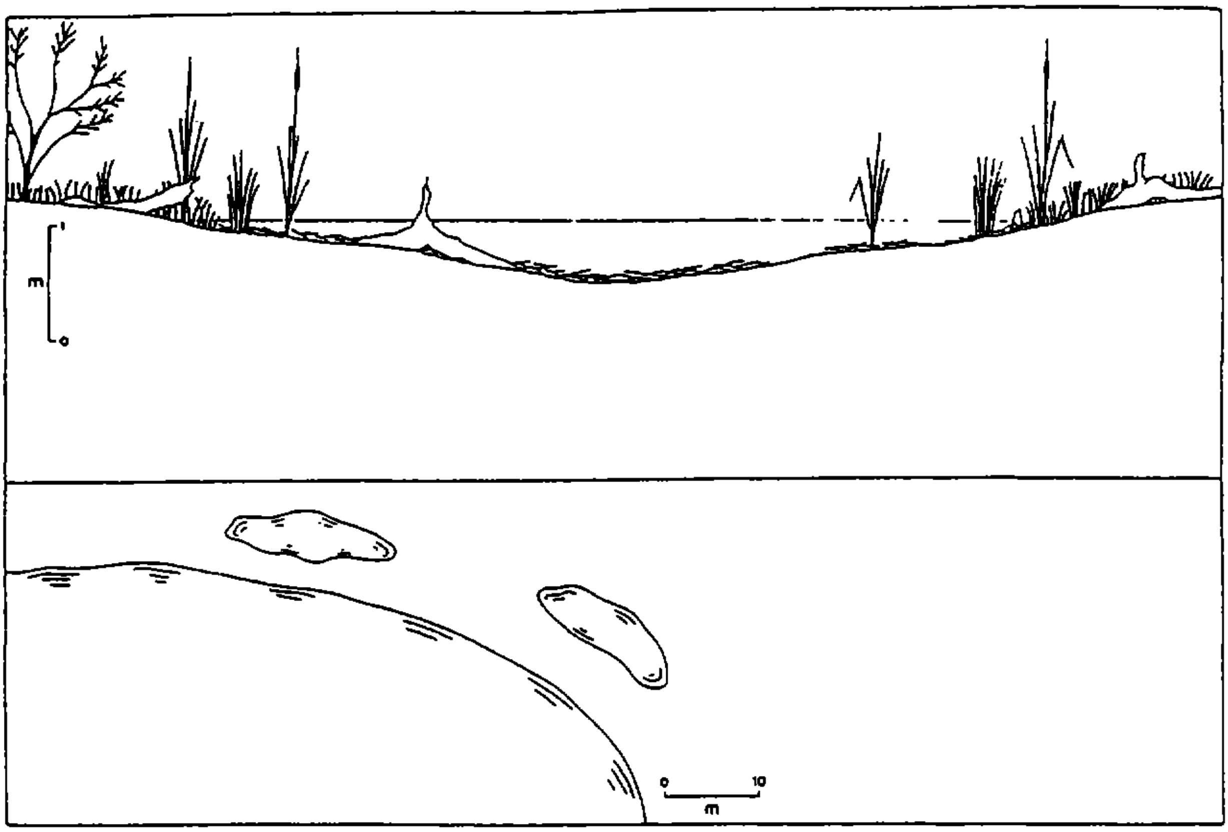


Figure 18. Side elevation and position diagram of a "Frog Hollow" developed for the Capel Wetlands Centre (M.J. Bamford pers. comm.).

10.0 The empirical development of rehabilitation technology at the Capel Wetlands Centre

Section 8 and 9 described the systematic pursuit of research into the ecosystem of the Capel Wetlands Centre. The long-term aim of all this research has been to improve the success and speed of rehabilitation of the mine pits to a self-sustaining wetland for waterbirds. At the same time many practical problems arose that required immediate resolution, using incomplete information, or information from other rehabilitation projects, often in other parts of the world. Such empirical solutions are worth recording, whether successful or not, as part of the contribution of the Capel Wetlands Centre to the technology of rehabilitation.

10.1 *Planting diverse species on sand tailings*

When the pits that now form the lakes of the Capel Wetlands Centre were dug, the mineral was separated from the sand and clay fractions. During this process the sand and clay fractions were also separated and put into separate tailings dumps. As a result the site has large areas of pure white sand and small areas of pure clay. Many of the sand tailing dumps form the uplands surrounding the lakes. Rehabilitation of these areas was important, not only for aesthetic reasons, but also to provide a hinterland from which organic matter could be washed into the lakes. Many thousands of seedlings were planted in these upland areas, often with very low success rates. Table 14 gives an example of the lack of success with early plantings.

Table 14: Survival of a sample of seedlings planted in July 1992; their status was determined in December 1992. Each seedling was marked by a stake, some of the dead ones (Unknown) could not be identified.

Genus & species	Total marked	% Alive	% Dead
Eucalyptus cornuta	1189	30	70
E. gomphocephala			
E. marginata			
E. patens			
E. calophylla			
E. haemotoxylon			
Banksia grandis	639	19	81
B.attenuata			
B. littoralis			
Acacia saligna	84	100	0
Hakea prostrata	77	95	5
Calothamnus quadrifidus	18	0	100
Unknown	53	0	100
Total	2060	31	69

A total of 20,984 seedlings were planted in 1992. The failure rate observed after six months in the sample listed in Table 14 appeared to apply generally throughout the plantings. This was in spite of careful preparation involving burning in March, spraying in early May, and light cultivation in late May, before planting in early June. In some cases the young plants had been destroyed by rabbits, but in most cases the cause of death was unknown. Subsequent counts indicated that more seedlings died before the end of the summer, so the failure rate was actually higher than is indicated in Table 14. A similar failure rate, not measured quantitatively, was also observed with screen plantings along Zircon and Ilmenite walks, from 1990 plantings.

