Ramsar additional infomation -
Richard Kingsford

Australian Government
National Water Commission

National waterbird assessment

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Waterlines

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Foreword

Scientific knowledge is essential to sustainably manage Australia's water resources and maintain high-value environmental assets. Both science and monitoring are critical to effective environmental watering strategies that deliver tangible ecological outcomes. This, in turn, underpins community confidence in the benefits of recovering water for the environment.

In 2007, the National Water Commission identified wetlands and waterbirds as important areas where targeted scientific research would improve Australian water planning and management, thereby progressing commitments made under the National Water Initiative. This Waterlines report was initiated to provide new data and analysis to support water planning and inform environmental watering decisions.

The *National waterbird assessment* report outlines the results of the 2008 National Waterbird Survey and analyses trends based on 27 years of data from the Australian Eastern Aerial Surveys. The report indicates a decline in waterbird numbers over the study period, and identifies individual wetlands where decline has occurred. Because the report provides an insight into waterbird species composition and abundances, it presents a baseline against which to compare future data, including more recent evidence of the recovery of waterbird populations as a result of wetter years in 2010 and 2011.

Importantly, the research has identified the top 20 wetlands in Australia, based on waterbird abundance. This information will assist policy, planning and management decisions regarding the conservation value of these wetlands at both a national and international level.

Although this study is a valuable contribution to current research on flow-ecology relationships, the National Water Commission acknowledges there are still many related issues that are not well understood.

As the Commission emphasised in its 2011 assessment of the National Water Initiative, targeted investment in new knowledge and ongoing monitoring to support sustainable water management is vital. Effective adaptive management requires knowledge to be continually extended and broadened, and the application of that knowledge in decision making.

Long-term, purpose-designed monitoring programs are needed to establish the links between flows and ecosystem outcomes and will provide critical input to adaptive management processes.

The National Water Commission congratulates the University of New South Wales and its partners on the production of this important piece of work.

James Cameron
Chief Executive Officer
March 2012

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Executive summary

Waterbirds provide a useful indicator of river and wetland condition in Australia that can be monitored across large spatial scales. Given the long history of waterbird research in Australia, waterbirds also provide a rare opportunity to assess long-term temporal trends in the ecological status of water-dependent ecosystems as well as in this iconic group of species. Understanding spatial and temporal trends in waterbird numbers has considerable significance both in terms of informing conservation and sustainable natural resource management as well as in meeting national and jurisdictional obligations to a wide range of conservation agreements of relevance to waterbirds (e.g. migratory bird treaties) and the wetlands which support them (e.g. the Ramsar Convention).

The National Water Resource Assessment Using Waterbirds: Ecosystem Health and Conservation Importance of Water-Dependent Ecosystems and Rivers project was funded by the National Water Commission and undertaken by the Australian Wetlands and Rivers Centre at the University of New South Wales, with the support and involvement of all state governments. The project addressed three major objectives:

- design and completion of a national survey of waterbirds in all major wetlands of Australia holding water in 2008
- assessment of long-term changes in waterbird numbers in relation to flow in key wetlands of eastern Australia, using data from the Eastern Australia Aerial Waterbird Survey
- design and establishment of a national waterbird database to store and access waterbird survey data.

Status of waterbirds—2008 National Waterbird Survey

- A continental-scale aerial waterbird survey was designed and conducted for the first time in Australia over two months in 2008 and supplemented by ground surveys in 55 sites.
- The 2008 National Waterbird Survey covered 3.8 million ha of wetlands comprising 4858 wetlands. Most of the wetlands holding water during the survey period were close to coastal regions. Of the 12 national drainage divisions, the Timor Sea division had the highest number of wetlands (20.5%), followed by the South-west Coast (15.3%) and the Gulf of Carpentaria (13.8%). The largest percentage of wetland area occurred within the Lake Eyre Basin division (33.1%), followed by the Gulf of Carpentaria (16.4%), Timor Sea (8.8%) and Indian Ocean (8.7%) divisions. There were relatively few wetlands and low percentage of wetland area in the Bullo–Bancannia, South Australian Gulf, Tasmania and Western Plateau divisions.
- Mean wetland size was 333 ha and the most frequently encountered sizes were in the 0–1 ha and 10–200 ha-size classes. The largest individual wetland, at 440 625 ha, was the Diamantina River floodplain in the Lake Eyre drainage division.
- Waterbirds were not observed in around 40% of surveyed wetlands and of the other 60% most supported fewer than 100 waterbirds. Very few had high waterbird concentrations and 39% of all recorded waterbirds occurred on the top 20 wetlands, as ranked by waterbird abundance, with over 6% occurring in the highest-ranked wetland alone, Eighty Mile Beach. Around 50% of all waterbirds surveyed occurred on just 41 wetlands, or 1.1% of all wetlands surveyed.

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- Four of the top five ranked wetlands in terms of waterbird abundance were in north-western Australia, i.e. Eighty Mile Beach, lakes Gregory and Argyle, and Roebuck Bay. The Coorong and Lower Lakes wetland complex at the mouth of the Murray–Darling drainage division was also among the top five, supporting over 100 000 waterbirds at the time of the survey. The top 20 ranked wetlands in terms of waterbird abundance were distributed around the country and included wetlands in southern and inland Australia, e.g. Dumbleyung Lake (south-western Western Australia) and the Cuttaburra Channels (Paroo River catchment of the western Murray–Darling Basin).
- Overall, 106 species of waterbirds were recorded. The species richness of individual wetlands exhibted a much lower range than waterbird abundance. Wetlands with high species richness occurred in all drainage divisions except Tasmania, which supported considerably fewer species. Species richness is a poorer differentiator between wetlands than abundance because it exhibits a much lower range. At a wetland scale, species richness was significantly correlated with abundance and high species numbers generally occurred on wetlands supporting high numbers of waterbirds, although a few with high abundances were dominated by particular species or functional groups of waterbirds, e.g. magpie geese in Nanjbagu Billabong in Kakadu National Park and migratory shorebirds in Eighty Mile Beach and Roebuck Bay.
- The tropical drainage divisions, especially the Timor Sea, were clearly more important to waterbirds in terms of abundance than other regions at the time of the survey, which occurred while eastern Australia was experiencing drought. Waterbird density was particularly high in some Timor Sea wetlands. High waterbird abundance, density and species richness also occurred in some inland wetlands, e.g. Lake Galilee and Cuttaburra Channels, and the Bulloo–Bancannia drainage division in particular supported a relatively high density of waterbirds.
- Waterbird community composition varied among drainage divisions, primarily reflecting distributions of tropical species, e.g. magpie geese and plumed whistling-duck versus temperate species, e.g. grey teal and small waders. The Indian Ocean, Timor Sea, Gulf of Carpentaria and Western Plateau drainage divisions were particularly important for migratory shorebirds, emphasising the significance of north-western Australia as a staging area and over-wintering sites for these species. Duck species dominated the Lake Eyre and Bulloo–Bancannia drainage divisions, reflecting their ability to capitalise on productive ephemeral wetlands in these regions (Figure 21, Appendix A).
- The total number of waterbirds recorded during the 2008 National Waterbird Survey was 4.55 million. An estimate of the true number at the time, extrapolating from randomly surveyed wetlands, is calculated to be 4.65 million. These estimates are considerably lower than an estimate of 9 million made in 1998 based on data from the late 1980s to the mid-1990s, which were based on extrapolations of data. The discrepancy reflects either a degree of underestimation in the current national survey, due to a relatively small sample of randomly selected small wetlands available, a decline in waterbird numbers across Australia over the past 20 years, or a combination of these factors. This decline has been well documented for shorebirds in eastern Australia and some wetlands in eastern Australia.
- The 2008 National Waterbird Survey provides a sound baseline for comparison with future equivalent national surveys to assess trends in waterbird abundance and composition.

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- The most abundant functional group of waterbirds was the herbivore group, which included Australian shelduck, Eurasian coot and black swans. The most abundant species (or taxa) recorded were magpie geese, accounting for almost 21% of all waterbirds counted, followed by small waders, plumed whistling-duck, grey teal, large waders, egrets, banded stilt, wandering whistling-duck, pink-eared duck, terns, black swan and Eurasian coot. These top 12 ranked species (or taxa) accounted for over 82% of all waterbirds counted. In contrast, the 43 least abundant species comprised less than 1% of all waterbirds surveyed.
- Population sizes of several abundant species from the national survey are comparable to past estimates—for example, a national magpie goose population of around 900 000 compared with past estimates of around 1 million (although one regional estimate suggested a population of 1.6 million). Banded stilt are also estimated here to have a population size of about 200 000, which is comparable to a past estimate of 206 000 in 2006.
- Grey teal are estimated to have a current (i.e. 2008) population size of around 320 000, which is considerably lower than past estimates of over 1 million. Furthermore, counts of 150 000 in eastern Australia and 135 000 in south-western Australia alone in the early 1990s suggest that this species may have significantly declined in population.
- The estimated abundance of shorebirds in Australia is lower than past estimates, consistent with another recent survey. It was not possible to survey every shoreline of the Australian coast during the current survey, so the results are not definitive.

Long-term changes in waterbirds in eastern Australia

- A significant decline is evident in the numbers of waterbirds counted in the Eastern Australian Aerial Waterbird Survey over a 27-year period from 1983 to 2009. While particularly high numbers of waterbirds were recorded early in this period, in 1984, when Lake Eyre flooded, a significant long-term decline in waterbird abundance remains apparent, even when this date is excluded from analyses. Numbers of breeding waterbirds have exhibited considerable highs and lows over the survey period, generally corresponding to periods of flooding and drying. Long-term decline in both the number of waterbirds breeding and the number of breeding species, however, is evident over the survey period.
- Wetland area and the number of wetlands surveyed (i.e. holding water) in the eastern Australia survey region fell between 1983 and 2009. Wetland area declined significantly from 1983–1984 and again from 2000 to 2009, the latter period demonstrating the effects of the recent drought. In contrast, the number of wetlands varied considerably between 1983 and 1999 then declined significantly until 2009 when numbers rose again, almost reaching the long-term mean.
- There was considerable variation in wetland area, waterbird abundance and density across 11 selected wetlands within the survey region. This includes 10 wetlands identified as being of high importance to waterbirds, based on their overall waterbird numbers during the survey period, and the Macquarie Marshes, which is a Ramsar site and had high waterbird numbers during early survey dates. Not all of the wetlands held water during each survey date, although regulated wetlands typically held water more frequently than the unregulated wetlands investigated.

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- Significant long-term declines in waterbird abundance were evident over the 27-year survey period in seven of the 11 selected wetlands, including all of the wetlands within the Murray–Darling drainage division (i.e. Menindee Lakes, the Lowbidgee, Macquarie Marshes, the Naracoorte wetlands and the Paroo–Cuttaburra Channels) and two wetlands in the Lake Eyre drainage division (i.e. Lake Eyre and Cooper Creek wetlands). No long-term trends in waterbird abundance were apparent in the other four wetlands, all in the Lake Eyre drainage division (i.e, Lake Galilee, lakes Torquinie and Mumbleberry, Lake Hope and Lake Moondarra).
- At a regional scale, waterbird abundance and the number of breeding waterbirds were strongly explained by wetland area and the number of wetlands, which were significantly correlated. The number of breeding waterbird species was also well explained by wetland area but less so by the number of wetlands. Good explanatory models were developed for waterbird abundance in the individual wetlands considered, except for Lake Moondarra. Wetland area was a highly significant predictor in all cases as was river flow in all cases where this data was available. Rainfall was also a significant predictor of waterbird numbers in two wetlands that fill from local runoff, Naracoorte and Lake Galilee, as well as in the Cooper Creek wetlands for which flow was additionally highly significant.
- Significant long-term declines in waterbird abundance were evident in all of the regulated wetlands examined here, except Lake Moondarra. Significant shifts through time in the composition of waterbird communities were also apparent in all of the regulated wetlands, including Lake Moondarra, and particularly in the Lowbidgee and Macquarie Marshes.
- Waterbird abundance also declined in four of seven unregulated wetlands, but waterbird community composition in unregulated wetlands exhibited fewer significant changes during the survey period than in regulated wetlands.
- River regulation has reduced the area of wetlands like the Macquarie Marshes. Additional effects of river regulation on waterbird communities and condition, beyond those mediated by wetland area, are known from other studies but these were not assessed in this research project. A more in-depth analysis of the species contributing to community-level variation may sugggest the mechanisms driving it.

National Waterbird Database

- A national waterbird database was designed and developed during this project to provide a repository of waterbird survey data, to enable improved data storage and accessibility as well as analyses across a range of spatial and temporal scales. A trial web version of the National Waterbird Database is available by contacting the Australian Wetlands and Rivers Centre at the University of New South Wales via email address: *awrc@unsw.edu.au*.
- The National Waterbird Database currently holds data from the:
  - 2008 National Waterbird Survey (see Chapter 2)
  - Eastern Australian Aerial Waterbird Survey database (72 524 records from 1983–2008)
  - Northern Murray–Darling Surveys (5655 records)
  - Murray Icon Surveys (MIS) (4157 records 2007 and 2008).

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- The database could be enhanced considerably through the inclusion of additional past and future survey data, including ground-survey data. However, this will require resources for data processing and quality control. In some cases additional issues of accessibility, licensing and metadata need to be addressed before data can be included. The structure and methodolology developed in the construction of the national database can be used to guide the effective collection of waterbird survey data in the future across a range of scales.

Key recommendations

Recommendations for policy and management

- Data from the 2008 National Waterbird Survey identified many individual wetlands as being of high national (and international) importance to waterbirds in terms of abundance and density, including (but not limited to):
    - the top five ranked wetlands (Eighty Mile Beach, lakes Gregory and Argyle, Coorong/Lower Lakes and Roebuck Bay), which all supported over 150 000 waterbirds
    - the top 20 ranked wetlands, which together supported approximately 40% of all waterbirds counted.

This data should also contribute to national and jurisdictional assessments of:

- the existing reserve/protected area network to ensure their adequate protection and conservation
- existing listings of wetlands under Ramsar or as important wetlands
- high conservation value aquatic ecosystems as per the requirements of the National Water Initiative
- development proposals that have the potential to impact on these wetlands.

- The importance of northern Australia to waterbirds in particular should be recognised at a national (and international) level. Data from the 2008 National Waterbird Survey can be used to inform critical assessments of the existing reserve/protected area network in tropical regions, as well as listings of wetlands under Ramsar, or as important wetlands. The information from the survey should also be used to inform planning and prioritisation of off-reserve conservation measures, e.g. corridors, development controls and climate change adaptation measures in tropical Australia.
- The significance of ephemeral wetlands of inland Australia to waterbirds, especially duck species, even during a dry year such as 2008, should be recognised at national and jurisdictional levels. An assessment of the current reserve network and off-reserve conservation measures of dryland wetlands identified here as important to waterbirds should be conducted with particular consideration of water (e.g. limits on extraction and environmental flow allocations) and land management practices (e.g. protection of waterbodies, including floodplains and drainage lines).
- Comparison of results from the 2008 National Waterbird Survey with past research suggests that the grey teal is one common waterbird species that is likely to have significantly declined in population (up to 80%) over the past 20 years. Using the results of the current survey to inform the development of a management plan and a reassessment of conservation status for this and other species should therefore be a priority.

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- The current project has included only preliminary analyses of the extensive dataset produced by the 2008 national survey and many recommendations relevant to policy and management require further analyses and consideration in the context of specific management questions. These include:
  - identification of wetlands of national importance to particular species of waterbirds to ensure these wetlands are adequately protected by the reserve network and conservation agreements, e.g. Ramsar
  - identification of wetlands of regional importance to waterbirds, both overall and to particular species (i.e. within state jurisdictions or drainage divisions and catchment), to ensure these wetlands are adequately represented by the reserve network and off-reserve conservation measures, e.g. water management planning
  - identification of wetlands of local importance to waterbirds, using data on species and functional compositions (e.g. breeding and foraging habits of community) to inform appropriate on-ground management actions (e.g. protection of nesting habitat or water-level manipulation) and contribute to the development of wetland-scale management plans (e.g. for national parks)
  - identification of waterbird species of potential concern to develop targeted species management plans.
- Much of the value of the National Waterbird Survey will come from repeating it over time, particularly for wetlands of high and very high importance, and supplementing it with longitudinal studies of targeted wetlands that respectively explore long-term temporal trends and finer seasonal and event-based fluctuations. The latter could be undertaken by skilled volunteers from organisations such as BirdLife Australia.
- Given the potential decline in migratory shorebirds, and the significance of migratory birds to many of Australia' international agreements (e.g. JAMBA, CAMBA and ROKAMBA), there is considerable merit in extending the amount of shoreline covered in future surveys, with targeted surveys of regions of known importance, to improve estimates of shorebird numbers in Australia.
- The long-term assessment of waterbird numbers in eastern Australia conducted during this project provides further evidence that wetland area, waterbird numbers and numbers of breeding waterbirds and breeding species have all declined in this region over the past 27 years. While climate, especially the recent drought, is obviously implicated in many of these trends, changes in the composition of waterbird communities through time in regulated—but not unregulated—wetlands, indicate that river regulation is, at least partially, contributing to the declines. Detailed analyses of changes to river flow regimes, published in peer reviewed journals, support this interpretation. Other factors not measured in our study could also be contributing to reductions, partiularly long, dry periods. Waterbirds could serve as a focus in addressing overallocation and flow regime alteration in regulated systems of the Murray–Darling Basin (MDB) through the mechanism of the MDB planning processes, and could also serve as a baseline for protecting the mostly unregulated rivers and wetlands of the Lake Eyre Basin.

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- The Eastern Australian Aerial Waterbird Survey provides a valuable long-term ecological dataset for examining human impacts on waterbird populations and wetland condition and for assessing the efficacy of management actions, e.g. wetland restoration or rules for water planning and management. Long-term data sets (such as the aerial surveys of waterbirds) are critical for measuring the success of water management plans, ecological recovery following drought and responses to climate change. Such analyses needs to also include assessment of potential explanatory factors including changes to flow regimes and climate.
- The National Waterbird Database developed in this project is a significant resource that provides a baseline against which to comapre future data, including more recent evidence of the recovery of waterbird populations as a result of wetter years in 2010-11. The database has the potential to inform the management of Australia's rivers and wetlands and could influence future research on Australia's waterbirds. As a rigorously constructed platform, the database can support national waterbird data into the future, and could substantially contribute to the current strategic planning for national waterbird data requirements. Continued collaboration between the Australian Government, jurisdictions, researchers, and key non-government organisations committed to bird conservation will provide the best opportunity for the development of a successful national approach to the organisation, storage and dissemination of waterbird data.

Recommendations for future research

- The waterbird survey data, now accessible via the National Waterbird Database, including the extensive spatial dataset produced by the 2008 national survey and the long-term dataset from the Eastern Australian Aerial Waterbird Survey, has considerable potential to generate new knowledge about the ecological structure, function and condition of Australian rivers and wetlands. Some of the key questions that might be addressed using the existing dataset include:
    - how do patterns of waterbird diversity and abundance at a national scale relate to patterns of diversity and abundance of other aquatic organisms, e.g. frogs, fish, wetland plants?
    - The mechanisms in which river regulation may affect whole ecosystems (e.g. food webs, feeding and nesting areas) for waterbirds.
    - what spatial patterns exist in the distribution of waterbird species at a national scale and how do these relate to wetland area and type, climate, hydrology, land use and landscape factors, e.g. proximity to other wetlands or urban centres?
    - to what extent can the effects of climate, changes to flow (e.g. river regulation) and other landscape factors, e.g. land use, be identified in temporal and spatial patterns of waterbird abundance and community composition?
    - how vulnerable are wetlands of importance to waterbirds to climate change and water resource development in different regions of Australia in terms of projected exposure?
    - how will climate change, habitat loss and flow modification interact with identified population declines and what are the implications for adequacy of the current reserve network and waterbird conservation?