Such a rate of failure represented a great waste of money, time and effort, so that other trials were undertaken to try to improve the situation. One of these had actually been made in July 1989, when 9 half acre (c.0.25 ha) plots had been laid out on a sand tailing site. Each plot was treated with a different top dressing, listed in Table 15, and each sown with the same seed mixture. The trial was deficient because there were no replicates, no control plot and because the application of some of the treatments was uneven, but by 1991 it could be concluded that slimes and gravel oversize appeared to be the best soil amendment. The plots were inspected again in 1997 with the counts given in Table 15, confirming the earlier conclusion.

Table 15. Germination and establishment recorded in pilot experiments sown in 1989, using nine methods of soil amendment on sand tailings.

	1991		No. of plants of each species 1997									
Treatment	No. of species	Plants/sq. metre	A	B	C	D	E	F	G	H	I	J
Slimes	12	0.064	27	1	2			12	14	19		
Oversize	9	0.044	29					12	6	50		
Jarrah Bark	10	0.020	9	1		1				10		
Sawdust	7	0.013	23				2			11		1
Fowl manure	8	0.011	16									
Feedlot Mulch	2	0.001	1									
Hay	2	0.001	4							1		
Iron Oxide	1	0.0004	2								26	
Terolas	0	0	8			1						4

Legend for species: A - *Acacia saligna*; B - *Acacia cyclops*; C - *Acacia pulchella*; D - *Jacksonia* sp.; E -*Viminaria* sp.; F - *Casuarina obesa*; G - *Melaleuca acerosa*; H - *Regelia ciliata*; I - *Kunzea* sp.; J - *Calathamnus quadrifidus*.

Notwithstanding the inadequacies of this trial, gravel oversize was spread over large areas in 1992 and seedlings planted into it, but with little success. Both these data sets indicated the success of *Acacia saligna*, a vigorous but short lived species; further studies were needed. Planning for the next empirical trial was begun in November 1993, when Creative Land Management was contacted. They recommended that the addition of Neo-min Rock Minerals to the plantings would be beneficial. Accordingly a site on sand tailings and adjacent unmined ground was prepared for planting in winter 1993. Deep furrows were run through the site and 1600 *Acacia saligna* seedlings planted. Every second row was treated with a mulch made up by Creative Land Management containing ground granite and composted mulch of seaweed and animal manures. Table 16 gives the early results of the trial.

Table 16. Mean height of seedling *Acacia saligna* planted in June 1993 in the Neo-min trial.

Date	Treated Number	Treated Height (cm)	Untreated Number	Untreated Height (cm)
27 September	228	4.8	215	6.2
10 December	220	14.2	171	8.7

Visible signs of grazing by rabbits were recorded on most seedlings, with many reduced to small stumps. Many seedlings were completely gone and the signs were that rabbits had dug them out. Of the seedlings that died between September and December seven of the nine recorded deaths in the treated seedlings were attributed to rabbits while of the untreated seedlings 42 out of 44 recorded deaths were rabbit related. It appeared that the rabbits were avoiding the fresh mulch. Over a year after planting 67% of the plants that received mulch were alive but only 50% of those without much had survived. The mean stem height of the treated seedlings was 30.5 cm compared with 23.4 for the untreated ones. Subsequent observations indicated that although the mulch did improve survival somewhat, a greater difference in survival was related to whether the seedlings were planted on mined or unmined land. Those on unmined land survived and grew much better than those on the tailings.

Table 17 shows the results of comparing mined and unmined land in the 1994 plantings:

Table 17. Survival of seedlings on mined and unmined land near Ibis Lookout in 1994. All seedlings were in the mulched group and provided with rabbit guards.

Soil type	No. assessed	No. alive	No. dead	% alive	% dead
Unmined	59	26	33	44	56
Mined	237	68	169	29	71

Further plantings in deep furrows were made in 1994. As in other trials, survival differed between species, as shown in Table 18:

Table 18. Survival of each species of seedling planted in trenches at two sites in 1994; Site A near Paperbark Lake; Site B near Ibis Lookout.

Species	Site A Total No	Site A No alive	Site A % alive	Site B Total No	Site B No alive	Site B % alive
Eucalyptus cornuta	230	15	6	44	12	27
Eucalyptus patens	130	7	5	43	5	12
Corymbia calophylla	394	62	15	49	22	45
Banksia grandis	104	5	4	42	8	19
Banksia attenuata	110	16	14	32	6	19
Banksia littoralis	68	11	16			
Acacia saligna	345	181	52	43	33	77
Acacia cyclops	217	17	7	43	8	19
Hakea prostrata	116	16	13			

Table 19. Survival in April 1998 of seedlings planted in the winters of 1996 and 1997. Each was planted out in 10 litres of top soil in its planting site in sand tailings.

Species	1996 Total	1996 Alive	1996 % alive	1997 Total	1997 Alive	1997 % alive
Eucalyptus cornuta				9	9	100
Eucalyptus gomphocephala	5	5	100	37	26	70
Eucalyptus marginata	11	10	91	3	1	33
Eucalyptus rudis				66	53	80
Corymbia calophylla	11	9	82	38	16	42
Agonis flexuosa	2	2	100	92	58	63
Melaleuca sp.	1	1	100	78	36	46
Calothamnus sp.	1	1	100	37	33	89
Banksia sp.	4	4	100			
Hakea prostrata	16	14	88	63	38	60
Hakea ruscifolia	1	1	100	14	5	36
Adenanthos meisneri				45	15	33
Acacia littorea				5	2	40
Acacia coclearis				14	14	100
Acacia cyclops	12	3	25			
Acacia saligna	7	7	100			
Acacia pulchella	7	1	14			
Brachysema praemorsum				36	9	25
Templetonia retusa	10	4	40	2	2	100
Pelargonium capitatum	12	11	92			

The survival shown in Table 19 was an improvement on previous years, but some of the trees that we particularly wanted to establish were still surviving poorly. One factor that we recognised was the great depth (over 8m) of some tailings dumps, which would make it difficult for small seedlings to reach the water table, let alone keep up with it as it sank in summer. To counter this, large quantities of tailing were removed from sites before plantings; sometimes these could be used elsewhere on the mine site, in other cases they were simply stockpiled.

Another retarding factor was identified. Investigations of soil profiles in the sand tailings showed that the soil was compacted in layers, reflecting successive deposits of tailings. The roots of plants were deflected by the interface between the top and second layer, so that they were unable to keep pace with the dropping water table as the summer progressed. To counter this in 1998 the areas which were to be planted, having been skimmed of 1-3 metres of sand, were then thoroughly disturbed to at least one metre depth with an excavator to destroy this layering. The seedlings were planted in 10 litres of top soil as in 1996 and 1997. Survival improved after these treatments Table 20, which have been adopted in subsequent plantings.

Table 20. Mean percentage survival after eight months of seedlings planted at four sites on the Capel Wetlands Centre in the winter of 1998.

Species	Paperbark Lake		Entrance Road		Amphitheatre		Ruabon	
	Total put out	% alive	Total put out	% alive	Total put out	% alive	Total put out	% alive
Eucalyptus cornuta	657	95	265	55	3	33	543	63
E. gomphocephala	451	90	191	29	9	100	862	85
E. leucoxylon	22	100	19	53				
E. rudis	381	95	62	44	13	100	368	80
Corymbia callophyla	2	100	2	50	3	67		
Agonis flexuosa	290	92			20	60	986	50
A. linearifolia	6	83						
A. parviceps							7	100
Melaleuca acerosa							44	27
M. hamulosa					32	84		
M. incana					1	100		
M. lateritia					20	95		
M. preissiana			3	33	11	100		
M. raphiophylla					2	100		
Melaleuca sp.	290	79					344	52
Kunzea ericifolia	6	67						
Calothamnus quadrifidus	5	80	21	90	25	68		
Adenanthos meisneri	6	83	14	29	5	20		
Banksia littoralis					2	100		
Hakea prostrata	33	97						
H. ruscifolia			90	30				
Brachysema praemorsum	4	75	24	42				

The overall survival of seedlings planted at the Capel Wetlands Centre has improved from 23% with the 1990 plantings, to 31% for 1992, 73% for 1998 and 87% for 1999.

10.2 *Direct seeding*

Except for the trials sown in 1989 only two substantial direct seedings have been undertaken at the Capel Wetlands Centre, along the old haul road, now called the Wetlands Road, and one on 8 ha east of Tiger Snake Lake in 1997. Apart from a single lane track, this was ripped and seeded in 1990. The results showed that while germination was good in many places, establishment of good stands of plants only occurred on sites where gravel dominated. In the 1997 project 1-1.5 m of sand was first removed from the site and used to build an island in Tiger Snake Lake. Once this had been done dry slimes were spread over half the area to a depth of 100 mm, and this was covered with several centimetres of mulch. The whole area was ripped with spring-tyne harrows and direct seeded with a mixture of seeds of native plants. Germination was successful and the resultant coverage satisfactory. Other small areas, including a section of the second old haul road in 1996, have been direct-seeded from time to time, always with the same result – seedlings establish on gravel but not on sand.

10.3 *Transplanting of rushes*

From early in the project the simple technique of collecting rushes and sedges from sites where mining was about to start, breaking up the clumps and planting the propogules around the bare edges of lakes has been a regular spring and summer activity. Results have shown that summer plantings, when the water levels are low, are most successful, but many metres of dense fringing vegetation have also been established in this way. One unexpected discouragement was the assult on the newly planted stolons by Purple Swamphens; they uprooted and ate the roots and tubers. In a sense this demonstrated the success of our rehabilitation efforts in attracting waterbirds, but it also provided yet another frustration for the Project Manager! Many of the original transplantations are now being cropped to provide material for transplantation elsewhere.

10.4 *Rabbits*

The Capel Wetlands Centre can offer no magic wand for the control of rabbits. These introduced pests have large warrens in sandy areas between the lakes and in piles of rocks wherever they occur. Trapping and baiting has been a continuous activity for the management team, assisted by outbreaks of myxomytosis and rabbit calici virus from time to time. The ultimate aim is to rid the site of rabbits altogether. To this end over 10 km of rabbit netting has been installed, encircling the whole Capel Wetlands Centre, and completed in April 1997. It will require continual maintenance, but is a necessary precursor to the final elimination of rabbits.

10.5 *Construction of spits and islands*

From the initiation of rehabilitation siteworks the creation of hollows, spits and islands in the lakes has been a continuing task. The first endeavour was the creation of the Wet Woodland, an area aimed to provide a *Melaleuca* woodland, that would flood each winter and mimic the Ludlow Swamp, so attractive to colonial nesting waterbirds. Eight hectares were encircled with a moat and the sand dug from it used to build an earth bank around the perimeter. Between one and two metres of sand were then removed from the enclosed area and used to build spits and islands elsewhere. The excavation was done to create three different environments. In one-third of the area, deep channels were dug to break the area up into islands; in the middle third as much sand was removed as possible before the machinery encountered clay slimes, on which it could not work. In the last third sand was removed wherever possible, but in much of this area clay was close to the surface, and only shallow hollows could be created. The plan was to have some parts, the channels, where there was always water, some parts where flooding from winter rain persisted for at least six months, the middle section, and some parts which flooded only shallowly, but might grow grassland in the summer. The project is partly successful, having the advantage of good water quality because it is not connected to the discharge channel, but the trees are growing slowly and may eventually become a dense woodland, but only after the passage of many more years.