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1. Introduction

Reliable information about changes in the distribution and abundance of species over time is critical both to an understanding of ecology and conservation biology as well as to the sustainable management of ecosystems and natural resources. Addressing key questions about the status of species, their habitat and resource use, as well as human impacts on them, requires well-established and repeatable methods of data collection. In turn, the development of appropriate methods for obtaining credible and useful information from which long-term changes in ecosystem condition can be assessed depends largely on identifying robust 'indicators' such as the population sizes of key species (or groups of species) suitable for monitoring. There are few rigorous measures of species' population sizes, however, that are distributed widely across different landscapes, particularly on a continental scale.

For rivers and wetlands, which are among the world's most threatened habitats, monitoring information is needed to assess the impacts of human activities, e.g. river regulation and water extraction, as well as the effectiveness of management efforts and restoration. There is considerable interest in Australia at both government and community levels surrounding the protection and restoration of rivers and wetlands to achieve biodiversity and ecosystem health objectives. This is reflected by the commitments to water-dependent ecosystems made through the National Water Initiative. These issues are increasingly addressed through the purchase of environmental water by the Commonwealth Environmental Water Holder, as well as through the development of the Murray–Darling Basin Plan under the *Water Act 2007*. To be effective, such adaptive management of Australian rivers, wetlands and water resources requires information relevant to the assessment of river and wetland health. This report focuses on the use of waterbirds as a useful indicator of river and wetland condition in Australia. Waterbirds are particularly useful as ecological indicators at large regional, and even national, scales and, given the long history of waterbird research in Australia, also provide a rare opportunity to assess long-term temporal trends in the ecological status of Australian rivers and wetlands.

This report presents the results of the *National Water Resource Assessment Using Waterbirds: Ecosystem Health and Conservation Importance of Water Dependent Ecosystems and Rivers* project funded by the National Water Commission and managed by the Australian Wetlands and Rivers Centre at the University of New South Wales. With the support and involvement of all state governments, the project included a survey, in 2008, of waterbirds in major wetlands across the whole of Australia. This national waterbird survey represents the first continental-scale waterbird survey in the world and allows an unprecedented spatial assessment of the status of waterbirds and the wetlands supporting them across Australia. The project also included a temporal assessment of long-term changes in waterbird numbers in key wetlands of eastern Australia, using data obtained from the annual Eastern Australian Aerial Waterbird Survey, which has been running since 1983.

Additionally, a national waterbird database was designed and established during this project to store and provide access to data from these past surveys and the 2008 National Waterbird Survey. The database will guide future surveys, ensuring that waterbird data can be widely accessed and can effectively inform management and policy aiming to improve the condition and status of Australian rivers and wetlands as well as the many waterbirds that rely on them.

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1.1. Background

1.1.1. Waterbirds as ecological indicators

Research on waterbirds, unlike many groups of organisms, has a long history, driven primarily by the need to manage recreational hunting of waterfowl or wildfowl belonging to the Anatidae bird family, i.e. ducks, geese and swans. More recently, the focus has shifted, particularly in Australia, to the potential of waterbirds as indicators of river and wetland condition, including the monitoring of human impacts.

There is considerable evidence that changes in river and wetland condition, particularly those related to altered flows, are reflected by changes in the abundance and composition of waterbird communities (Kingsford and Thomas 1995; 2004; Leslie 2001; Kingsford et al*.* 2004; Kingsford and Auld 2005; Kingsford and Porter 2009) Waterbird numbers vary in response to other hydrologic indicators as well (e.g. Lyons et al*.* 2007) and changes in wetland and river ecosystems, e.g. food web structures, can also be reflected by changes in the abundance of waterbird functional groups, e.g. invertebrate feeders, herbivores and fish-eating birds (Kingsford and Porter 1994; Kingsford et al. 2004). Furthermore, waterbirds can be surveyed at large spatial scales via aerial surveys (Braithwaite et al. 1986).

Large flock of brolgas over the floodplains of the Northern Territory (Photo: RT Kingsford)

Monitoring temporal and spatial changes in the abundance of waterbirds also has direct relevance to Australia's many international obligations to protect and conserve waterbirds, as well as those that relate to wetland and river heath, including the Ramsar Convention, the Convention on Conservation of Migratory Species of Wild Animals (the Bonn Convention), the China–Australia Migratory Bird Agreement (CAMBA), the Japan–Australia Migratory Bird Agreement (JAMBA), the Republic of Korea–Australia Migratory Bird Agreement (ROKAMBA) and the Convention on Biological Diversity, all of which the Australian Government implements through the *Environment Protection and Biodiversity Conservation Act 1999*. Additionally, the importance of a wetland is often measured in terms of the number of waterbirds supported, with a threshold of 20 000 waterbirds providing a key criterion for qualification as a wetland of international importance under the Ramsar Convention.

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In Australia, waterbirds are regularly surveyed in different areas using comparable methods that enable continental-scale comparisons, as well as allowing exploration of the impacts of overused systems and identification of sustainable levels of water extraction for particular wetlands such as the Macquarie Marshes (Kingsford and Thomas 1995).

1.1.2. Aerial waterbird surveys

The potential value of aerial surveys of waterbirds was first recognised in the late 1940s for North American wetlands, leading to the development of the world's most extensive waterbird survey at that time (Martin et al. 1979). Aerial surveys are a very cost effective technique for collecting data on waterbird populations and allow the distribution of waterbird populations to be measured over large areas (Caughley 1979; Kingsford 1999). As with most surveys, the objective of aerial waterbird surveys is typically to effectively collect data, using repeatable methods that allow spatial and temporal comparisons to be made, while maximising the spatial coverage of the survey and minimising costs.

Several large-scale aerial waterbird survey programs exist around the world (Kingsford and Porter 2009). One of the longest running and more extensive wildlife surveys globally is the breeding waterbird survey of North America that began in the 1950s. In this survey, estimates of the abundance of 20 duck species are systematically surveyed every year in breeding grounds across a survey region of about 3.37 million km^2, with a primary objective of providing population data to enable the establishment of harvest or bag limits for waterfowl (Blohm et al. 2006; Padding et al. 2006).

A few regional aerial waterbird surveys have also been conducted in Europe, but these have seldom maintained continuity (Kingsford and Porter 2009). In Denmark, for instance, numbers of mostly ducks, geese and swans were estimated during 14 country-wide surveys between 1966 and 1973 to determine their distribution, abundance and potential implications for hunting (Joensen 1968; 1974), but coverage areas varied between surveys. Surveys of Anatidae were also conducted in Sweden between 1969 and 1974 within 14 districts (Nilsson 1975) and multispecies aggregations were also estimated across 25–39 wetlands in Uzbekistan from 1986 to 1988 and in 2000 (Kreuzberg-Mukhina 2006).

Aerial surveys are conducted at low levels over wetlands and waterbirds estimated and identified, using tape recorders, to provide an estimate of the species and their abundance for each wetland (Photo: RT Kingsford)

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1.1.3. Large-scale aerial waterbird surveys in Australia

In Australia, aerial surveys are a popular and effective method of estimating the abundance and distribution of waterbirds and have ranged from the scale of individual wetlands to that of large regions (Figure 1). With the notable exception of the breeding waterbird survey mentioned above, North American waterbird surveys have tended to focus on the abundance and nesting activity of a single or a few waterbird species, typically waterfowl (McLaren and McLaren 1982; Reinecke et al. 1992; Schneider et al. 1994; Drewien et al. 1996; Drewien and Benning 1997; Dolbeer et al. 1997). In contrast, many Australian waterbird surveys, though not all, have surveyed the distribution and abundance of all waterbird species occurring within particular wetlands (Kingsford and Porter 1993; Halse et al. 1998; Kingsford 1999; Kingsford et al. 2004a).

At least 17 major regional or large-scale surveys of waterbird populations have been undertaken since the 1980s (Table 1).Most of these have monitored the abundance and distribution of waterbirds in response to flooding or documented the composition of waterbird communities in a particular wetland or estuarine site. The dominant methods used have been total or partial counts of individual wetlands, although transects have also been used in extensive and homogenous wetlands such as floodplains (Morton et al. 1990a; Kingsford et al. 1999a; Halse et al. 2005). The longest-running and most extensive aerial waterbird survey in Australia, extending for 25 years and sampling around one-third of the continent, is the Eastern Australian Aerial Survey of Waterbirds (Figure 1, Table 1).

Figure 1: Location and coverage of major aerial waterbird surveys in Australia.

Horizontal lines (30 km wide) show the 10 survey bands of the eastern Australian aerial survey flown each October, 1983–2009 (1), the two northern survey bands flown in 1984 (1b) and the two survey bands flown across Tasmania in 1995. Dashed lines were flown in only 1985 and 1995. Hatched blocks were regional surveys of wetlands. See Table 1 for full details of surveys matching numbers.

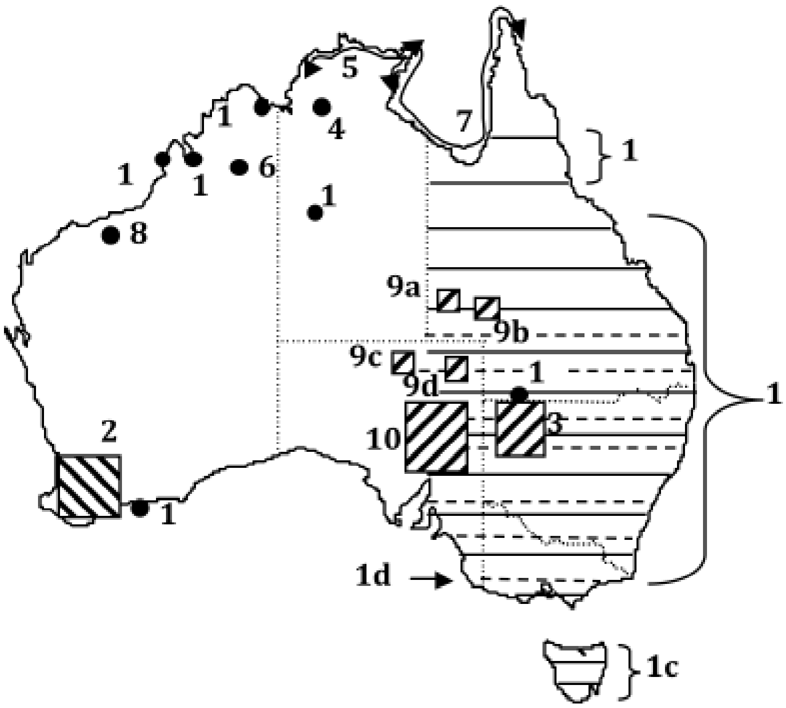

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Table 1: Summary of large scale aerial surveys of waterbirds within Australia.

Name of survey[a]	*Description*	*Time frame*	*References*
Aerial survey of waterbirds in eastern Australia[1a]	Annual survey on 10 survey bands (30 km wide) across eastern Australia. Up to 50 waterbird species surveyed on up to 2000 wetlands.	1983–2007; 25 years of data	Braithwaite et al. 1985a; Kingsford et al. 1999 random bands in Kingsford et al. 1997b
Two survey bands into northern Australia[1b]	Survey on two survey bands (30 km wide) across eastern Australia in northern Australia. Up to 50 waterbird species surveyed.	1984	Braithwaite et al. 1985b
Two survey bands in Tasmania[1c]	Survey on two survey bands (30 km wide) across eastern Australia in Tasmania. Up to 50 waterbird species surveyed.	1995	Kingsford et al. 1997a
Murray–Darling Division[1d]	Survey on seven survey bands (30 km wide) randomly placed within the Murray–Darling division. Up to 50 waterbird species surveyed.	1995	Kingsford et al. 1997
Waterbirds of south-western Australia[2]	Surveys of ducks, swans and coots at about 350 water bodies in stratified survey design across south-west WA used to estimate total waterfowl numbers in region. November counts in 1986–87, subsequently November and March. Ground comparisons made at selected wetlands.	1986-92	Halse et al. 1990, 1992, 1994, 1995, Jaensch & Vervest 1988
Waterbirds of north-western New South Wales	Selected surveys of wetlands.	1983-1985	Maher 1991; Maher and Braithwaite 1992
Waterbirds of north-western New South Wales[3]	Surveys on more than 20 wetlands every three months in north western New South Wales. Surveys involved four counts at each time period.	1987-1990	Kingsford et al. 1994; Roshier et al. 2002
Waterbirds of the Alligator Rivers Region[4]	Fixed transects were surveyed once a month for all waterbird species on the Magela, Nourlangie, East Alligator and Boggy Plain floodplains.	1981–1984	Morton et al. 1990a,b; 1993a,b,c

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Name of survey[a]	*Description*	*Time frame*	*References*
Magpie geese in Arnhem Land[5]	Abundance and nesting colonies of magpie geese were estimated on the coastal floodplains of Arnhem Land. Numbers varied from about 2 to 3 million while numbers of nests varied from about 1.5 million to 2.5 million.	1984–1986	Bayliss 1990a, b
Lake Gregory[6]	Counts of the Lake Gregory system 1989, 1990, 1991, 1993, 1995, 1998, 2000, 2005.	1989–2005	Halse et al. 1998,
Migratory shorebirds in the Gulf of Carpentaria[7]	Four summer surveys and four winter surveys were done of different parts of the coast surveying shorebirds.	1981–1984	Garnett 1987
Mandora Marsh[8] Wetlands surveyed as part of Arid Flo[9a-d]	Transect counts in August 1999 and June and August 2000. Observers counted wetland areas with transects and total or proportion counts.		Halse et al. 2005 Arid Flo project unpubl. info.
Lower Cooper wetlands[10]	Surveys flown over the major wetland systems of the Lower Cooper including Lake Eyre, every 3 months.	1989–1990	Kingsford & Porter 1993; Kingsford et al. 1999
Currawinya Lakes[11]	Surveys were done on two lakes (Wyara and Numalla) in south-western Queensland every three months. Surveys involved four counts at each time period.	1987–1990	Kingsford & Porter 1994
Cape Barren goose populations in Western Australia[12]	Helicopter survey of all but two islands/islets in the Archipelago of the Recherche and plane survey of surrounding coastline.	*	Halse et al. 1995
Tanami Desert wetlands[13]	19 wetlands surveyed for all waterbirds over a two day period.	2006	Reid et al. 2006
Cambridge Gulf[14]	Surveys in February and April 1993 of the Victoria–Bonaparte mudflat, adjacent coast (extending east of the Victoria River in the Northern		Halse et al. 1996

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Name of survey[a]	Description	Time frame	References
	Territory) and wetlands on the Ord River floodplain.		
Western Northern Territory[15]	Counts of waterbirds within about 15 200m-wide transects in the Northern Territory in April 1993 after cyclonic rainfall in February.		Jaensch 1994
Fitzroy Valley[16]	Counts at selected wetlands in the Fitzroy Valley, WA, in April 1993 and 2005. Survey in 1993 was part of a wider survey of Magpie Geese in northern Western Australia.		Halse & Pearson 1993,
North-west Western Australia shorebird counts[17]	Irregular counts of shorebirds in coastal sites since 1982, with focus on Roebuck Bay and Eighty Mile Beach (associated with ground counts).		Minton & Martindale 1982; Minton & Jessop 1994

[a]Refer to Figure 1 for location

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The Eastern Australian Aerial Waterbird Survey

The Eastern Australian Aerial Waterbird Survey was initiated primarily to track changes in duck populations as a result of hunting in south-eastern Australia. In the early 1980s, there was estimated to be over 100 000 recreational duck hunting licences in south-eastern Australia but information about the abundance of duck populations was relatively poor, consisting primarily of bag-size indices and waterfowl surveys on a few major wetlands before hunting seasons (Briggs et al. 1983; 1993).

In 1983, conservation authorities in Australia's eastern states—New South Wales, Queensland, South Australia and Victoria—along with the Australian Government and CSIRO, initiated an aerial waterbird survey to address this knowledge gap, sampling an area of 2.697 million km^2 within 10 survey bands, each of 30 km width (Figure 2). The western limit of the survey was set by logistical constraints and a belief at the time that the arid zone was unsuitable habitat for waterfowl (Frith 1982). Two additional northern survey bands were surveyed in the second year, 1983, but were not flown again because these areas supported mainly tropical waterfowl species that seldom extended south into areas of recreational hunting (Frith 1982). The survey was also extended south to Tasmania in 1995 (Figure 1), but as there were relatively few wetlands within these survey bands, they were not continued in later surveys.

The Eastern Australian Aerial Waterbird Survey has been conducted within the initial 10 survey bands every October from 1983 to 2009. The same survey methodology has been used to ensure comparability across surveys, although considerable improvements have been implemented in data recording and processing and navigation due to technological advances such as GPS.

Lake Mokoan in Victoria is regularly surveyed for waterbirds during the eastern Australian aerial survey of waterbirds (Photo: RT Kingsford).

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Systematic survey bands

Systematic survey bands were originally selected for the Eastern Australian Aerial Waterbird Survey for ease of navigation. Knowledge of wetland distribution within Australia, particularly the inland, was poor in 1983. Potential issues associated with the use of systematic survey bands, including the possibility of bias due to systematic variation in environmental features or waterbird populations, potentially lower precision, and the possible effects of autocorrelation on estimates of standard error (Caughley 1977) were outweighed by the practical constraints of surveying large expanses of inland Australia.

The 30-km wide survey bands, which vary in length, were each centred on 2° of latitude ranging from 36°30' to 26°30', covering about one-third of the continent (Braithwaite et al. 1986). The 30-km width was chosen because it provided a sampling intensity of around 10% of the survey region's land surface area and allowed relatively easy detection of large wetlands within the boundaries of the band. Survey bands were drawn along the east–west midline of 1:250 000 topographic maps (Division of National Mapping, Department of Development and Energy) that were later used to navigate each wetland. All wetland features >1 ha, including lakes, swamps, floodplains, rivers and reservoirs, were marked on topographic maps within each band. Where wetlands crossed survey bands, only the part within the current survey band was considered.

To undertake the survey, a high-winged Cessna aircraft was flown at 46 m height and around 167 km/hr between marked wetlands within a survey band. At each marked wetland, the full complement of waterbirds, including cormorants, grebes, herons, egrets, ibis, waterfowl and wading birds, was recorded. In addition, small (<1 ha) wetlands, typically farm dams, were surveyed on an ad hoc basis while the surveyors travelled between wetlands.

The use of systematic survey bands each year, while initially adopted for ease of navigation, has provided long-term data for individual wetlands. This has enabled the assessment of long-term changes in wetland condition that might otherwise have been difficult if bands had been randomly selected.

2007–2009 aerial surveys

Three aerial waterbird surveys (2007–09) of eastern Australia were completed as part of the current project. The 2008 survey was completed independently of the National Waterbird Survey (Chapter 2) as it was considered important to keep the Eastern Australian Aerial Waterbird Survey independent to ensure continuity of data and the use of the consistent methodology. Data obtained from the 2008 eastern aerial survey was used, however, in conjunction with data from the National Waterbird Survey, also conducted during this project, to compile estimates of waterbirds across Australia in 2008.

The results of each annual eastern aerial survey are presented as summaries, including maps of the hydrological status of key wetlands during the survey, to jurisdictions that support the aerial survey in eastern Australia, i.e. New South Wales, Queensland, South Australia and Victoria. Summaries of the 2007–09 surveys undertaken as part of this project are provided as an appendix to this Waterlines (Appendix E).