Elsewhere the siteworks provide ephemeral water bodies, the spits and islands security from ground predators for loafing and nesting waterfowl, and the irregular shorelines shelter for them during the frequent strong winds of south-western Australia. Techniques have remained little changed. Large scrapers have been used to bring sand to a lake shore, bulldozers used to push it out into the water and form the island shape, excavators brought in to smooth the surface, and finally to cut the channels that isolate the islands from the shore. Trees planted on such islands have grown successfully and rapidly stabilise the loose sand. Dense planting has been used, because the islands are close to water level, and drought is seldom a controlling factor.

11.0 Impacts of the project - Where are we?

The conversion of the disturbed environment left after conventional sand-mining to a productive ecosystem requires time and money; the lesson from the Capel Wetlands Centre is that it requires large amounts of both. When Roger Jaensch drew up the initial feasibility study for what was then AMC Mineral Sands Ltd. he visualised the plan for five years. It would have been ambitious at the time to have forecast any further ahead. Now, fifteen years since he made his initial assessment, we can see more clearly than he could the problems involved and the time it takes to overcome them. Brooks (1992,1993), Nicholls and Davies (1993) and Doyle and Davies (1998) have previously reviewed the progress of the project.

11.1 *The ecosystem*

The opportunity to create wetlands suitable for waterbirds arose because the site was a wetland from the outset. It took a while to realise that, in terms of an ecosystem, water was not just water; it had characteristics that gave it a quality and that, at the site, the quality needed a great deal of modification before it would support a productive, self-sustaining ecosystem. Part of that modification could be made by treatment of the water coming from the processing plant, water that was too acid, had too many heavy metals, too many salts and a woeful imbalance of nutrients. It took years to understand what was wrong and we are still some way from recognising all the measures that need to be taken to achieve natural solutions to the water quality problems.

Of the techniques that have been most successful, the addition of hay to the lakes has been outstanding. The hay, in the form of bales, can be floated out on the surface, contained in the desired area with a single line of bales threaded along a wire, and allowed to sink to the bottom, a process that takes about a week. Once on the bottom it rots slowly, releasing carbon and nutrients, while providing a structure that will shelter small animals. Branches and whole trees put in the lakes have the same effects, although the release of nutrients and carbon from them is slower than from the hay. Fringing vegetation has been planted each year and debris from it is gradually adding organic matter to the ecosystem. The studies at the Centre have shown that the diversity and productivity of the lakes are slowly improving; the rate is much slower than we hoped, but is in the right direction. Looking at similar projects elsewhere we can see that the development of them all has taken many years; the Capel Wetlands Centre is no exception.

Although fringing vegetation is doing well, submerged aquatics have been slower to establish. The factor inhibiting them seems to be quality of the water which is still not as good as it might be. It is steadily improving as we rely less and less on water from processing, allowing the rainfall and groundwater to flush out the lakes. Part of the difficulty is that many undesirable chemicals are stored in the sediments, which release them only slowly, so that for years the full development of ecosystem function may be limited by their presence.

One group of animals that has been very slow to recolonise rehabilitated areas is the reptiles. It seems that their rate of movement from undisturbed areas onto the rehabilitated uplands is to be counted in decades rather than years. It is not clear why the reptile fauna is so difficult to restore, but we are now recording some success, especially in areas near the stream zones and where brushing of the sand with cut branches of local shrubs has been extensive. In contrast, the native fish are steadily invading the lakes and native mammals appear to be thriving wherever rehabilitation has provided dense shelter.

11.2 *The birds*

The aim of the rehabilitation is to create an environment that will attract waterbirds. In this the Capel Wetlands Centre has been successful. The diversity of waterbird species now living on or visiting the lakes matches that of the nearby natural wetland, McCarley's Swamp. But the Centre does not match McCarley's in the abundance of individuals nor does the Centre attract many breeding species. The fact that such diversity can be seen at the Centre indicates that our efforts to provide a variety of environments is working. We know that the productivity of the lakes is low, equivalent to oligotrophic wetlands, whereas McCarley's Swamp is clearly eutrophic. It would be ideal to have some lakes in the Centre eutrophic and some oligitrophic, so that we could present variety to the visiting public. We know that such a situation can ultimately be achieved, but we continue to be frustrated by the slow rate of improvement of water quality. In this respect our planting programme is paying handsome dividends; each year more and more organic matter is being added to the lakes, as the bulk of fringing vegetation and overhanging trees increases. The frequency with which crakes and rails are now appearing is especially encouraging, because they are characteristic climax species, providing evidence that the environments they favour have reached maturity at the Centre. Each year sees an improvement, not only in the waterbird population, but in the increasing numbers of bushbirds as well. Some of the bushbirds considered typical of undisturbed native vegetation, such as the Splendid Fairy-wren, are now common around the lakes, many of them old birds as we know from recaptures of banded individuals. The reticulation of water spreading around the public facilities will attract more bushbird species into public view and enhance the attraction of the area for visitors. One of the best indicators of the richness of the environment is the number of species of birds of prey that have now been recorded at the Centre.