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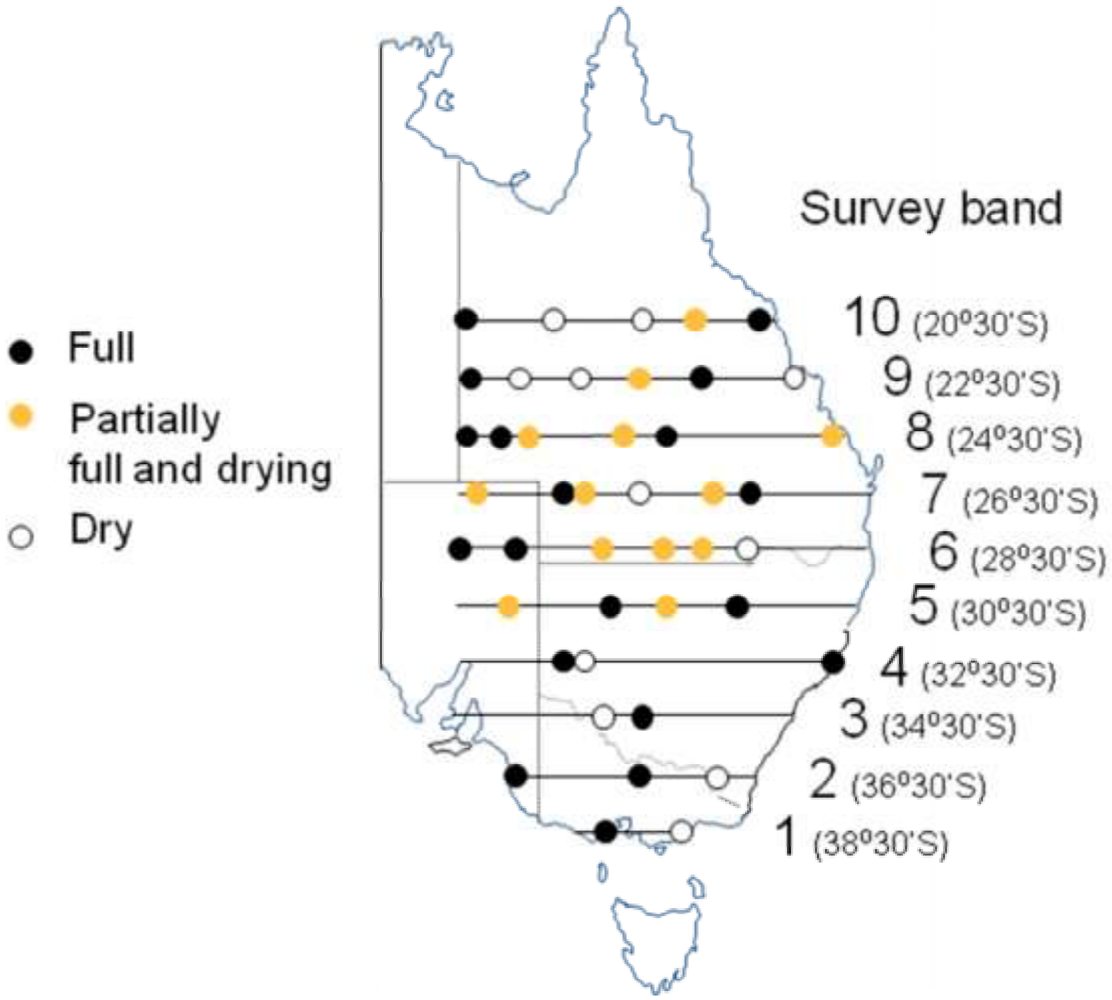
Figure 2: Ten survey bands (30 km wide) crossing eastern Australia, surveyed for waterbirds each year by the Eastern Aerial Waterbird Survey (1983–2009).

A hypothetical filling status is also shown for important wetlands within the survey region. From west to east, by survey band (1–10), these are: 10 Lake Moondarra, Cloncurry River (R), Flinders R, Campaspe R, Burdekin R; 9 Georgina R, Eyre Ck, Hamilton R, Diamantina R, Lake Galilee, Styx R; 8 Mumbleberry–Torquinnie lakes, Eyre Ck, Diamantina R, Thomson R, Barcoo R, various small coastal wetlands; 7 Goyder Lagoon, Lake Yamma Yamma, Cooper Ck, Bulloo R, Paroo R, Warrego R; 6 Lake Eyre, Lake Hope, Bulloo R, Paroo R, Warrego R, Balonne R; 5 Lake Frome, Paroo O'flow, Darling R, Macquarie Marshes; 4 Menindee Lakes, Talyawalka Lakes, Myall Lakes; 3 Murray River Lakes, Lowbidgee Swamp; 2 Coorong, Cooper and Mokoan Lakes, Cooma–Monaro; 1 Curdies Inlet, Jack Smith Lake.



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1.2. Project objectives

The three major objectives of this project were to:

- design and undertake a national survey of waterbirds in all major wetlands of Australia holding water in 2008
- assess long-term changes in waterbird numbers in relation to flow at a regional scale and within key wetlands of eastern Australia
- design and establish a national waterbird database for storing and accessing waterbird survey data.

The project also included three waterbird surveys of eastern Australia (2007–2009) using the methods of the Eastern Australian Aerial Waterbird Survey (see Section 1.1.4) These surveys contributed to meeting all three of the project's major objectives but were particularly important in facilitating the assessment of long-term trends in waterbird numbers in eastern Australia.

1.3. Report structure

This Waterlines reports on the methods and results of each of the three major project objectives listed above. Chapter 2 discusses the 2008 National Waterbird Survey while Chapter 3 discusses the results of the assessment of long-term changes in waterbird numbers in eastern Australian wetlands. An overview of the National Waterbird Database, developed during this project, is provided in Chapter 5. Finally, Chapter 6 provides a synthesis of the key findings of this project along with its recommendations for future research, policy and management.

Curdies Inlet off the southern coast of Victoria, Australia, is a key site surveyed each year during the eastern Australian aerial survey of waterbirds (Photo: RT Kingsford)

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2. The 2008 National Waterbird Survey

2.1. Introduction

The National Waterbird Survey represents the first attempt to undertake a continental-scale survey of waterbirds globally and in Australia. Prior to this, the most comprehensive survey of waterbirds in Australia was the Eastern Australian Aerial Waterbird Survey, which has run for 28 years (1983–2010), covering about one-third of the continent (see Section 1.1.4). The National Waterbird Survey presented here aimed to survey waterbirds in all major wetlands in Australia holding water in 2008 and covered an area of 7.62 million km^2.

The major objectives of the 2008 National Waterbird Survey were to:

- identify important wetlands for waterbirds across the Australian continent
- identify important regions for waterbirds across the Australian continent
- estimate population sizes of waterbird species (or taxa) surveyed.

The information yielded by the national survey is intended to inform the identification of key wetlands for waterbird conservation, as well as management strategies that aim to reduce the vulnerability of species that may be restricted in their distributions or under threat from habitat loss. This information is also of relevance to assessing broad patterns of river and wetland condition.

2.2. Methods

2.2.1. Survey design

Wetland selection

Three groups of wetlands sites were selected for inclusion in the national survey:

- wetlands of known significance to waterbirds
- randomly selected wetlands
- opportunistically surveyed wetlands (Table 2).

Identifying wetlands well known for their use by waterbirds was the first step in the survey design since most waterbirds concentrate on relatively few wetlands, e.g. around 80% of all waterbirds surveyed across nearly 800 wetlands every year from 1983 to 2000 in the Eastern Aerial Waterbird Survey were present on only 3.7% of wetlands surveyed (Kingsford and Porter 2009). There is a relatively long history of waterbird research and observation in Australia (Kingsford and Norman 2002) and many major areas of waterbird concentration are known, although some inland wetlands have only recently been identified (Kingsford 1995; Kingsford and Halse 1998; Kingsford and Porter 2009).

Wetlands of known significance to waterbirds included all 64 Australian Ramsar sites occurring on the Australian landmass and recognised as important for waterbird populations (Figure 3). Wetlands listed in the *Directory of important wetlands* (DEWHA 2010) that were not offshore sites and are known to be important to waterbirds were also included. Other wetlands known to be important sites for waterbirds were identified by reviewing all available records of large waterbird concentrations in Australia. The list of wetlands compiled in this first group was also circulated and further developed in a national workshop of waterbird ecologists held in 2007.

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Figure 3: Sixty-four Ramsar-listed wetland sites across Australia within each of 12 drainage divisions.

Surveys were done of all Ramsar sites which were listed as important for waterbird populations, if they held water in 2008.

The two other groups of wetlands—those randomly selected and opportunistically surveyed—were added to ensure the most comprehensive coverage of wetlands possible given the constraints of the survey. Randomly selected wetlands were drawn from the 1:250 000 national waterbody layer (Geoscience Australia 2006), which represents the most detailed spatial dataset available for wetlands at a national scale. To maximise efficiency during the survey, randomly selected wetlands were chosen to be within about 20 km of major survey routes once these were established (see below), ensuring that each of Australia's 12 river divisions (Table 3, Figure 4a) was represented. The third group surveyed was chosen opportunistically while aerial surveys were being conducted and included those wetlands holding water that were encountered en route between wetlands within the other groups.

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Table 2: Major groups of wetlands sampled during the national aerial survey of waterbirds in 2008.

Group		*Description*	*Survey methodology*
1. Wetlands of known significance to waterbirds	Ramsar-listed wetlands	All Ramsar listed wetlands (see Figure 3) that were known to be important for waterbirds were identified.	An assessment was made on whether they had water (e.g. inland) in 2008 before attempting a survey using available satellite imagery.
	Directory of Important Wetlands in Australia (DIWA)	All DIWA-listed wetlands that were known to be important for waterbirds but not already identified as Ramsar-listed wetlands were identified (see Figure 4b).	An assessment was made on whether they had water (e.g. inland) in 2008 before attempting a survey using available satellite imagery.
	Additional wetlands from literature search and expert knowledge	Determined via a national workshop of waterbird ecologists held in 2007.	
2. Randomly selected wetlands		Within each of the main survey regions, a sample of wetlands adjacent to survey routes (<20 km) was randomly selected from the 1:250 000 waterbody layer (Figure 4a).	Survey routes incorporated randomly selected wetlands in each of the main survey regions.
3. Ad hoc wetlands		En route between wetlands identified in the three categories above, wetlands that were not originally identified on the mapping layer could also be surveyed if they were close to the aircraft survey route.	These wetlands were generally within the flight path on a survey route that included wetlands identified in the three categories above.

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Figure 4a: Distribution of wetlands across Australia, mapped at the 1:250 000 scale within each of the 12 drainage divisions (seeTable 3 for names of drainage divisions matching numbers). Wetlands that were not already identified as important for waterbirds were randomly surveyed for waterbirds from this coverage within survey regions (see Figure5). This formed the base layer of wetlands that held water in 2008.

Figure 4b: Wetland sites across Australia listed within the *Directory of important wetlands in Australia* (DEWHA 2010). Surveys were done of all these wetland sites, which were listed as important for waterbird populations if they held water in 2008, but omitting offshore or marine sites such as the Great Barrier Reef (shaded off the coast of Queensland).

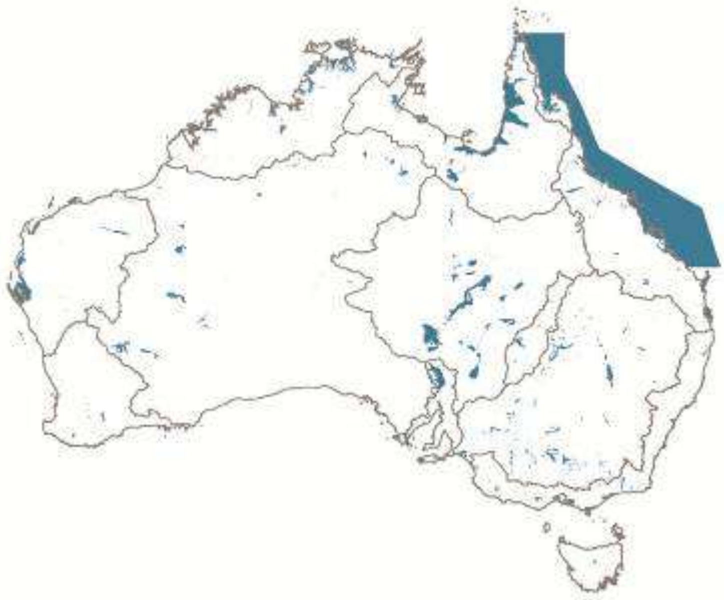

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Table 3: Distribution by area (km^2) of major wetland types in Australia, based on the Geoscience Australia 1:250 000 waterbody data layer (Geoscience Australia 2006, Figure 4).

Numbers in parentheses indicate percentage of total natural wetlands in each drainage division. Numbers can be used to locate drainage division (Figure 4) while acronyms are used in later tables.

Drainage Division	*Acronyms*	*Total natural wetlands*[a]	*Lakes*	*Floodplains*[b]	*Swamps*	*Marine wetlands*[c]	*Rivers*[d]	*Man-made wetlands*[e]
1. North East Coast	NEC	9813.80(4)	469.76	3224.65	1140.37	3221.78	1757.24	1132.93
2. South East Coast	SEC	7222.36(3)	2588.56	2438.47	870.64	842.63	482.06	696.95
3. Tasmania	TAS	1724.83(1)	364.11	100.62	540.60	480.97	238.53	1199.60
4. Murray–Darling Division	MDB	53 416.56(23)	10 066.29	39 500.09	2985.75	16.07	848.38	1996.23
5. South Australian Gulf	SAG	7542.77(3)	5860.36	465.57	13.79	1177.67	25.38	98.69
6. South West Coast	SWC	11 965.06(5)	6141.72	5138.29	437.62	79.81	167.61	115.26
7. Indian Ocean	IOC	17 089.32(7)	3693.70	4824.89	97.87	3493.25	4979.60	115.27
8. Timor Sea	TMS	42 406.43(18)	737.51	23 526.56	2669.56	11 925.26	3547.54	1101.17
9. Gulf of Carpentaria	GFC	34 838.10(15)	648.44	22 256.51	1725.69	7362.34	2845.11	128.10
10. Lake Eyre Division	LEB	72 212.60(31)	25 292.04	43 686.57	1334.01	0.00	1899.98	18.90
11. Bulloo–Bancannia	BBC	9436.04(4)	607.58	7696.99	1121.02	0.00	10.45	8.49
12. Western Plateau	WPU	53 576.15(23)	44 116.12	7856.14	241.39	448.09	914.41	46.22
Total		**233 077.84**	**75 095.41**	**109 847.67**	**7189.54**	**23 228.94**	**17 716.29**	**6657.79**
% of types			32.2	47.1	3.1	10.0	7.6	

Notes: [a]Includes lakes, floodplains, swamps, watercourses, rapids and marine wetlands; [b]areas subject to inundation; [c]saline coastal flats, foreshore flats and marine swamps; [d]watercourses and rapids; [e]canals, salt evaporation divisions, aquaculture, flood irrigation storage, settling ponds and town rural storages

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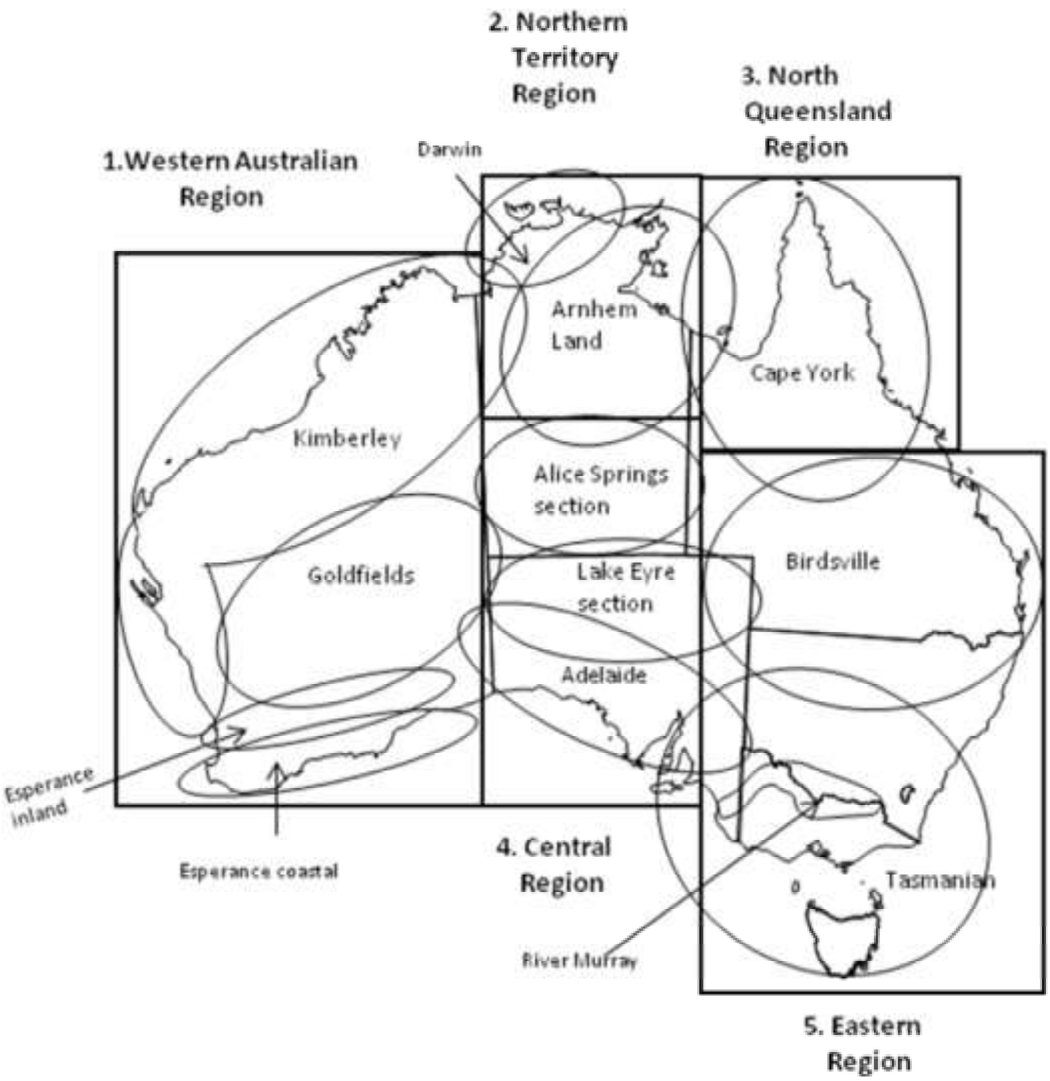
Survey routes

Five regions were identified across the continent as appropriate survey blocks for planning and conducting the National Waterbird Survey (Figure 5). Fourteen survey routes were then determined based on these regions and the distribution of wetlands of known significance to waterbirds (see Table 2). The survey bands of the Eastern Australian Aerial Waterbird Survey were also included (see Section 1.1.4). Other factors taken into account in selecting survey routes included aircraft endurance capability, availability of aircraft fuel within about three hours flight time, and availability of accommodation. Where survey routes overlapped, wetlands were allocated to specific survey routes to ensure that they were only surveyed once.

Figure 5: Five major regions identified for different aerial survey teams of observers during the National Waterbird Survey in 2008 and within each of the regions. Broad survey routes were identified as ellipses.



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Assessment of satellite imagery

To improve the efficiency of the aerial survey, satellite imagery (Landsat or MODIS) was also inspected for remote inland parts of the continent to identify wetlands that contained water. This process identified both wetlands occurring in large parts of inland Australia that were dry and did not need to be surveyed as well as some additional wetlands to be added to the survey, i.e. a complex of desert lakes north-west of Alice Springs that were holding water.