11.3 *The community*

Increasing numbers of visitors are passing through the Capel Wetlands Centre. Many schools now make a visit there part of their class expeditions, so that over 2,000 pupils a year now have some experience of the Centre. The public tours organised by the committee of the Titanium Industry Committee visit the Centre every week. Many groups from the region take advantage of the pathways and barbecue facilities for their outings, especially since the added publicity provided by the Living Windows programme of the South West Development Commission. The Coolilup Pet Cemetery is another direct contact between the Centre and the local community. Its attractive garden is expanding as its availability is becoming well known. We consider it to be very important, that the Centre should have a respected place as one of the attractions of the district and hope in the future to make it as well recognised a tourist destination as some of the similar establishments in other parts of the world. At the same time it is important to control the disturbance that the public can cause to the waterbirds. This is being achieved not only by dense screen plantings but by the erection of sand mounds (bunds) around the margins of some of the lakes, so that people and vehicles can pass without each time disturbing loafing birds. The provision of hides and viewing points is an important part of our strategic planning, to enable visitors to watch undisturbed waterfowl. At present there are five hides and two viewing points, placed to take advantage of good outlooks in directions that keep the sun as much behind the viewers as possible.

11.4 *The company*

Throughout the project the companies have been generous in their support, maintaining it during times when the prices of their product were low, just as strongly as when the mineral was selling well. The benefits to the industry may seem intangible but are real in terms of the public image of an organisation that is prepared to give something back to the community and landscape from which it draws its wealth. It is clear that the company has been satisfied with the achievements of the Centre. One of the best demonstrations of this was the enthusiasm with which the Board of RGC Mineral Sands Ltd., on a visit to the Centre, set out to use the pictorial key to the local plants devised by Robyn Donnelly. The exercise may have been devised for primary school children but it equally fascinated and absorbed the Captains of Industry. If the Capel Wetlands Centre can continue to develop such universally admired attractions, it need not fear for its future.

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14.0 Appendices

Appendix 1. **Plants of the Capel Wetlands Centre**

ALGAE

Blue Green Algae (Cyanobacteria)

Anabaena sp.
Gloeocapsa sp.
Lyngbya sp.
Merismopedia sp.
Oscillatoria sp.
Phormidium musicola

Dinoflagellates

Glenodinium sp.
Peridinium sp.

Desmids

Closterium sp.
Cosmarium sp.
Euastrum sp.
Netrium sp.
Pleurotaenium sp.
Staurastrum sp.
Tetmemorus sp.

Euglenophyta

Euglena mutabilis

Filamentous green algae

Mougeotia sp.
Oedogonium sp.
Spirogyra sp.
Ulothrix sp.
Zygnema sp.

Diatoms (Bacillariophyta)

Achnanthes minutissima Kütz.
Amphora veneta Kütz.
Anomoeoneis sphaerophora (Kütz.) Pfitzer
Brachysira serians (Bréb.) Round and Mann (formerly *A. serians* var. *brachysira*)
Brachysira vitrea (Grun.) Ross (sometimes called *Anomoeoneis exilis* (Kütz) Cleve)
Caloneis bacillum (Grun.)Mereschkowsky
Chaetoceros muelleri Lemmermann
Cyclotella menegheniana Kütz
C. stelligera Cleve and Grun.
Cymbella cesatii (Rabh.) Grun.
C. microcephala Grun.
C. minuta Hilse ex Rabenh.
C. pusilla Grun.

Eunotia curvata (Kütz.) Lagerst
E. pectinalis (O.F. Muller) Rabh.
E. valida Hust.
Fragilaria construens Ehrenb. (Grun.)
Frustulia megalismontana Cholnoky
Gomphonema gracile Ehrenb.
Mastogloia elliptica (Ag.) Cleve
M. smithii Thwaites
Navicula aff. *cari* Ehrenb.
N. cincta (Ehrenb.) Kütz.
N. cryptocephala Kütz.
N. cuspidata Kütz.
N. aff. *festiva* Kasske
N. halophila (Grun.) Cleve
N. monoculata Hust. (?)
Nizschia communis Rabn.
N. obtusa W. Smith
N. palea (Kütz) W. Smith
N. paleaeformis Hustedt
N. pupula Kütz.
N. rhynchocephala Kütz.
N. salinarum Gurn.
N. sp. 1.
Pinnularia biceps Greg.
P. borealis
P. braunii (Grun.) Cleve
P. divergentissima (Grun.) Cleve
P. gibba (Ehrenb.) O. Muller
P. subcapitata Greg.
P. viridis (Nitzsch.) Ehrenb.
Rhopaloida gibba (Ehrenb.) O. Muller
R. novae zealandae Hustedt
Stauroneis legleri Hust.
S. pachycephala Cleve
Synedra rumpens Kütz.
Thalassiosira weissflogii Hustedt.

Charophyta

Chara sp. 1
Chara sp. 2
Nitella hyalina

Other algae

Ankistrodesmus sp.
Chlamydomonas sp.
Pediastrum sp.
Scenedismonas sp.
Trachelomonas sp.

Filicopsida - Ferns

DENNSTAEDTIACEAE

Pteridium esculentum

Cycadopsida

ZAMIACEAE

Macrozamia riedlei

Coniferopsida

PINACEAE

Pinus pinnaster
P. radiata

Magnoliopsida

CASUARINACEAE

Allocasuarina humilis
Casuarina obesa

POLYGONACAE

Emex australia

DILLENIACEAE

Hibbertia cuneiformis
H. hypericoides
H. lineata
H. rhadinopoda
H. stellaris
H. vaginata
H. sp.

DROSERACEAE

Drosera leucoblasta
D. pallida
D. sp.

BRASSICACEAE

Brassica tournefortii
Cardamine hirsuta

EPACRIDACEAE

Brachloma preissii
Leucopogon constephiodes
L. oxycedrus

PRIMULACEAE

Anagallis aruensis var.

CRASSULACEAE

Crassula alata (?)

MIMOSACEAE

Acacia alata
A. browniana/tayloriana
A. coclearis
A. cyclops
A. decurrens
A. extensa
A. flagelliformis
A. incurva
A. littorea
A. longifolia
A. pulchella
A. saligna
A. sclerosperma
A. semitrulata
A. stenoptera
A. wildenowiana
A. sp.
Albizzia distachya
A. lophantha

FABACEAE

Aotus intermedia
Bossiaea eriocarpa
B. laidlawiana
Brachysema praemorsum
Daviesia divaricata
D. incrassata
D. sp.
Eutaxia epacrioides
Gompholobium marginatum
G. tomentosum
Hardenbergia comptoniana
Hovea trisperma
Jacksonia furcellata
J. spinosa
Kennedia coccinea
K. prostrata
Lotus suaveolens
Lupinus angustifolius
L. cosentinii
L. luteus
Mirbelia dilata
Ornithopus compressus
Oxylobium cariaceum
O. cuneatum
O. lanceolatum
O. linearifolium
Pultenaea ochreata
Templetonia retusa
Viminaria juncea

PROTEACEAE

Adenanthos cygnonum

A. meisneri
A. sp.
Banksia attenuata
B. grandis
B. ilicifolia
B. littoralis
B. menziesii
Dryandra nivea
D. sessilis
Grevillea commutata
G. hookeriana
Hakea cristata
H. petiolaris
H. prostrata
H. ruscifolia
H. varia
Isopogon dubius
Persoonia longifolia
P. saccata
Pterophile linearis
Stirlingia latifolia
Synaphea itians
S. petiolaris
S. sp.
Xylomelum occidentale

THYMELAEACEAE

Pimelea hispida
P. rosea

MYRTACEAE

Agonis flexuosa
A. linearifolia
A. parviceps
Astartea fascicularis
Callistemon speciosus
Callistemon speciosus var. *phoeniceus*
Calothamnus lateralis
C. quadrifidus var. *acerosa*
C. rupestris
C. rupestris x quadrifidus
Calytrix fraseri
Corymbia calophylla
Eucalyptus camaldulensis
E. cornuta
E. ficifolia
E. globulus
E. gomphocephala
E. haemotoxylon
E. lehmannii
E. leucoxylon
E. marginata
E. patens
E. rudis
Hypocalymma angustifolium
H. robustum

Kunzea ericafolia
K. micromera
K. spicata
Leptospermum ellipticum
L. laevigatum
Melaleuca acerosa
M. amalaria
M. argentata
M. cuticularis
M. hamulosa
M. incana
M. laterita
M. preissiana
M. quinquenervia
M. radula
M. raphiophylla
M. teretifolia
M. thymoides
M. undulata (?)
Regelia ciliata
Vertcordia picta (?)
V. spicata

LORANTHACEAE

Nuytsia floribunda

STACKHOUSIACEAE

Stackhousia brunonis

EUPHORBIACEAE

Euphorbia peplus
Phyllanthus calycinus

TREMANDRACEAE

Platytheca verticellata

RUTACEAE

Boronia denticulata
B. spathulata

ZYGOPHYLLACEAE

Zygophyllum sp. (?)

OXALIDACEAE

Oxalis purpurea

GERANIACEAE

Erodium botrys
Pelargonium capitatum

GENTIANACEAE

Centaurium sp. (?)

SOLANACEAE

Solanum nigrum

BORAGINACEAE

Echium plantagineum

LAMIACEAE

Hemiandra incana
Westringia fruticosa

OROBANCHACEAE

Orobanche minor

CAMPANULACEAE

Wahlenbergia capensis

STYLIDIACEAE

Stylidium brunonianium

ASTERACEAE

Angianthus sp.
Arctotheca calenduca
Cotula coronopifolia
Hypochaeris radicata
Olearia sp. (?)
Pseudognaphalium luteoalbum
Taraxacum officinale
Ursinia anthemoides
Vellereophytan dealbatum

JUNCAGINACEAE

Triglochin striata

POTAMOGETONACEAE

Potamogeton ochreatus

DASYPOGONACEAE

Dasypogon bromelliifolius
Lomandra sp.

ANTHERICACEAE

Corynotheca micrantha

Sowerbaea laxiflora

COLCHICACEAE

Burchardia multiflora
B. umbellata

IRIDACEAE

Freesia sp.
Patersonia umbrosa

ORCHIDACEAE

Caladenia flava
Elythranthera brunonis
Thelymitra flexuosa

HAEMODORACEAE

Angiozanthus viridis
A. mangelsii
Conostylis aculeata

TYPHACEAE

Typha orientalis

JUNCACEAE

Baumea articulata
B. rubiginosa
Juncus articulatus
J. effusus
J. holoschoenus
J. microcephalus
J. pallidus

CYPERACEAE

Baumea articulata
B. juncea
Cyperus congestus
C. papyrus
C. rotundus
C. tenellus
Gahnia trifida
Isolepis prolifera
Lepidosperma longitudinale

RESTIONACEAE

Leptocarpus tenax
Lyginia barbata
Loxocarya cinerea

POACEAE

Aristida sp.
Avena barbata
Briza maxima
B. minor
Bromus diandrus
Cynodon dactylon
Ehrharta longiflora
Holcus lanatus
Lolium rigidum
Paspalum distichum
Pennisetum macrourum
Poa annua
Polypogon monospeliensis ?
Stipa sp.

 Animals of the Capel Wetlands Centre

INVERTEBRATES

Coelenterata

Hydra (?) sp.

Platyhelminthes

Turbellaria sp.

Nematoda

Nematomorpha

Gordidae sp.

Annelida

Chaetopoda: Oligochaeta sp.
Hirudinea sp.

Arthopoda

CRUSTACEA

Branchiopoda

Cladocera

Ceriodaphnia sp.
Daphnia carinata (King)
Simocephalus sp.