2.2.2. Data collection

Aerial survey approach

The National Waterbird Survey was conducted from 30 September until the end of November 2008. Waterbirds were counted from high-winged aircraft (e.g. Cessna 206), each carrying a pilot and two observers: a front-right observer, who was also the navigator, and a back-left observer. Up to three aircraft were deployed simultaneously around the continent during the survey, each of which covered different survey routes (Table 4).

Prior to the survey, wetland spatial data was extracted from the 1:250 000 national waterbody layer using GIS software (Arc GIS 9.3, ESRI 2008) and imported into GPS mapping software (MapSource Version 6.13.7, Garmin 2008) to generate aircraft routes. This information was loaded onto onboard GPS systems (Garmin Map 296) within each aircraft. Broadscale navigation information was provided by Google Earth and the 1:250 000 national waterbody layers were loaded into ER Viewer (Version 7.2, Geosystems Geospatial Imaging Pty Ltd 2008).

Large floodplain wetland in the Alligators River Region, Northern Territory (Photo: RT Kingsford).

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Track logs of aircraft flight paths were obtained by recording location (latitude and longitude) every 10 seconds during the survey to allow for quality control and to enable confirmation of wetland locations post survey. Survey times for all legs of the aerial survey were also recorded (Appendix D). Each wetland surveyed was given a unique code so that survey records could be matched between the two observers in each aircraft. In addition, the two observers recorded the time of survey for each wetland from synchronised clocks and, wherever possible, also manually recorded latitudes and longitudes for wetlands on audio recorders.

Observers also recorded the proportion of each wetland that was filled with water at the time of the survey as a percentage of the total area of the wetland according to the 1:250 000 national waterbody layer. Where wetlands were not mapped, the total area of water within the wetland at the time of the survey was directly estimated by observers.

Table 4: Dates and pairs of observers used on each of the main survey routes during the 2008 National Waterbird Survey.

Routes	*Observers*	*Dates*
Eastern Australia (Qld)	John Porter/Terry Korn	3–13.10.08
Eastern Australia (Vic.)	John Porter/ Peter Ewin	20–23.10.08
Eastern Australia (NSW)	John Porter/ Alison Curtin	27–30.10.08
Alice Springs	Terry Korn/Julian Reid	9–10.11.08
Cape York/ Carpentaria: Cape York	Peter Morris/Richard Kingsford	22–24.10.08
Cape York/Carpentaria: Georgetown to Townsville	Terry Korn/Peter Morris	2.11.08
Cape York/Carpentaria: Karumba	Terry Korn/Peter Morris	31.10.08
Cape York/Carpentaria: Karumba to Georgetown	Terry Korn/Peter Morris	1.11.08
Cape York/Carpentaria: Musgrave to Karumba	Terry Korn/Peter Morris	29.10.08
Western Australia (WA): Kimberley section	Stuart Halse/Adrian Boyle	30.09.08–11.10.08
WA: Coastal section	Stuart Halse/Adrian Boyle	14–18.10.08
WA: Inland section	Stuart Halse/Adrian Boyle	22–24.10.08
Cape York/Carpentaria: Weipa to Musgrave	Terry Korn/Peter Morris	28.10.08
Cape York/Carpentaria: Weipa	Peter Morris//Richard Kingsford	25–26.10.08
Central: Lake Eyre	Julian Reid/Ray Chatto	12–16.11.08
Eastern: Sydney to Townsville	Richard Kingsford/John Porter	3–8.11.08
Townsville/Windorah to Armidale	John Porter/Peter Morris	10–15.11.08
Murray Icon	Terry Korn/Richard Kingsford	12–15.11.08
Northern Territory (NT) West: South	Mark Ziembicki/Richard Kingsford	2–4.10.08

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West Darwin		
NT: East Darwin (Arnhem)	Richard Kingsford/Mark Ziembicki	6–12.10.08
NT: East Darwin (Arnhem)	Richard Kingsford/Ray Chatto	14–18.10.08
Tasmania/Victoria: Sydney to Cobar	Richard Kingsford/John Porter	18–26.11.08
South Australia	Stuart Halse/Paul Wainright	23–27.11.08

Aerial surveys of waterbirds are a rapid technique for estimating multispecies populations of waterbirds on wetlands (Photo: A Carlson)

Aerial counting methods

To conduct the aerial surveys of waterbirds at each wetland, aircraft were flown at a speed of 167–204 km hr^{-1} (90–110 knots) at a height of 30–46 m (100–150 feet) within 150 m of the wetland's shoreline (Figure 6), since this is where waterbirds usually congregate (Kingsford and Porter 1994). The observers on each side of the plane estimated numbers of waterbirds on their side of the aircraft, recording the information on small tape recorders for later transcription.

All waterbirds were identified to species except those that could not be consistently identified to species level from the air and were grouped as follows: small grebes (Australasian little grebe, hoary headed grebe), large egrets (intermediate egret and great egret), terns (see Appendix A) and small and large migratory wading birds (Charadriformes; see Appendix A). Waterbirds were counted singly and in groups, with group sizes estimated by counting birds in small 'parcels' of an estimated 5, 10 or 50 individuals. For larger groups of birds, counting parcels were increased to 100, 200, 500, 1000 and sometimes 2000 individuals. Observers independently identified and recorded species abundances and numbers of nests and broods. Where no birds, nests or broods were observed, a zero count was recorded.

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Grey teal and radjah shelduck on a small wetland in the Gulf of Carpentaria (Photo: RT Kingsford)

Three counting techniques were used during the aerial surveys depending on the type of wetland and the distribution of waterbirds: 1) total counts, 2) proportion counts and 3) transect counts (Figure 6). Total counts, i.e. counting all birds observed during a circumnavigation of the wetland, was the preferred method for most wetlands, given that waterbird distributions were often clumped within wetlands. For this approach, the aircraft was positioned so that one observer counted all waterbirds between the aircraft and the shoreline, while the other observer counted waterbirds from the aircraft to the middle of wetland (Kingsford and Porter 1994). Total counts covered the full perimeter of the wetland or, where wetlands were small, the aircraft was flown directly over or alongside them.

The second counting technique, proportion counts, was used to reduce fuel and time inefficiencies where it was either difficult to cover an entire wetland due to manoeuvrability constraints of aircraft around narrow bays and inflowing creeks or for large reservoirs with few birds present. For this method, a proportion of a wetland or river system (e.g. half of a reservoir) was surveyed and these proportional counts were extrapolated to give total counts for the entire river channel or wetland area that was holding water at the time of the survey.

The final method used was transect counts. This technique was employed on some large wetlands that comprised braided channels and vegetation without a defined wetland 'edge' (e.g. floodplains) and where waterbirds were distributed throughout the wetland rather than being in distinct clumps (Figure 6). For this method, waterbirds were counted within 200 m-wide transects, i.e. 100 m on each side of the aircraft, that were delineated across the wetland by attaching tape to each aircraft wing strut to represent 100 m on the ground when the plane was flown at a height of 46 m. Estimates for waterbirds at the wetland scale were then made by multiplying bird counts within the transect by the area of the wetland at the time of the survey (see above), divided by the area of water covered in the transect. The area of water covered in the transect was calculated by timing the length of the transect and estimating the area covered using the aircraft's speed. Corrections were also made where dry land, if any, occurred within the area covered by water that was traversed by the transect.

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Waterbirds were counted by recording on small digital recorders that were then transcribed onto data sheets before import into the database. (Photo: RT Kingsford)

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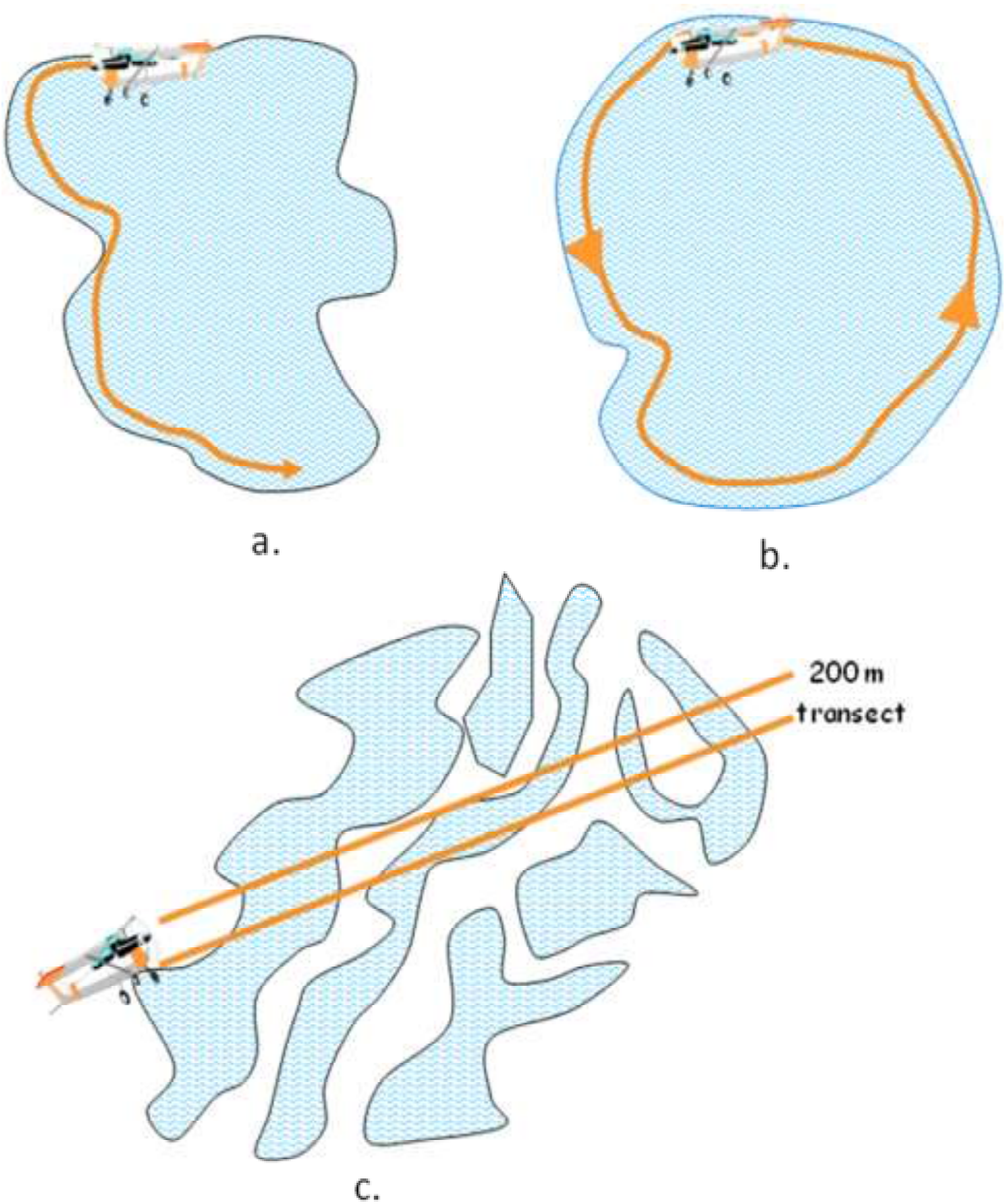
Figure 6: Three counting techniques used in aerial surveys of waterbirds: proportion counts a), total counts b) and transect counts c) (after Braithwaite et al. 1985).

Arrows indicate the flight path of the aircraft. Proportion counts were usually done on parts of rivers, large reservoirs or wetlands where manouevability of the aircraft was restricted. Total counts were usually done for discrete waterbodies (<50 ha), river channels, small reservoirs (<1ha), large lakes, swamps or dams birds concentrated along the shoreline. Transect counts were done if a floodplain with patches of water was interspersed with dry ground or across complex drainage systems.



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Ground surveys

Ground surveys were also conducted as part of the National Waterbird Survey to complement the results of the aerial surveys and provide more detailed information on rare and cryptic species, as well as nesting activity and habitat in some of the larger wetlands of known significance to waterbirds. Fifty-five wetlands were selected for ground surveys across all of the jurisdictions, chosen for accessibility, location, size, visibility, availability of survey teams and the known importance of a site to waterbirds. Many inland wetlands were unsuitable for ground surveys because of their remoteness, inaccessibility, dense vegetation or because they were likely to be dry at the time of the survey.

Ground surveys were conducted during October and November 2008 as close as possible to the timing of aerial surveys. Counts were done by individuals or small teams of observers using telescopes and/or binoculars to count, identify and record all waterbirds, nests and broods. Large wetlands were counted in portions as observers moved between vantage points by foot or motor vehicle. Where only a proportion of a wetland was counted, the boundaries of the area surveyed were recorded on topographic maps or GPS equipment. In most cases, sufficient vantage points were available to ensure all parts of the wetland were observed although the density and distribution of vegetation varied considerably between wetlands. The time taken to complete ground surveys was also recorded as this varied considerably in relation to wetland size, waterbird abundance and other local conditions.

Ground surveys were conducted on a few wetlands, although some difficultly was experienced accessing remote wetlands. (Photo: A Briggs)

2.2.3. Data processing and quality control

Recorded data from the aerial surveys was initially transcribed by observers to data sheets, enabling observers to ensure that times and names of wetlands corresponded between the pairs of observers on each survey leg. Data for each observer were then entered into spreadsheets for each of the survey routes and further matching and checking of wetland names, times and locations were conducted. Each observer’s counts for each species at each wetland were initially entered as separate records in these spreadsheets. Data was then

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merged across the pairs of observers to produce estimates of the total abundance of each waterbird species at each wetland.

Flight-track logs were also assessed in relation to available GIS layers to check and determine the names and locations of wetlands, particularly for unmapped wetlands for which latitudes and longitudes were manually recorded during the aerial surveys. Track logs were used to find missing latitudes and longitudes by matching times on data sheets with locations captured by onboard GPS track logs. Known locations and times on data sheets (usually only separated by a few minutes) were used to fill gaps for entries with missing times and locations (<5 % of entries). As a measure of quality control, wetlands were also assigned a spatial accuracy index: 1 for wetlands with locations known to an accuracy of <1 minute, 2 for locations within 1–6 minutes accuracy and 3 for locations within a 6 minute to 1 degree accuracy.

Where wetlands were not named on any available maps, names were ascribed according to location and wetland type that comprised natural features, i.e. rivers, lakes, swamps, estuaries and coastlines, and artificial wetlands, e.g. dams, fish farms. Wetland names were taken from nearby landmarks with a direction ascription, e.g. a dam to the east of Mount Hope might be named Mount Hope Dam East. Where multiple unnamed wetlands occurred in close proximity, letters were used to differentiate between them.

During transcription of the data, each wetland was given a sequence number for each observer (see Appendix D) to enable further checks of wetland locations and survey data. Where data was missing for wetland area, it was usually possible to crossmatch one observer's records with the other to account for this. In some cases, GIS mapping tools were used to calculate wetland areas when these were missing from survey data. Transcription errors in species codes were corrected by referring to data sheets. For further quality control, it was ensured that all count types (i.e. total, proportion or transect counts) were linked to a percentage of wetland area counted.

2.2.4. Data analyses

Total numbers of waterbirds were determined for each species at wetland and continental scales as well as within each of the 12 Australian drainage divisions. The latter represented actual counts made during the survey and did not involve any extrapolation from the number of waterbirds counted on randomly surveyed wetlands that were drawn from the 1:250 000 national waterbody layer. The number of and total area of wetlands holding the largest numbers of waterbirds were also determined using cumulative ranking.

Patterns in the community structure of waterbirds across major wetland systems over large spatial scales were explored using species abundance distributions and species accumulation curves. Species abundance distributions illustrate the relationship between the number of individuals and the number of species in a sample, while species accumulation curves describe the relationship between species richness and sampling area or sample effort whereby the proportion of data incorporated increases as sampling effort increases. Species accumulation curves are a well-established technique used by ecologists to compare and assess community structure, rarity, dominance and evenness (Harte et al. 1999; Magurran 2004; Dengler 2009; Ulrich et al*.* 2010). Such analyses have rarely been done over such large spatial scales, however, and this study provides a rare opportunity to examine the key structural attributes of waterbird communities at a continental scale (Magurran 2005; 2007).

Waterbird species were also divided into broad functional groups (or foraging guilds) to examine potential patterns in aquatic food resources. These groups included piscivores, herbivores, large wading birds, dabbling ducks and migratory shorebirds (see Appendix A).

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2.3. Results

2.3.1. Wetland distribution

Over 3.8 million ha of wetlands, comprising 4858 wetlands, were surveyed during the 2008 National Waterbird Survey (Table 5, Figure 7). The distribution and area of surveyed wetlands varied considerably across the continent, with the majority occurring in coastal regions that were holding water during the time of the aerial survey (Figure 7).

Among the 12 Australian drainage divisions, the highest number of wetlands surveyed occurred in the Timor Sea division (20.5%), followed by the South-west Coast (15.3%) and Gulf of Carpentaria (13.8%) divisions (Table 5). The greatest total wetland area surveyed was in the Lake Eyre division (33.1%), followed by the Gulf of Carpentaria (16.4%), Timor Sea (8.8%) and Indian Ocean (8.7%) divisions (Table 5). The Bulloo–Bancannia, South Australian Gulf, Tasmania and Western Plateau divisions had relatively low numbers of wetlands surveyed, as well as low total wetland area (Table 5). With respect to jurisdictional areas, the greatest total wetland areas were in Western Australia and Queensland (Table 6).

The mean size of all wetlands surveyed was 333.4 ha (± 4.52 standard error) and the most commonly encountered size classes of wetlands were between 0–1 ha and between 10–200 ha (Figure 7). The largest individual wetland surveyed was the Diamantina River floodplain, in the Lake Eyre drainage division, at 440 625 ha. At a jurisdictional level, the highest (and most variable) mean wetland areas occurred in South Australia and Queensland (Table 6).

Table 5: Number of wetlands, percentage number of wetlands, wetland area and percentage area of wetland surveyed in each of 12 major drainage divisions, relative to total number and area surveyed (percentages given in parentheses), and combined across Australia for data collected during aerial surveys in 2008.

Drainage Division	No of wetlands surveyed (%)	Wetland area (%)	Mean wetland area (± SE)
1. North East Coast	620 (12.9)	174 213 (6.4)	277.9 (35.1)
2. South East Coast	402 (8.3)	215 966 (7.9)	537.2 (74.0)
3. Tasmania	122 (2.5)	31 068 (1.1)	254.7 (75.1)
4. Murray–Darling Division	564 (11.6)	215 436 (7.9)	392.4 (123.1)
5. South Australian Gulf	108 (2.2)	17 685 (0.6)	163.8 (35.0)
6. South-west Coast	744 (15.3)	121 322 (4.5)	163.1 (18.0)
7. Indian Ocean	252 (5.2)	237 586 (8.7)	942.8 (714.5)
8. Timor Sea	995 (20.5)	240 905 (8.8)	242.1 (102.4)
9. Gulf of Carpentaria	671 (13.8)	447 553 (16.4)	667.0 (426.9)
10. Lake Eyre Division	200 (4.1)	902 573 (33.1)	4512.9 (2371.8)
11. Bulloo–Bancannia	34 (0.7)	15 888 (0.6)	467.3 (178.2)
12. Western Plateau	139 (2.9)	104 157 (3.8)	749.3 (406.8)
Total	**4858**	**2 724 351**	

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Figure 7: Distribution of wetland area surveyed during the 2008 national aerial survey in relation to 12 drainage divisions across Australia. Areas of wetlands (ha) are represented by different sized circles.