Ostracoda

Copepoda

Calanoida sp.
Cyclopoida sp.
Harpacticodia sp.

Malacostraca

Amphipoda sp.
Cherax quinquecarinatus

INSECTA

Pterygota

Ephemeroptera
Cloeon sp.
Tasmanocoenis tillyardi
Odonata

Aeshna brevistyla
Amphiterigida sp.
Austroagrion coeruleum
Austrolestes annulosus (Selys)
Austrogamphus lateralis
Diplacodes haematodes (Burm.)
Hemicordulia australiae
H. tau (Selys)
Nannophya dalei
Orthetrum caledonicum (Brauer)
Procordulia affinis
Xanthagrion erythroneurum (Selys)

Hemiptera

Agraptocoryxa sp.
Anisops sp.
Micronecta sp.
Mesoveliidae sp.
Veliidae sp.

Tricoptera

Leptoceridae
- *Notilina fulva* Kimmins
- *Oecetis* sp.
- *Triplectides australis*

Coleoptera

Dytiscidae
- *Homeodytes scutellaris* Germ.
- *Rhantus* sp.

Hydrophilidae sp.
- *Allodessus* sp.
- *Antiporus femoralis*
- *Berosus* sp.
- *Lancetes lanceolatus* Clk.
- *Lymbodessus* sp.
- *Megaporus solidus* (Sharp)
- *Necterosoma darwini* (Babington)
- *Rhantus suturalis* Macl.
- *Sternopriscus browni* Sharp

Carabidae sp.
Curculionidae sp.
Gyrinidae sp.

Diptera

Tipulidae
- Limoniinae sp.

Psychodidae sp.
Chironomidae
- *Ablabesmia notabilis* (Skuse)
- *Chironomus occidentalis* Skuse
- *C. tepperi* Skuse
- *C.* aff. *alternans* Walker
- *C.* sp.
- *Cricotopus ? albitibia* (Walker)
- *Cladopelma curtivalva* Kieffer
- *Coelopynia pruinosa* Freeman
- *Corynoneura* sp.

Cryptochironomus grieseidorsum Kieffer
Dicrotendipes conjunctus
Kiefferulus intertinctus
K. martini
Limnophyes pullulus (Skuse)
Macropelopia dalyupenis Freeman
Orthocladiinae sp.
Paramerina levidensis (Skuse)
Paratanytarsus parthenogenetica (Freeman)
Pentaneura levidensis
Polypedilum nubifer (Skuse)
Procladius paludicola (Skuse)
P. villosimanus
Riethia sp.
Stenochironomus sp.
Stictocladius sp
Tanytarsus sp.
Thienemanniella sp.

Ceratopogonidae sp.
Empididae sp.
Dolichopodidae sp.
Muscidae sp.
Tabanidae sp.

Lepidoptera sp.

ARACHNIDA

Acarina

Eylis sp.
Hydracarinid sp.
Porohalacaridae 2 sp.

Mollusca

GASTEROPODA

Planorbidae
Isoderella sp.
Physa sp.

VERTEBRATES

Fish

Galaxiidae
Galaxias occidentalis

Percichthyidae

Bostockia porosa

Nannopercidae

Edelia vittata

Goboidae

Pseudogobius olorum

Poeciliidae

Gambusia holbrooki

Cyprinidae

Carassius auratus

Frogs (Amphibia)

Myobatrachidae

Crinia georgiana
C. (Ranidella) glauerti
C. (Ranidella) insignifera
Geocrinia leai
Heleioporus eyrei
Limnodynastes dorsalis
Pseudophryne guentheri

Hylidae

Litoria adelaidensis
Litoria moorei

Reptiles (Reptilia)

Chelidae

Chelodina oblonga

Pygopodidae

Lialis burtonis

Agamidae

Pogona minor

Varanidae

Varanus gouldii
V. rosenbergi

Scincidae

Bassiana (Leiolopisma) trilineata
Cryptoblepharus plagiocephalus
Ctenotus impar
Egernia napolensis
E. kingii
Hemiergis peronii
Lerista distinguenda
Menetia greyii
Morethia lineoocellata
Tiliqua rugosa

Typhlopidae

Ramphotyphlops australis

Elapidae

Notechis scutatus
Pseudonaja affinis

Birds (Aves) (following the order of Christidis and Boles 1994)

Emu	*Dromaius novaehollandiae*
Brown Quail	*Coturnix ypsilophora*
Blue-billed Duck	*Oxyura australis*
Musk Duck	*Biziura lobata*
Black Swan	*Cygnus atratus*
Australian Shelduck	*Tadorna tadornoides*
Australian Wood Duck	*Chenonetta jubata*
Pacific Black Duck	*Anas superciliosa*
Australasian Shoveler	*A. rhynchotis*
Grey Teal	*A. gracilis*
Chestnut Teal	*A. castanea*
Pink-eared Duck	*Malacorhynchus membranaceus*
Hardhead	*Aythya australis*
Australasian Grebe	*Tachybaptus novaehollandiae*
Hoary-headed Grebe	*Poliocephalus poliocephalus*
Great Crested Grebe	*Podiceps cristatus*
Darter	*Anhinga melanogaster*
Little Pied Cormorant	*Phalacrocorax melanoleucos*
Pied Cormorant	*P. varius*
Little Black Cormorant	*P. sulcirostris*
Great Cormorant	*P. carbo*
Australian Pelican	*Pelecanus conspicillatus*
White-faced Heron	*Egretta novaehollandiae*
Little Egret	*E. garzetta*
White-necked Heron	*Ardea pacifica*
Great Egret	*A. alba*
Cattle Egret	*A. ibis*
Nankeen Night Heron	*Nycticorax caledonicus*
Australian White Ibis	*Threskiornis molucca*
Straw-necked Ibis	*T. spinicollis*
Yellow-billed Spoonbill	*Platalea flavipes*
Osprey	*Pandion haliaetus*
Black-shouldered Kite	*Elanus axillaris*
Whistling Kite	*Haliastur sphenurus*
White-bellied Sea Eagle	*Haliaeetus leucogaster*
Swamp Harrier	*Circus approximans*
Spotted Harrier	*C. assimilis*
Brown Goshawk	*Accipiter fasciatus*
Collared Sparrowhawk	*Accipiter cirrhocephalus*
Wedge-tailed Eagle	*Aquila audax*
Little Eagle	*Hieraaetus morphnoides*
Brown Falcon	*Falco berigora*
Australian Hobby	*F. longipennis*
Peregrine Falcon	*Falco peregrinus*
Nankeen Kestrel	*Falco cenchroides*
Buff-banded Rail	*Gallirallus philippensis*