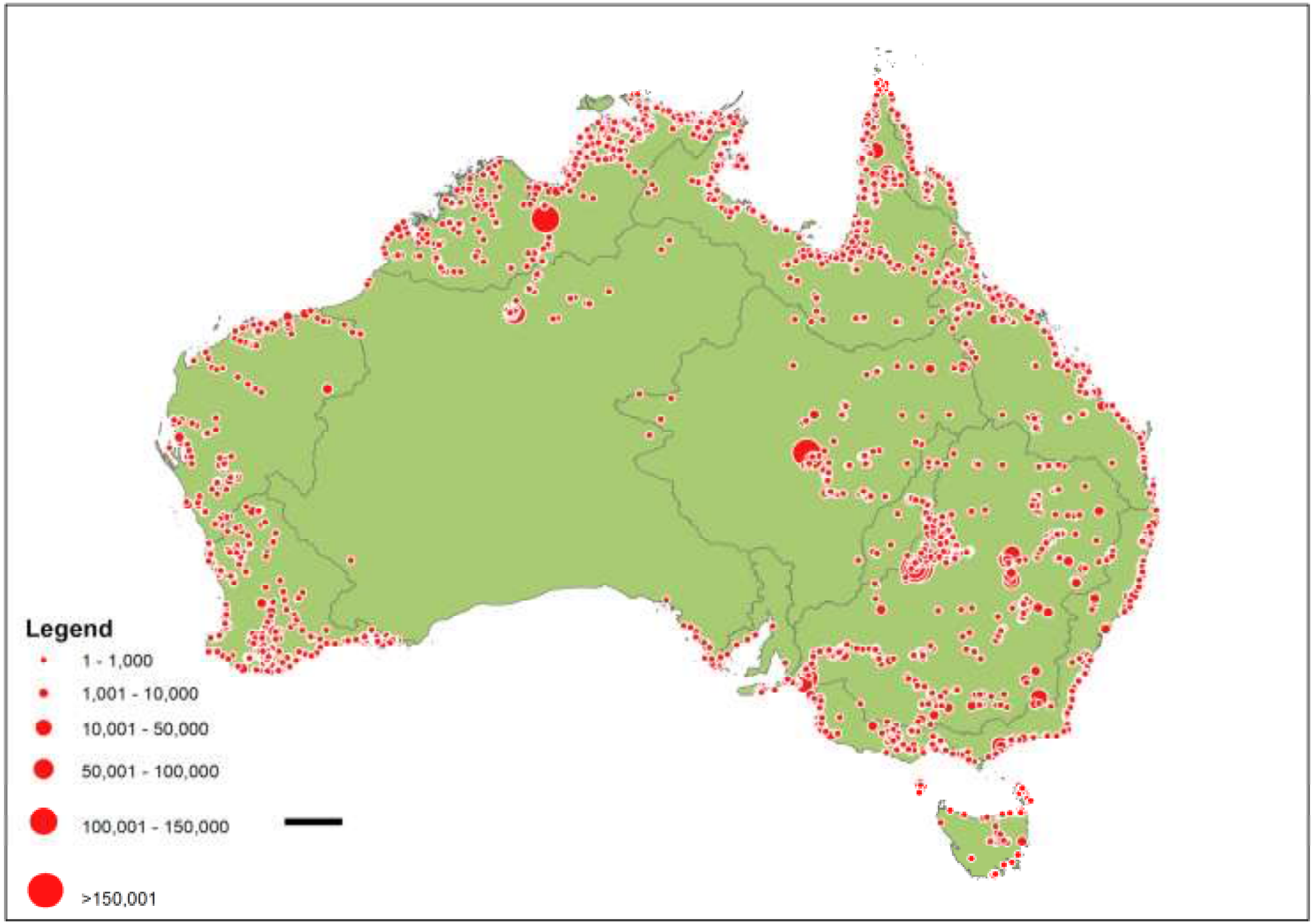

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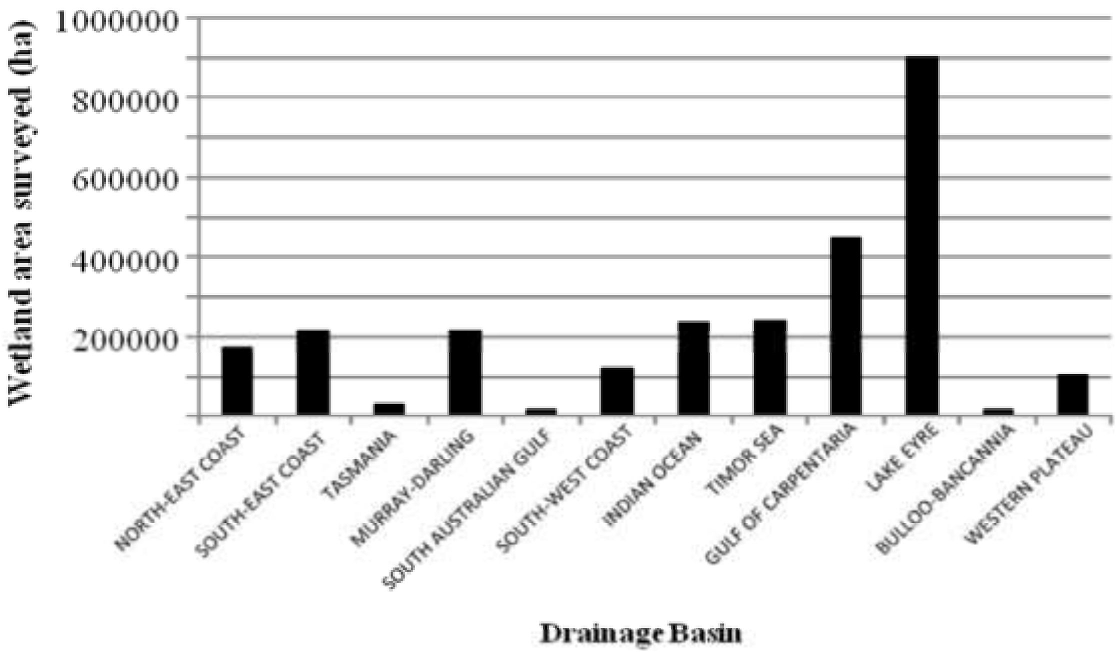
Table 6: Number of wetlands, total wetland area, mean wetland area surveyed during the 2008 National Waterbird Survey separated into states and the Northern Territory.

State	*No. of wetlands*	*Total wetland area (ha)*	*Mean area (±SE) of wetlands*
New South Wales and Victoria[a]	900	320 420.71	356.02 (43.13)
Queensland	1659	1 356 934	817.92 (326.74)
Tasmania	134	32 870.1	245.30 (68.55)
Northern Territory	881	154 800.9	175.71 (19.98)
South Australia	347	329 118.65	948.47 (440.81)
Western Australia	1435	687 496.87	479.09 (166.34)

Notes: [a]Includes the Australian Capital Territory

Figure 8: Area of wetland surveyed across Australian during the 2008 national aerial survey of waterbirds across the 12 drainage divisions in Australia.



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2.3.2. Waterbird distribution

Abundance and density

Approximately 4.6 million waterbirds representing 106 species were recorded during the 2008 National Waterbird Survey (Table 7). Waterbirds were widespread across the continent, but relatively few wetlands supported large numbers of waterbirds (i.e. >10 000) and most supported fewer than 1000 waterbirds (Figure 9 and Figure 10). Almost 40% of wetlands surveyed supported none. These were generally small wetlands or parts of rivers and creeks. Of the remaining 60% surveyed, most supported fewer than 100 waterbirds (Figure 10).

Table 7: Abundance of waterbirds, percentated abundance, breeding index and number of species within each of 12 river divisions and combined across Australia for data collected during aerial surveys in 2008.

Percentages given in parentheses.

Drainage division	*Waterbird abundance (%)*	*No. of species*
1. North East Coast	428 504 (9.2)	61 (56.5)
2. South East Coast	226 520 (4.9)	59 (54.6)
3. Tasmania	20 787 (0.5)	33 (30.6)
4. Murray–Darling Basin	446 334 (9.6)	66 (61.1)
5. South Australian Gulf	25 142 (0.5)	45 (41.7)
6. South West Coast	200 070 (4.3)	56 (51.9)
7. Indian Ocean	227 227 (4.9)	61 (56.5)
8. Timor Sea	1 933 247 (41.6)	85 (78.7)
9. Gulf of Carpentaria	340 002 (7.3)	57 (52.8)
10. Lake Eyre Basin	155 548 (3.3)	52 (48.1)
11. Bulloo–Bancannia	71 793 (1.5)	44 (40.7)
12. Western Plateau	575 078 (12.3)	61 (56.5)
Total	**4 650 252**	**108**

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Figure 9: Concentrations of waterbirds on wetlands estimated during the National Waterbird Survey of Australia, Oct.–Nov. 2008.

Figures show low (1–1,000) to high concentrations of waterbirds (1001–300 000).

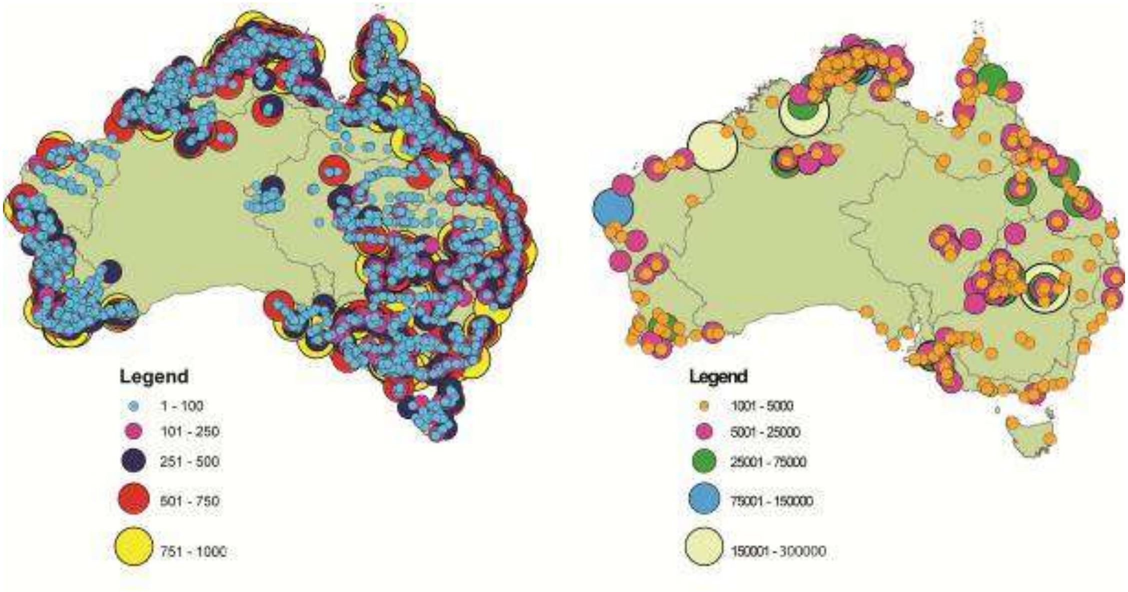
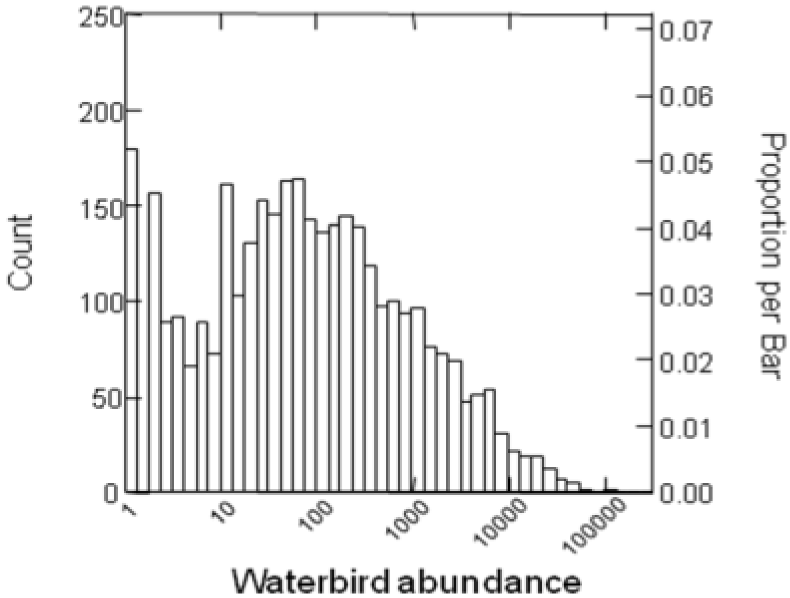


Figure 10: Frequency distribution of waterbird abundance on wetlands.

Note log scale of waterbird abundance.



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The relatively small number of surveyed wetlands supporting high or extremely high concentrations of waterbirds (Figure 8) were spread across northern Australia, Western Australia, central Queensland and western New South Wales (Figure 9). The wetland complex comprising the Coorong, Lake Alexandrina and Lake Albert at the mouth of the Murray–Darling drainage division also fell into this category, with more than 100 000 waterbirds recorded during the 2008 survey (Figure 9). In contrast, relatively low numbers of waterbirds were recorded from central Western Australia and western South Australia as few wetlands in these regions held water during the 2008 survey, reflecting the relatively dry nature of wetlands in these states most of the time compared with those in the Northern Territory and northern Queensland.

Waterbird abundance varied across the 12 Australian drainage divisions, with over 40% of all waterbirds recorded occurring in the Timor Sea division (Table 7, Figure 11). A further 12% were recorded in the Western Plateau drainage division, while other divisions all had less than 10% of the total number of waterbirds recorded during the survey. The density of waterbirds in individual wetlands, while highly variable, was also highest in the Timor Sea division, followed by the Bulloo–Bancannia and Western Plateau drainage divisions (Figure 12). Across the various jurisdictions, most waterbirds (1.9 million or 40%) were recorded in the Northern Territory, followed by Western Australia (over 1 million or 28%) (Figure 13). Fewest waterbirds were recorded in Tasmania (Figure 13).

The top 20-ranked of wetlands surveyed, as ranked by total waterbird numbers, supported 39% of all waterbirds counted (Table 8). The highest ranked wetland, Eighty Mile Beach, alone supported more than 6% of all waterbirds counted. Apart from the lower Lakes and the Coorong, the five most important wetlands for waterbirds in terms of waterbird abundance, were all in tropical Australia. Other wetlands ranked in the top 20 for waterbird abundance were spread throughout the country, including southern Australia, e.g. Dumbleyung lake and Cuttaburra channels. Over 50% of all waterbirds surveyed occurred on just 41 wetlands or 1.1% of the total number of wetlands surveyed (Figure 14).

Figure 11: Concentrations of waterbirds on wetlands estimated during the National Waterbird Survey of Australia, Oct.–Nov. 2008 in relation to the 12 drainage divisions.

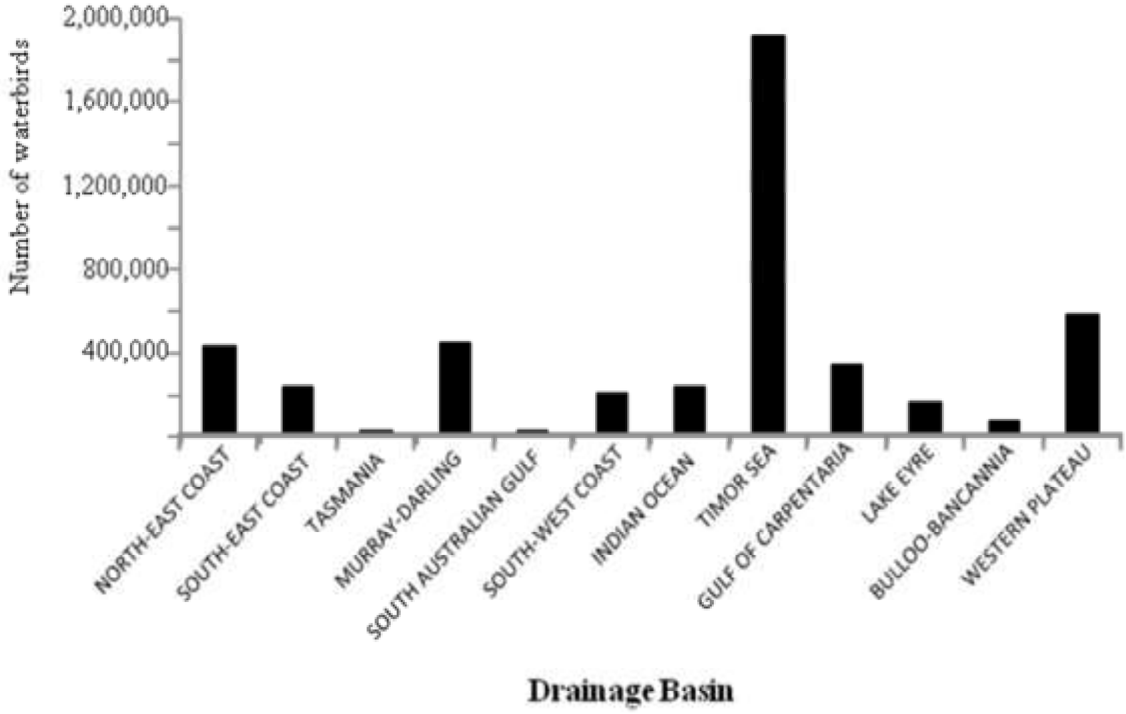

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Figure 12: Density of waterbirds (waterbirds ha^{-1}) estimated during the National Waterbird Survey of Australia, Oct.–Nov. 2008, on wetlands in each of the 12 drainage divisions.

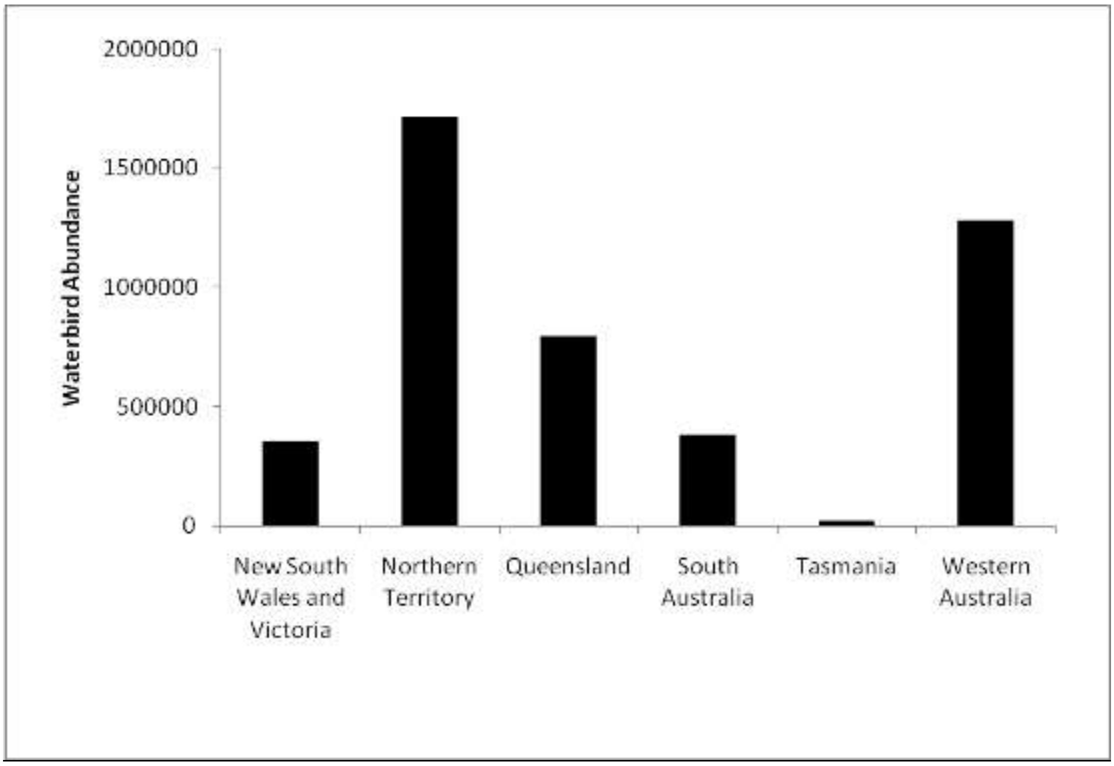

Figure 13: Total waterbird abundance estimated during the National Waterbird Survey of Australia, Oct.-Nov. 2008, among different states and the Northern Territory.

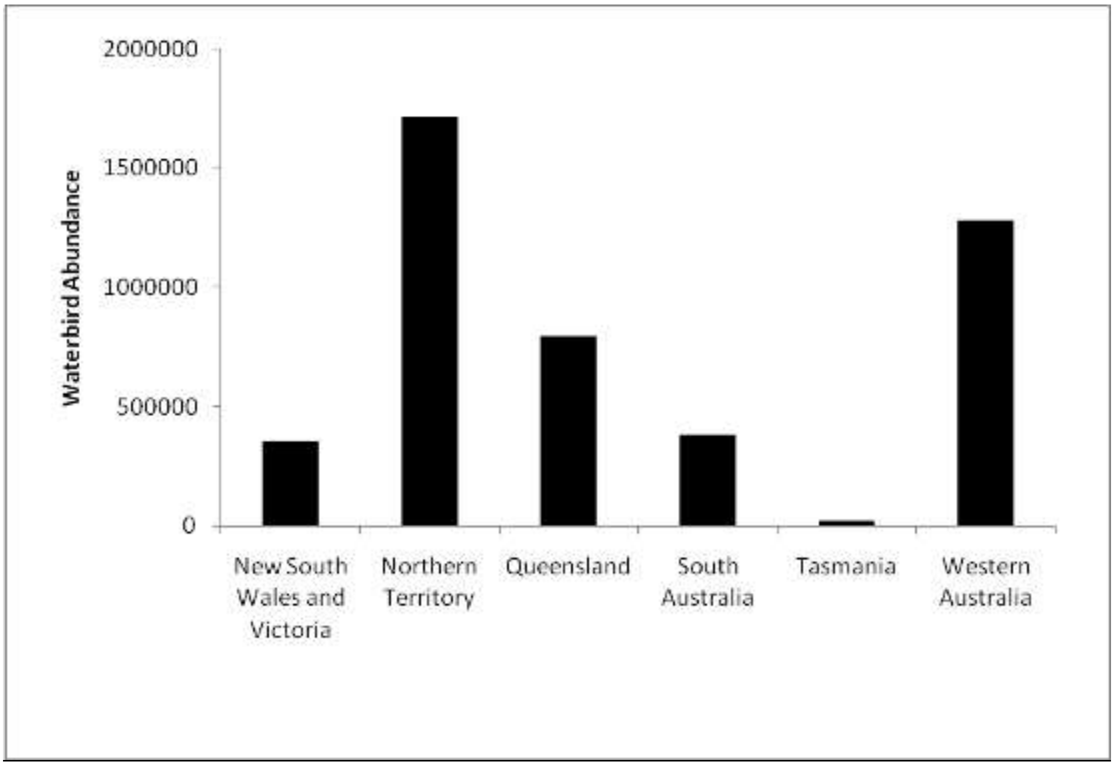

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Table 8: Abundance, relative proportion of waterbirds, cumulative percentage of all waterbirds and location of the highest 20 wetlands ranked by waterbird abundance, based on aerial survey counts during the National Waterbird Survey, Oct.–Nov. 2008.

Wetland	*Abundance*	*%*	*Cum. %*	*Rank*	*Latitude*	*Longitude*
Eighty Mile Beach	282 341	6.07	6.07	1	–19.03444	121.5172
Lake Gregory	227 619	4.89	10.97	2	–20.2525	127.5044
Lake Argyle	215 948	4.64	15.61	3	–16.34139	128.7531
Lower Lakes–Coorong	172 654	3.72	19.32	4	–35.355	139.3881
Roebuck Bay	152 323	3.27	22.60	5	–17.97222	122.2578
Lake MacLeod	114 874	2.47	25.07	6	–23.96972	113.7089
Nanjbagu (Billabong)	106 433	2.28	27.36	7	–12.57194	132.5075
Hunters Camp	81 210	1.74	29.10	8	–12.64056	132.8394
East Alligator River Pools	58 417	1.25	30.36	9	–12.21806	132.702
Chirracarwoo Lagoon	52 537	1.13	31.49	10	–12.705	132.6292
Red Lily Billabong (East)	50 286	1.08	32.57	11	–12.85028	132.5506
Jarrahwingkoombarngy Swamp	48 682	1.04	33.62	12	–12.68306	132.6144
Kumbunbur Creek (North)	44 803	0.96	34.58	13	–14.47417	129.6347
Dumbleyung Lake	40 271	0.86	35.45	14	–33.37889	117.6722
Werribee Sewerage Treatment Plant	35 669	0.77	36.22	15	–37.98417	144.6775
Sand Bay	35 005	0.75	36.97	16	–21.075	149.2047
Cuttaburra Channels	34 339	0.74	37.71	17	–30.39667	144.2417
Ludtanba River Mouth A	33 735	0.73	38.43	18	–13.15667	136.0058
Lake Galilee	32 678	0.71	39.13	19	–22.48444	145.7703
Lower Gracemere	30 137	0.65	39.78	20	–23.40667	150.4072

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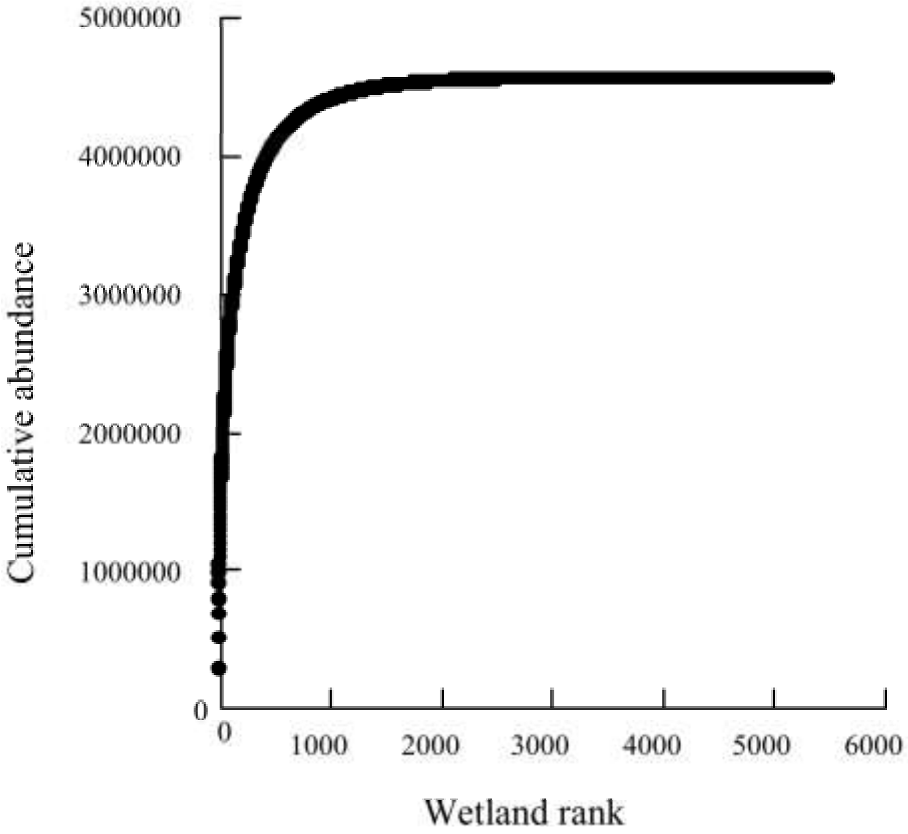
Figure 14: Cumulative waterbird abundance relative to wetland ranked abundance for all wetlands surveyed during the National Waterbird Survey.



Species richness

The species richness of waterbird communities varied across the continent, generally reflecting patterns of abundance. Species richness did not discriminate between wetlands as much as abundance, however, because the range of richness was considerably lower. The highest species richness occurred in waterbird communities of large wetlands in northern Australia and Western Australia (Figure 15). Typically, wetlands with high abundances of waterbirds also had greater species richness, and species richness in wetlands was significantly positively correlated to total waterbird abundance ($r^2 = 0.77$, $p<0.001$, $n = 4127$; Figure 16).

Numbers of waterbird species varied across drainage divisions (Figure 17), but again species richness was less discriminatory at a regional scale than abundance and density patterns due to its small range. The Timor Sea division had the highest number of species, followed by the Indian Ocean, Murray–Darling, North-east Coast and Western Plateau drainage divisions (Figure 17). Considerably fewer species of waterbirds were recorded in Tasmania (Figure 17).

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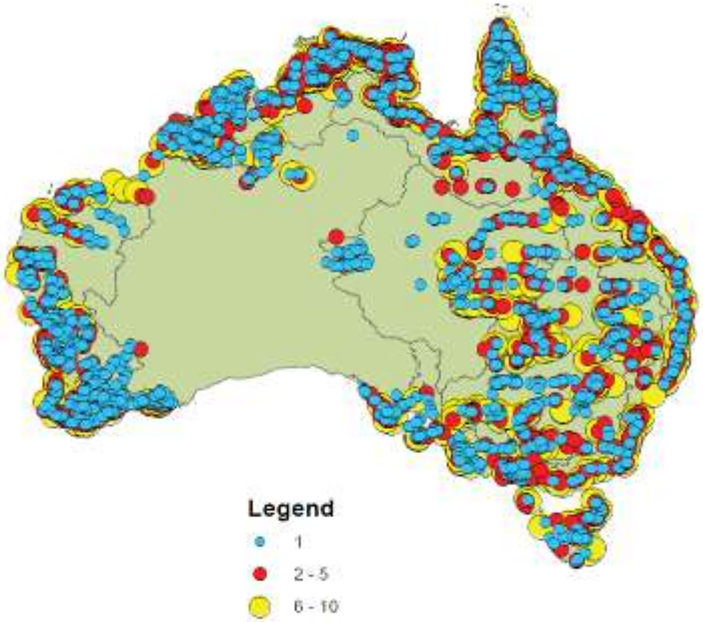
Figure 15: Species richness (number of species) of waterbirds on wetlands estimated during the National Waterbird Survey of Australia, Oct.–Nov. 2008, showing low (1–3) to high numbers of waterbird species (36–50).



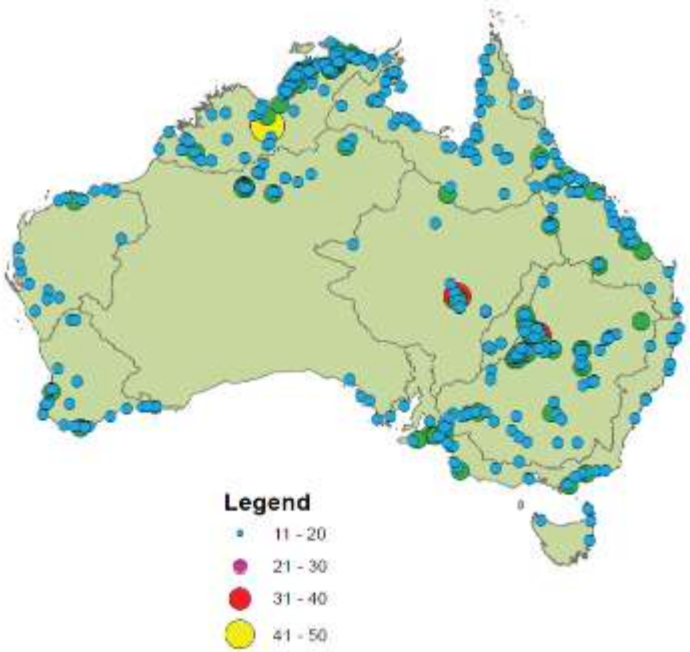


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Figure 16: Significant relationship between species richness (number of species) and waterbird abundance on all wetlands surveyed in the National Waterbird Survey.

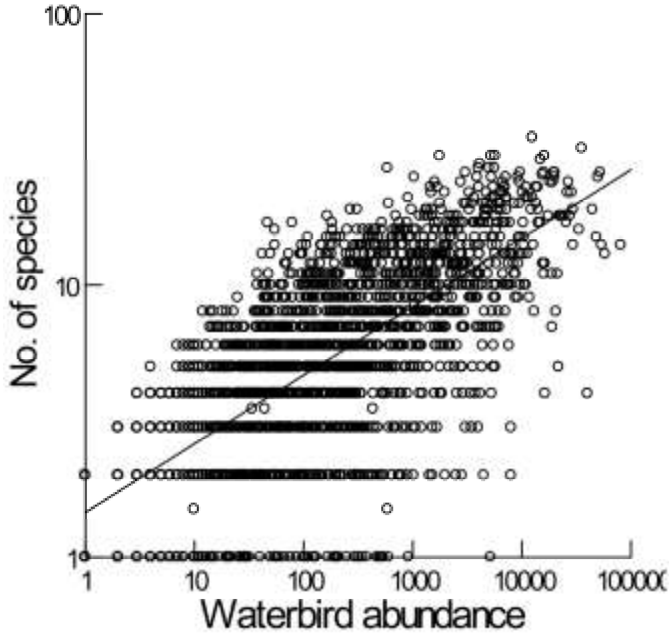
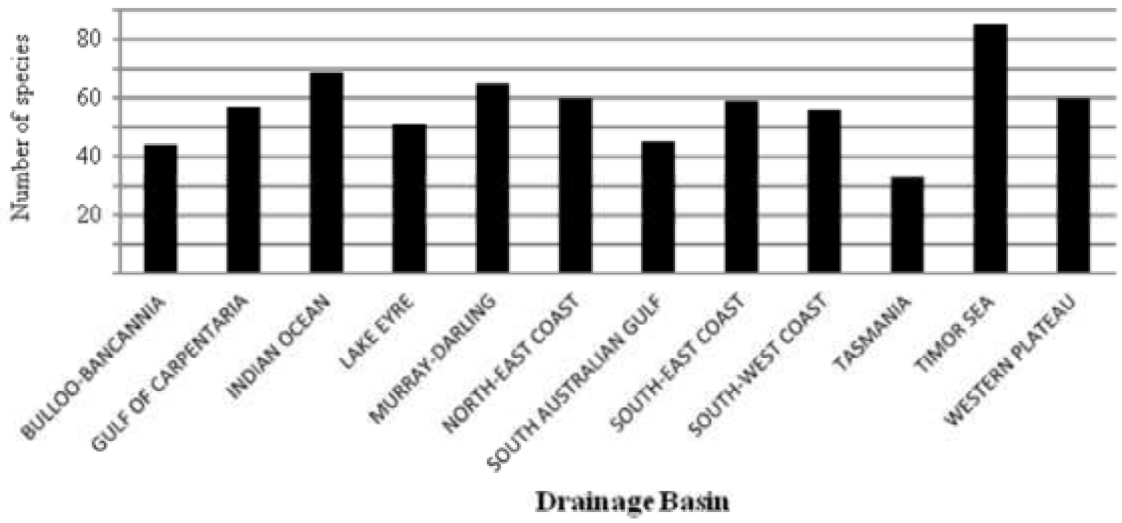


Figure 17: Species richness (number of species) of waterbirds on wetlands estimated during the National Waterbird Survey of Australia, Oct.–Nov. 2008, in relation to the 12 drainage divisions.



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2.3.3. Species distributions

Magpie geese were by far the most abundant species recorded during the 2008 National Waterbird Survey, accounting for almost 21% of all waterbirds counted (Figure 18, Table 9). The next most abundant species at a continental scale were small waders, followed by plumed whistling-duck, grey teal, large waders, egrets, banded stilt, wandering whistling-duck, pink-eared duck, terns, black swan and Eurasian coot (Figure 18). These top 12 ranked species accounted for more than 82% of all waterbirds counted (Table 9, Figure 19). In contrast, the 43 least abundant species comprised less than 1% of all waterbirds surveyed (Figure 19).

Magpie geese and egrets feeding on the floodplains of the East Alligator River in Kakadu National Park (Photo: RT Kingsford).

The relative abundance of different species varied across drainage divisions and the 10 most abundant species (i.e. different suites of species) in each accounted for 79–84% of total abundances within that division as follows: Bulloo–Bancannia >93%, Gulf of Carpentaria 86%, Indian Ocean 94%, Lake Eyre 88%, Murray–Darling 83%, North-east Coast 79%, South Australian Gulf 85%, South-East Coast 86%, South-west Coast 89%, Tasmania 94%, Timor Sea 90%, and Western Plateau 84%.

In the northern Australian drainage divisions, except Lake Eyre, shorebirds were among the most abundant group of waterbirds and were particularly dominant in the Gulf of Carpentaria division (Figure 20). Magpie geese dominated the Timor Sea division and were ranked second and third in the Gulf of Carpentaria and the North-east Coast divisions respectively (Figure 20). Plumed whistling-ducks were also significant in northern divisions, ranking second in the Timor Sea division and fifth in the Indian Ocean division (Figure 20).

Across the southern Australian drainage divisions, grey teal and small waders were both ranked in the highest 10 species, with the exception of the latter in the South-west Coast division (Figure 21). In the Murray–Darling division, the most numerous species were grey teal, pink-eared duck and Australian shelduck (Figure 21).

Further detail concerning the distributions of a range of individual species is provided in Appendix B.

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Figure 18: Pie chart showing the 12 most numerous species and all remaining species, estimated during the national aerial survey of wetlands in 2008.

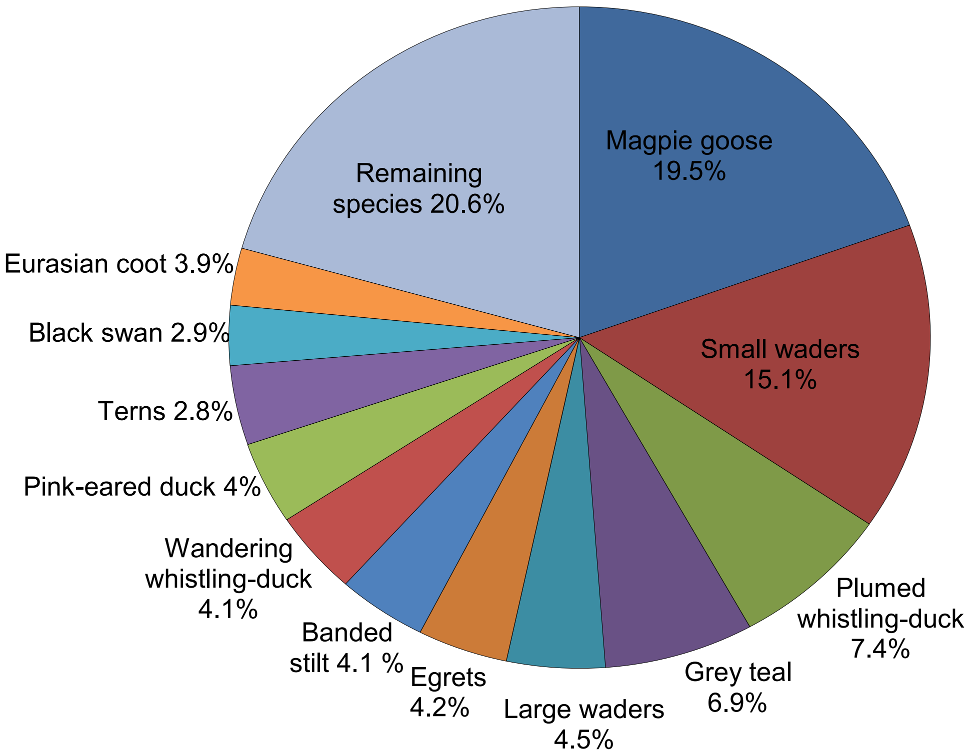

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Table 9: Abundances of the highest 20 ranked waterbird species (or groups of species) over the whole national survey in 2008, ranked by total abundance, within each of the drainage division and their national ranking.