Spotless Crake	*Porzana tabuensis*
Purple Swamphen	*Porphyrio porphyrio*
Dusky Moorhen	*Gallinula tenebrosa*
Black-tailed Native-hen	*G. ventralis*
Eurasian Coot	*Fulica atra*
Painted Button-quail	*Turnix varia*
Snipe	*Gallinago* sp.
Common Greenshank	*Tringa nebularia*
Common Sandpiper	*T. hypoleucos*
Black-winged Stilt	*Himantopus himantopus*
Banded Stilt	*Cladorhynchus leucocephalus*
Red-capped Plover	*Charadrius ruficapillus*
Black-fronted Dotterel	*C. melanops*
Red-kneed Dotterel	*Erythogonys cinctus*
Great Skua	*Catharacta skua*
Whisered Tern	*Childonis hybrida*
Laughing Turtle-Dove	*Streptopelia senegalensis*
Common Bronzewing	*Phaps chalcoptera*
Crested Pigeon	*Ocyphaps lophotes*
Short-billed Black-Cockatoo	*Calyptorhynchus latirostris*
Long-billed Black-Cockatoo	*C. baudinii*
Purple-crowned Lorikeet	*Glossopsitta porphyrocephala*
Regent Parrot	*Polytelis anthopeplus*
Western Rosella	*Platycercus icterotis*
Australian Ringneck	*Barnardius zonarius*
Red-capped Parrot	*Purpureicephalus spurius*
Elegent Parrot	*Neophema elegans*
Fan-tailed Cuckoo	*Cacomantis flabelliformis*
Shining Bronze-Cuckoo	*Chrysococcyx lucidus*
Southern Boobook	*Ninox novaeseelandiae*
Barn Owl	*Tyto alba*
Tawny Frogmouth	*Podargus strigoides*
Spotted Nightjar	*Eurostopodus argus*
Laughing Kookaburra	*Dacelo novaeguineae*
Sacred Kingfisher	*Todiramphus sanctus*
Rainbow Bee-eater	*Merops ornatus*
Splendid Fairy-wren	*Malurus splendens*
Spotted Pardalote	*Pardalotus punctatus*
Striated Pardalote	*P. striatus*
White-browed Scrubwren	*Sericornis frontalis*
Western Gerygone	*Gerygone fusca*
Inland Thornbill	*Acanthiza apicalis*
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*
Red Wattlebird	*Anthochaera carunculata*
Little Wattlebird	*A. chrysoptera*
White-naped Honeyeater	*Melithreptus lunatus*
Brown Honeyeater	*Lichmera indistincta*
New Holland Honeyeater	*Phylidonyris novaehollandiae*
Tawny-crowned Honeyeater	*P. melanops*
Western Spinebill	*Acanthorhynchus supercilliosus*
White-fronted Chat	*Epthianura albifrons*
Scarlet Robin	*Petroica multicolor*
White-breasted Robin	*Eopsaltria georgiana*
Golden Whistler	*Pachycephala pectoralis*
Rufous Whistler	*P. rufiventris*
Grey Shrike-thrush	*Colluricincla harmonica*
Restless Flycatcher	*Myiagra inquieta*
Magpie-lark	*Grallina cyanoleuca*

Grey Fantail	*Rhipidura fuliginosa*
Willie Wagtail	*R. leucophrys*
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*
White-winged Triller	*Lalage sueurii*
Black-faced Woodswallow	*Artamus cinereus*
Grey Butcherbird	*Cracticus torquatus*
Australian Magpie	*Gymnorhina tibicen*
Australian Raven	*Corvus coronoides*
Richard's Pipit	*Anthus novaeseelandiae*
Red-eared Firetail	*Stagonopleura oculata*
Welcome Swallow	*Hirundo neoxena*
Tree Martin	*Hirundo nigricans*
Clamorous Reed-Warbler	*Acrocephalus stentoreus*
Little Grassbird	*Megalurus gramineus*
Silvereye	*Zosterops lateralis*

Mammals (Mammalia)

MONOTREMATA

Tachyglossidae

Short -beaked Echidna	*Tachyglossus aculeatus*

MARSUPIALIA

Peramaelidae

Southern Brown Bandicoot (Quenda)	*Isodon obesulus*

Petauridae

Western Ringtail Possum	*Pseudocheirus peregrinus occidentalis*

Phalangeridae

Common Brushtail Possum	*Trichosurus vulpecula*

Macropodidae

Western Grey Kangaroo	*Macropus fuliginosus*

EUTHERIA

Muridae

Water Rat	*Hydromys chrysogaster*
Black Rat	*Rattus rattus*
House Mouse	*Mus musculus*

Leporidae

Rabbit	*Oryctolagus cuniculus*

Canidae

Red Fox	*Vulpes vulpes*

Felidae

Feral cat *Felis catus*