(See Table 5 for acronyms used for river divisions).

SPECIES	BBC	GFC	IOC	LEB	MDB	NEC	SAG	SEC	SWC	TAS	TMS	WPU	TOTAL
Magpie goose		64 348			60	50542		14			783 185	7844	**905 993**
Small waders	447	132 261	53 780	3504	16 229	50755	2182	24 902	1468	911	139 243	278 522	**704 204**
Plumed whistling-duck	1000	9472	820	6533	17 497	18782					257 071	32 732	**343 907**
Grey teal	12 149	6623	7450	24 506	94 447	55399	4124	35 490	19 007	515	24 826	36 087	**320 623**
Large waders		8984	27 353	2	10	45224	105	1444	171	32	131 480	191	**214 996**
Egrets	52	13 383	2273	1076	1405	20519	211	452	708		152 494	862	**193 435**
Banded stilt			101 138	50	31 207				59 123				**191 518**
Wandering whistling-duck		24 289		391	30	11873					152 928	995	**190 506**
Pink-eared duck	19 872		690	58 513	59 830	12		6272	962		200	41 439	**187 790**
Eurasian coot	19 800	1173	4793	23 806	31 157	8278	302	2363	7739	25	9520	71 733	**180 689**
Black swan	5927	785	3930	3182	16 531	13414	4983	48 080	18 482	9621		11 070	**136 005**
Tern	860	16 787	5235	3135	28 119	36225	40	5223	684	105	17 833	15 530	**129 776**
Pacific black duck	1164	10 920	887	2868	5991	41660	553	13 370	7912	224	32 725	9029	**127 303**
Australian shelduck	132		1167	251	42 341		4369	21 513	51 645	1072		2378	**124 868**
Hardhead	1912	93	1269	2484	11 402	9682	4	15 726	1747	84	16 376	19 424	**80 203**
Australian pelican	422	3451	1943	5019	22 232	8231	802	3849	1235	251	15 074	6958	**69 467**
Glossy ibis	242	4143		190	3676	1297		1237	1		42 505	750	**54 041**
Brolga	1	14 710	107	253	127	1117		8			32 136	3510	**51 969**
Black-winged stilt	310	3063	2471	1949	4114	5545	159	6324	4218	10	13 997	3977	**46 137**
Australian wood duck[a]	1654	313	487	1770	16 451	7566	50	390	405		85	4682	**33 853**

Notes: [a]This was a considerable underestimate because many small wetlands, the prominent habitat for Australian wood duck, were not counted.

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Figure 19: Relative species abundance plots for the national aerial survey, Oct.–Nov. 2008, showing the contribution of each ranked species to overall abundance as a percentage. (Note the log scale).

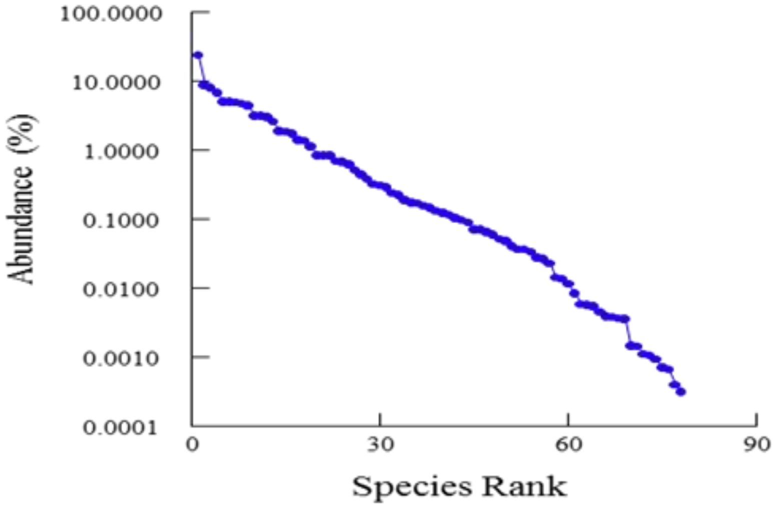

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Figure 20: Abundances of the highest-ranked species or groups of species in each of the six drainage division across northern Australia, including two inland division.
(Acronyms are listed in Appendix A. Note the differences in scales).

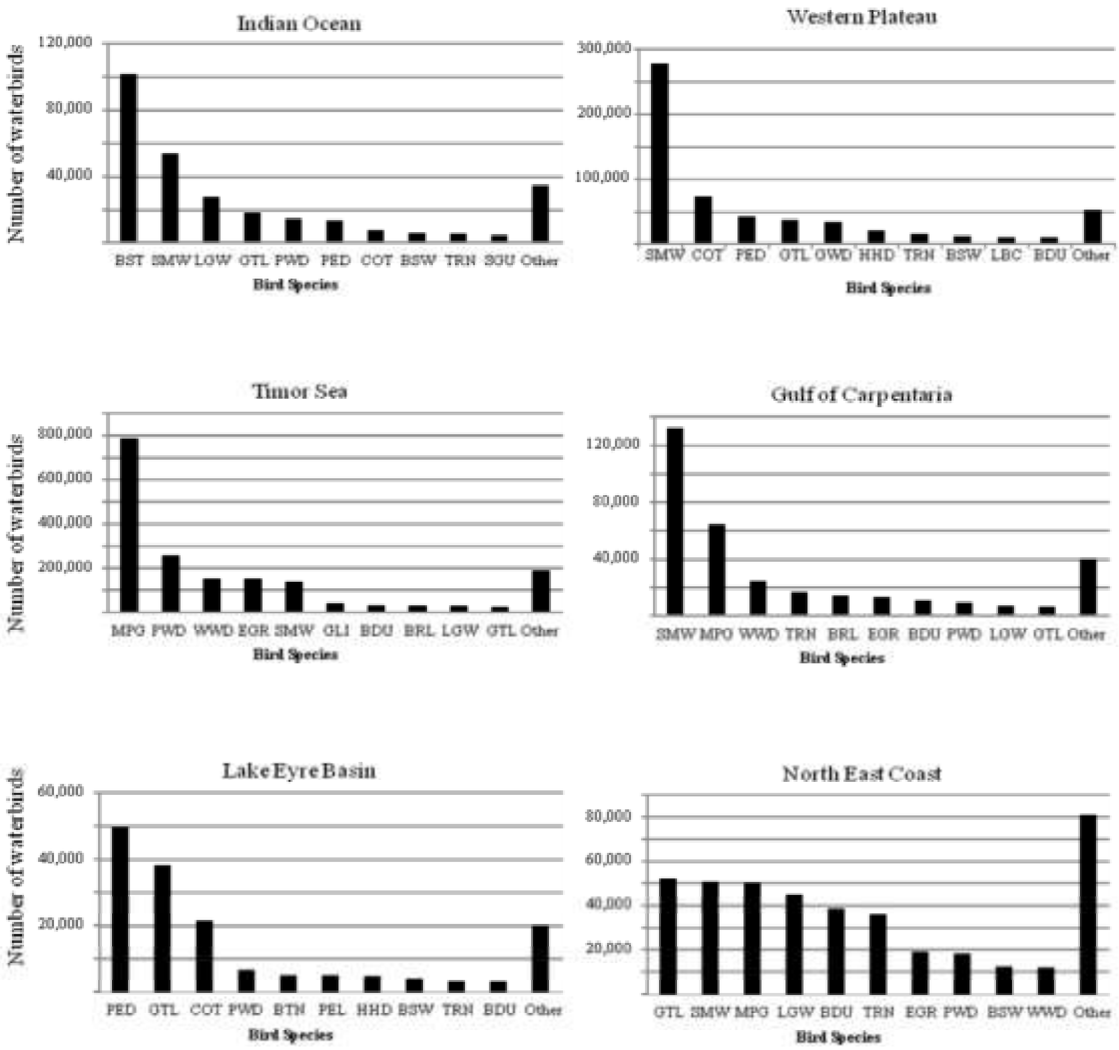

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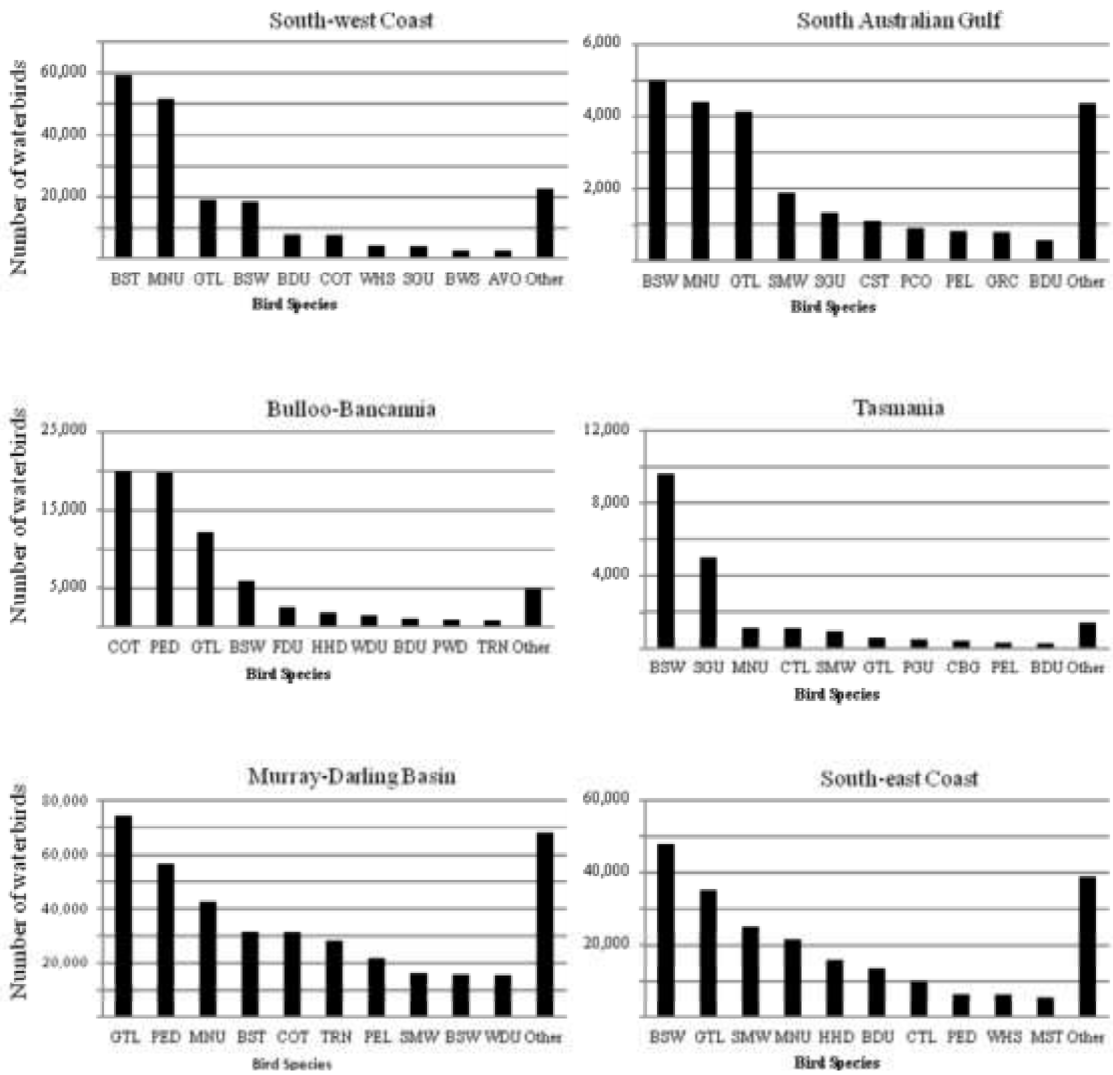
Figure 21: Abundances of the highest-ranked species or groups of species in each of the six drainage divisions across southern Australia, including two inland divisions.
(Acronyms are listed in Appendix A. Note the difference in scales).



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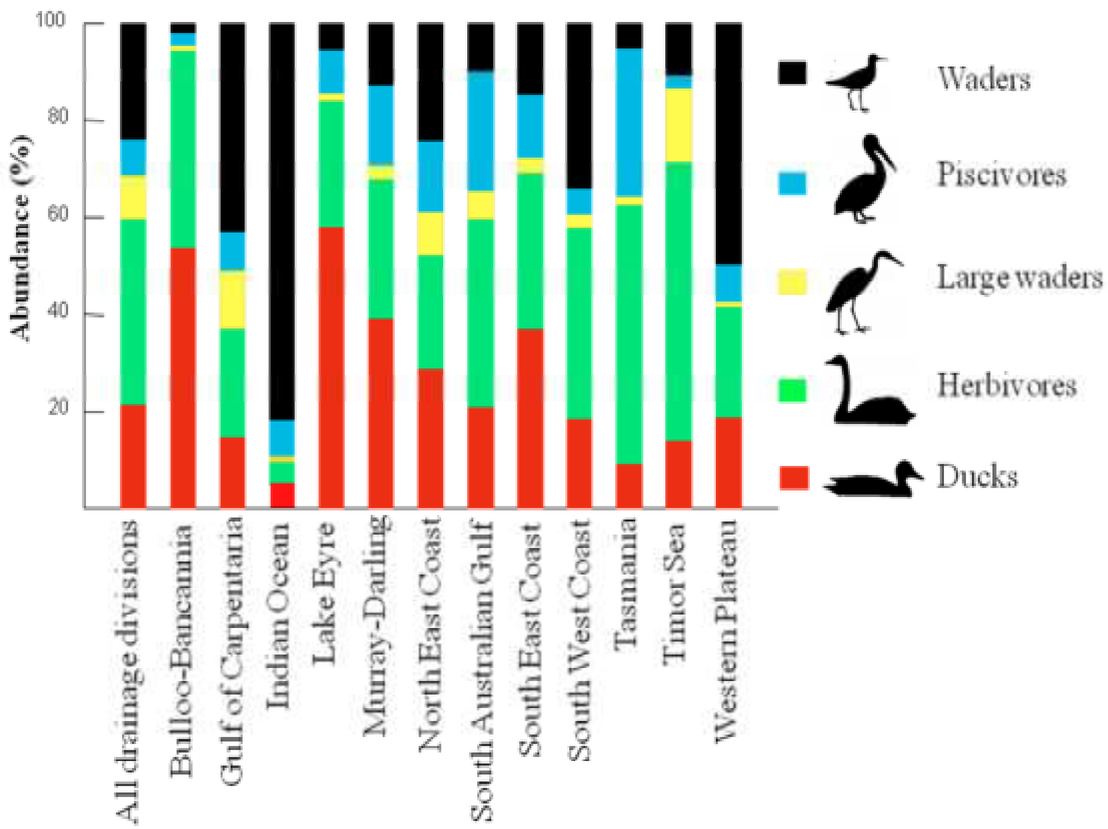
2.3.4. Functional group distributions

Herbivores represented the most common functional group of waterbirds recorded overall during the 2008 National Waterbird Survey (Figure 22). Within the Gulf of Carpentaria and Indian Ocean drainage divisions, where there are large areas of mudflats, the most abundant functional group was the small waders group (i.e. shorebirds). Ducks dominated the Lake Eyre and Bulloo–Bancannia divisions and were also well represented in the Murray–Darling and Western Plateau divisions. This reflects the importance of ephemeral habitats to this functional group of waterbirds—which includes species such as pink-eared duck and grey teal—that are able to rapidly exploit temporary habitats in arid regions such as those that occur in these drainage divisions. Piscivorous waterbirds were most abundant in the Murray–Darling, South Australian Gulf and Tasmania drainage divisions, while large wading birds were most prominent in the Timor Sea and Gulf of Carpentaria divisions.

Figure 22: Waterbird functional groups within then entire national aerial survey (all drainage divisions) and within each of 12 river divisions.

Species that were included in each of the functional groups are listed in Appendix A. Waders included migratory and resident shorebirds.



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2.3.5. Ground survey results

Around 74 900 waterbirds were surveyed across 55 wetlands during the ground surveys conducted as part of this project (Table 10). Only 12 of these wetlands had more than 1000 waterbirds and only one supported more than 10 000 waterbirds. Species numbers ranged from one to 48 and tended to increase with wetland size.

Plumed-whistling duck flock on a wetland in the Lake Eyre division. (Photo: RT Kingsford)

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Table 10: Summary data (abundance and number of species) from ground counts of 55 wetlands in 2008 by different counters.

Wetland	Latitude	Longitude	Abundance	Number of species	Counters
Avalon Swamp	34.34.795	143.55.08	137	10	Rob Clemens
Balnagowan Wetland	23.43.44	150.79.5	244	13	Roger Jaensch
Centennial Parklands	33.53.56	151.53.56	1134	18	Daniela Binder and Jess Armstrong
Calioran	23.12.22	150.21.24	104	9	John McCabe and Jenny Bowles
Cargoon Lake	20.1462	144.82.87	9911	35	Roger Jaensch
Dump 1	23.22.15	150.31.49	574	17	Bruce Zimmer
Dump 2	23.22.15	150.31.49	262	16	Bruce Zimmer
Fitzroyvale Oxbow	34.34.795	150.6921	10394	39	Roger Jaensch
Frog Dam	33.53.56	144.11.90	55	10	Rob Clemens
Garden Lake	23.12.22	115.32.83	0	1	Adrian Boyle
Gavial Swamp	20.1462	150.31.40	527	12	John McCabe
Goose Swamp	33.54.06	150.66.28	461	15	Roger Jaensch
Gracemere Lagoon	23.4289	150.4362	6512	31	Roger Jaensch
Hershel Lake	31.59.72	115.31.80	60	2	Adrian Boyle
House Creek	31.59.72	115.31.80	53	10	Rob Clemens
Kinka 1	23.14.15	150.47.58	153	11	Barry Ellis
Kinka 2	23.14.15	150.47.58	135	10	Barry Ellis
Lake Baghdad			4890	10	Adrian Boyle
Lake Mungo	31.55.51	115.49.44	1206	16	Adrian Boyle
Lake Negri	31.59.89	115.30.77	56	3	Adrian Boyle
Lake Powlathanga	20.2394	145.9665	3530	40	Roger Jaensch

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Wetland	Latitude	Longitude	Abundance	Number of species	Counters
Lake Serpentine			721	6	Adrian Boyle
Lake Sirus	31.59.95	115.30.84	2	1	Adrian Boyle
Long Pocket	19.9608	145.582	103	16	Roger Jaensch
Lower Gracemere Lagoon	23.3826	150.4146	19487	48	Roger Jaensch
Mercedes Swamp	34.22.748	143.47.228	13	3	Rob Clemens
Monkem Creek	34.34.441	143.59.723	7	4	Rob Clemens
Nerimbera 1	23.24.30	150.35.04	612	18	Debra and Nick Corbet
Nerimbera 2	23.24.30	150.35.04	431	15	Debra and Nick Corbet
Nursery 1	23.03.47	150.43.30	243	13	Roger Delves
Nursery 2	23.03.47	150.43.30	735	18	Roger Delves
Pink Lake	32.00.04	115.30.79	0	1	Adrian Boyle
Pococks Swamp	34.22.822	143.46.969	0	1	Rob Clemens
Redbank Weir	34.22.822	143.46.969	20	7	Rob Clemens
Reeves Lake	19.8845	145.8337	1687	34	Roger Jaensch
Regulator/Murrumbidgee River	34.22.819	143.18.237	7	4	Rob Clemens
Ross River Dam 1	19.25.05	146.44.50	1201	22	Jo Wienkeke
Ross River Dam 2	19.29.47	146.50.07	272	18	Jo Wienkeke
Serpentine Lagoon			371	17	Cheryl Robertson
Shalom 1	23.20.13	150.29.54	328	21	Steve and Victoria Kerr
Shalom 2	23.20.13	150.29.54	353	22	Steve and Victoria Kerr
Shaws River	34.21.301	143.51.488	4	3	Rob Clemens
Sheepwash	23.26.51	150.28.50	697	27	John and Therese McCabe
South Yambe	23.12.02	150.20.48	209	13	John McCabe and Jenny Bowles

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Wetland	Latitude	Longitude	Abundance	Number of species	Counters
Spring Lake	19.8494	145.9962	1607	27	Roger Jaensch
Stock dam	34.32.111	143.55.160	37	5	Rob Clemens
Stock-domestic drains	34.35.355	143.55.191	405	44	Rob Clemens
Telephone Creek	34.30.802	144.01.465	172	18	Rob Clemens
Telpee Creek	34.32.380	143.43.315	62	6	Rob Clemens
Toomba Lake	20.0105	145.5929	4213	34	Roger Jaensch
Two Bridges	34.24.263	143.47.485	214	34	Rob Clemens
Wagourah Lagoon	34.23.228	143.52.748	13	4	Rob Clemens
Warwagee dams	34.35.252	143.59.072	32	8	Rob Clemens
White Falls Lake	19.9321	145.6467	92	14	Roger Jaensch
Yeppen 1	19.9321	145.6467	98	18	Allan Briggs
Yeppen 2	33.54.00	151.14.23	106	16	Allan Briggs

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2.4. Discussion

The 2008 National Waterbird Survey comprised the development and implementation of a national approach to estimating waterbird populations, using aerial surveys, across the entire continent. As a result of this undertaking, there is now an unprecedented amount of information on the distribution and abundance of waterbirds across the continent that can inform the management of Australia's land and water resources. The major findings of the 2008 National Waterbird Survey include:

- the identification of important wetlands for waterbirds in terms of waterbird concentration and species richness
- the identification of important regions for waterbirds in terms of waterbird concentration and species richness
- estimates of the abundance of waterbirds, including at the level of some individual species, at a national scale.

Ground surveys of waterbirds were also undertaken during the survey and the utility of such monitoring is also briefly discussed here.

Important wetlands for waterbirds

While good information already exists on the regional importance of different wetlands for waterbirds, with a wide range of data having been collected in different parts of Australia (e.g. Halse et al*.* 1998; Kingsford et al*.* 1999; Kingsford and Porter 2009), such information cannot easily be used to assess the relative importance of wetlands for waterbirds at a national scale because past datasets were collected at different times and sometimes using different methods. Consequently, the 2008 National Waterbird Survey allows a comparison of the relative importance of wetlands in Australia for waterbirds for the first time. Waterbird populations are inevitably distributed largely according to habitat availability (i.e. rivers and wetlands holding water), but there can be considerable discrimination between wetlands by waterbirds on the basis of water quality and various other habitat parameters (Cale et al. 2004; Kingsford and Porter 1994). Identifying important aquatic ecosystems for waterbirds across Australia is therefore a significant step towards improving land and water management practices for these systems and the waterbird species that rely on them.

Wetlands supporting waterbirds were widely distributed across Australia during the 2008 National Waterbird Survey. Waterbird numbers, however, were heavily concentrated in relatively few wetlands, with over 50% of recorded waterbirds occurring in only 41 wetlands or 1.1% of the total number surveyed. The highest-ranked wetland in terms of waterbird abundance, Eighty Mile Beach, alone supported more than 6% of all waterbirds counted. The five most important wetlands for waterbirds in terms of abundance were all in tropical Australia except for the Lower Lakes and the Coorong. Wetlands ranked in the top 20 for waterbird abundance, however, included several in southern and inland Australia, e.g. Dumbleyung Lake and the Cuttaburra Channels.

The importance of many large wetlands of known significance to waterbirds has been confirmed by the 2008 national survey, some of the most important of which, in terms of waterbird abundance, include the wetlands of the Alligator Rivers region (Morton et al. 1990a, b, 1993a, b, c), the Gulf of Carpentaria (Garnett 1987), Lake Gregory (Halse et al. 1998), Lake Argyle (Jaensch and Vervest 1990a), Lake McLeod (Jaensch and Vervest 1990b), wetlands in the western part of the Murray–Darling Division (Roshier et al. 2002) and the Lower Lakes and the Coorong wetlands at the mouth of the Murray–Darling Basin (Kingsford

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et al. 2011). Eighty Mile Beach and Roebuck Bay, each supporting more than 280 000 individuals during this survey, were also confirmed as being particularly important for shorebirds (Wade and Hickey 2008). Most of these wetlands are either already included in the national reserve system or listed as Wetlands of International or National Importance or as Important Bird Areas and the conservation significance of these wetlands is emphasised by the results of this survey.

For the most part, wetlands with high waterbird numbers also had high species richness, but in the case of a few wetlands high waterbird abundance was made up of relatively few waterbird species or groups. Magpie geese on Nanjbagu Billabong in Kakadu National Park and migratory shorebirds on Eighty Mile Beach and Roebuck Bay, for instance, made up most of the waterbirds counted at these sites. These wetlands are therefore likely to be particularly important for the conservation of these individual species.

Some other wetlands of known importance for waterbirds were not identified in this national survey because they were dry in 2008. Wetland availability fluctuates considerably with changing rainfall, river flows and inundation patterns (Roshier et al*.* 2001; Kingsford et al. 2001) and many of Australia's wetlands can be dry at any one time. Consequently, wetland area will differ between surveys as well as from mapped wetland areas. The National Waterbird Survey in 2008 was conducted over two months, representing a snapshot of wetlands that held water after a particulalry dry year. For example, wetlands known to be important for waterbirds that were dry at the time included Lake Eyre and wetlands of Cooper Creek in the Lake Eyre division (Kingsford and Porter 1993; Kingsford et al*.* 1999b).

The national survey was also undertaken in the dry season of the tropics, so numbers of wetlands and wetland area were considerably less than they would have been during the wet season when rivers flood. Consequently, major episodically flooded wetlands, such as Fortescue Marsh and Mandora Marsh in north-western Australia, known to be important for waterbirds (Halse et al. 2005) were not surveyed because they were dry at the time. Some of these large wetlands can support extremely high densities of waterbirds when they do hold water, e.g. Fortescue Marsh and Mandora Marsh: 17 waterbirds ha^{-1} (Halse et al*.* 2005), Lake Eyre: 34 waterbirds ha^{-1} (Kingsford and Porter 1993).

In addition to confirming the importance of many wetlands to waterbirds at national and international scales, the data collected during the 2008 National Waterbird Survey can be used to identify wetlands of importance to waterbirds at regional and local scales. Although analyses at these scales were not conducted during the current project, there were many wetlands distributed around coastal regions and scattered across the inland that supported more than 1000 waterbirds during the survey period. Many of these are likely to be regionally important for waterbirds in general or for particular species, e.g. rare species.

Important regions for waterbirds

The results of this survey are particularly useful for identifying the relative importance of different regions in Australia, e.g. drainage divisions, for total numbers and species of waterbirds. At a continental scale, extremely high numbers of waterbirds were supported on relatively few wetlands, most of which occurred in tropical regions, and the location of these had a strong influence on the abundance of waterbirds at a regional scale.

Given the number of wetlands with high waterbird numbers and densities in northern Australia, the tropical drainage divisions were clearly more important in terms of waterbird abundance and density than other drainage divisions at the time of the survey. In particular, the Timor Sea division dominated the relative abundance of waterbirds counted during the survey. High densities in this region reflect the concentration of fish resources and other prey that occurs as a result of the contraction of tropical floodplain habitats during the dry season

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in these areas. These patterns also reinforce current understanding that wetland ecosystems in tropical regions support higher biodiversity than temperate regions. The importance of northern Australia to waterbirds is increasingly recognised (see Garnett 1987; Morton et al. 1990a, b; 1993a,b; Halse et al. 2005) and the considerable difference between the Timor Sea and other drainage divisions recorded here in relation to waterbird concetrations further emphasises the significance of this region to waterbirds.

High waterbird abundance, density and species richness were also recorded during this survey on some wetlands in the inland drainage divisions, e.g. Lake Galilee and Cuttaburra Channels. The Bulloo–Bancannia drainage division, in particular, had high waterbird densities, reflecting its relatively small size but also the high numbers of waterbirds supported by its overflow lakes. Inland wetlands are well known for their capacity to support high numbers and densities of waterbirds (Kingsford and Porter 1993, 1994; Halse et al. 1998; Kingsford et al. 2004), which can sometimes be comparable to those of wetlands in tropical regions (Morton et al 1990a, b; 1993 a, b, c). High waterbird numbers in such wetlands reflect high levels of productivity across the entire food web of inland river systems (Boulton et al. 2006; Brock et al. 2006; Bunn et al. 2006a; 2006; Kingsford et al. 2006), driven largely by highly variable flow regimes (Puckridge et al. 1998).

Wetlands with relatively high waterbird species richness were scattered across most drainage divisions, reflecting the reasonably uniform numbers of species across all drainage divisions with the exception of Tasmania, which supported considerably fewer species. The composition of waterbird species, however, differed considerably between drainage divisions and was particularly distinct between tropical and temperate Australia. Patterns in composition generally reflected well described distribution patterns of waterbirds in Australia (Marchant and Higgins 1990), e.g. primary tropical species, such as magpie geese and wandering whistling-duck, were mainly found in tropical regions.

In terms of waterbird functional groups, herbivorous species, primarily comprising Australian shelduck, Eurasian coot and black swans, were the most well represented group across the whole of Australia, while waders, particularly migratory shorebirds, dominated the Indian Ocean, Western Plateau and, to a lesser degree, the Gulf of Carpentaria drainage divisions. There are large areas known to be important for migratory shorebirds in Western Australia (Wade and Hickey 2008) and the Gulf of Carpentaria (Garnett 1987). The prominence of shorebirds in the Indian Ocean division primarily reflects the importance of Eighty Mile Beach to this group of birds, but also the overall importance of north-western Australia as a staging area and over-wintering site for migratory shorebirds (Piersma 2007). The dominance of duck species in the Lake Eyre and Bulloo–Bancannia divisions reflects the relatively good ability of duck species, compared with other species, to quickly colonise Australia’s more ephemeral wetland habitats.

Waterbird population sizes

No previous estimates of the continental abundance of Australian waterbirds have been made using data collected at one point in time. The total number of waterbirds in Australia was estimated in 1998 to be around 9 million based on an assessment of data collected from the late 1980s to the mid-1990s (Kingsford and Halse 1998). The actual count of waterbirds in this national survey was 4.55 million and an estimate of the true number, extrapolating from a random sample of wetlands to estimate total numbers of waterbirds on the wetlands available, is 4.65 million. There are two main reasons why waterbird numbers according to the 2008 national survey may be less than suggested from the 1998 estimate. Firstly, waterbird numbers are likely to have been underestimated by the 2008 survey because of a lack of counts in small wetlands. Secondly, there is a strong evidence that overall waterbird numbers have declined over the past 20 years (Kingsford and Porter 2009). Shorebirds in eastern Australian wetlands are also known to have declined during this period (Nebel et al. 2008).

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The only other available estimates of waterbird numbers across the continent are for individual species (e.g. Delany and Scott 2006). Regional estimates of particular species have also been made (Morton et al. 1990a,b; Morton et al. 1990 a,b,c; Kingsford et al. 1999b) and while these are relatively accurate and have considerable local value, they lack context in terms of what was happening to waterbirds at that time in other parts of Australia and this hampers the interpretation of trends and causes of changes in bird numbers. The 2008 National Waterbird Survey represents a unique attempt to provide a continental-scale estimate of waterbird populations, which may contribute a greater understanding of these mobile species.

The most abundant species recorded during this survey, magpie geese, were predominantly found in northern Australia, reflecting the importance of tropical regions for this species which congregates in large floodplains of tropical rivers (Frith 1982; Marchant and Higgins 1990). Magpie geese have previously been estimated to occur in numbers of over 1 million (Delany and Scott 2006), with one regional estimate of 1.6 million made on the basis of adjusting for underestimation of aerial survey counts (Morton et al. 1990a). The count of 900 000 made in this National Waterbird Survey for the whole of Australia is well below these past estimates but, given the scale of this survey, may provide the first robust estimate of the Australian population size of this species. Causes of discrepancy between past and current estimates are likely to be at least partially due to differences between counting methods and extrapolation from ground counts. For instance, the current estimate does not include an extrapolation from the random sample of wetlands for this species.

Small floodplain lagoon in the Northern Territory provides habitat for a range of waterbirds (Photo: RT Kingsford).

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The estimated abundance of shorebirds in Australia, including small migratory and resident shorebirds (e.g. red-capped plover) calculated from this national survey, is approximately 700 000 birds. This is considerably lower than past estimates that around 2 million migratory shorebirds visit Australia each year (Watkins 1993). It was not possible to survey every shoreline of the Australian coast during the current survey, however, so this figure of 700 000 clearly underestimates the size of migratory shorebird populations present at the time. The results of the current survey are not, therefore, sufficient to further assess trends in shorebird populations as discussed by Nebel et al. (2008). The number is consistent with Nebel et al. (2008), who found numbers of shorebirds have declined in eastern Australia. Given the significance of migratory birds to many of Australia' international agreements, e.g. JAMBA, CAMBA and ROKAMBA, there is considerable merit in extending the amount of shoreline covered in future surveys, with targeted surveys of regions of known importance, to improve estimates of shorebird numbers in Australia.

Past estimates of Australian population sizes for plumed whistling-duck and grey teal, the next most abundant taxa recorded in the current survey, are 100 000–1 million and over 1 million respectively (Delany and Scott 2006). Estimates based on the 2008 National Waterbird Survey for these species, without including extrapolated estimates from sampled wetlands, are about 344 000 and 320 000 respectively. Given that about 150 000 grey teal were counted in eastern Australia alone in October in the early 1990s (Kingsford 1999a) and a further 135 000 in south-western Australia in March 1992 (Halse et al. 1990), the results of this survey suggest that the national population size of this species may have declined by up to 80% over the past 20 years. This is comparable to observed reductions in shorebird counts in eastern Australia (Nebel et al. 2008).

The estimated size of the national population of banded stilt based on this survey of just under 200 000 birds is comparable to a previous estimate of 206 000 (Delany and Scott 2006). Since this species tends to occur in large concentrations, surveying of banded stilt is more straightforward than for many other species. It should be noted that not all species estimates made from the 2008 National Waterbird Survey are so reliable. In particular, aerial surveys are not suitable for cryptic (e.g. bitterns, crakes and rails) or diving species (e.g. grebes, blue-billed duck) and are unable to produce estimates of the former and are likely to considerably underestimate the latter (Kingsford 1999). Furthermore, some waterbird species (e.g. straw-necked ibis, banded lapwing) also forage on dry land away from wetlands and their numbers are therefore likely to have been underestimated by the current survey which focused solely on wetlands.

Ground vs. aerial surveys

The ground surveys conducted here provide valuable information at a local scale for the management of the particular wetlands considered. Further counts in these targeted wetlands over time, e.g. through wetting and drying and seasonal cycles, will also greatly supplement aerial survey information and provide a more complete picture of waterbird population fluctuations. This localised information can only be adequately interpreted, however, in the context of the large-scale aerial surveys that provide information about waterbird patterns at broad regional, or continental, scales.

Ground surveys of waterbirds are often perceived as being more precise and accurate than aerial surveys, mainly because the rapidity of aerial surveys leads to an underestimation of waterbird diversity and abundance. Higher numbers of waterbird species tend to be recorded by ground surveys, particularly in small wetlands, because some species (e.g. small wading birds) cannot be differentiated from the distance at which aerial observers operate. Other species are cryptic and can be hidden in vegetation, while some dive as aircraft approach

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(Kingsford 1999). On a moderate-sized wetland with relatively high daily variability, however, ground counts were found to have only slightly greater precision than aerial counts

(Kingsford 1999). In several other examples of wetlands, aerial counts may even be more likely to be accurate than ground counts (Kingsford et al. 2008).

Ground surveys are considerably more labour intensive (Diem and Lu; 1960; Gabor et al. 1995) and take more time to complete than aerial surveys (Rodgers et al. 1995; Kingsford 1999) and there are substantial logistic difficulties involved in ground counting large or remote wetlands (Frederick et al. 1996). Furthermore, due to the greater amount of time taken to complete ground surveys relative to aerial surveys and the difficulty of accessing some areas, ground surveys are less likely to be repeatable than aerial surveys (Kingsford 1999) and tend to be less practical or efficient (Henny et al. 1972; Geldenhuys 1974). The main advantages of using aerial surveys therefore include: 1) extensive coverage at relatively low cost; 2) the ability to survey inaccessible wetlands; 3) avoiding double counting by flying faster than the waterbirds; and 4) rapidity compared to other methods. There is undoubtedly also a role for ground surveys providing additional data to aerial surveys. The two should be used where possible.

Implications

The data collected by the 2008 National Waterbird Survey has considerable value at local, regional, catchment and national scales for the development of policy and land and water management strategies. The information collected during this survey provides a baseline for assessment across these scales of the relative importance of wetlands for waterbirds and represents the first continental-scale snapshot of the composition of waterbird communities throughout Australia. As well as providing estimates of population size for different species, taxonomic and functional groups of waterbirds, the results of this survey have also identified important wetlands for waterbirds at multiple scales. For instance, wetlands appropriate for listing under the Ramsar Convention, i.e. wetlands supporting >20 000 waterbirds, can easily be identified from the survey results while, at state, regional and catchment levels, the identification of wetlands of importance to waterbirds should inform catchment and water management plans, e.g. guiding development or environmental flow allocations. Further analyses of the data will also support the identification of wetlands that are important for particular species for the development of species management plans.

The methods developed here provide a consistent methodology that can be used across Australia to provide comparative data for different wetlands and regions throughout the continent and, should these data be collected in the future, across different times. The 2008 survey was conducted over a relatively short period to minimise dynamic shifts in wetland conditions and waterbird populations. However, additional longitudinal counts of targeted wetlands through wetting and drying and seasonal cycles are needed to supplement this information and provide a more complete picture of waterbird population fluctuations. Such longitudinal surveys may be supported and undertaken by skilled members of organisations such as BirdLife Australia, but can only be adequately interpreted in the context of large-scale aerial surveys that provide a regional or continental picture over time. Information on the distributions of wetlands and waterbirds obtained via the 2008 national survey will also contribute to an improved sampling design for future surveys.

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3. Long-term changes in waterbird numbers in Eastern Australia

3.1. Introduction

Long-term decline in ecological condition is evident in many of the world's river systems and wetlands, as well as their dependent biota. It is widely attributed to river regulation and associated water diversions, and to pollution and invasive species (Allan and Flecker 1993; Nilsson et al*.* 2005; Kingsford et al. 2006). Flow regimes play a critical role in determining habitat availability for aquatic organisms and also strongly influence ecological processes in river and wetland systems (Ward 1998). Consequently, changes in flow regimes, due to river regulation and water extraction, have the potential to cause significant changes in the structure and function of aquatic ecosystems and the biological communities that depend on them.

The flow regimes of rivers and wetlands are characterised by the magnitude, timing, duration, rates of rise and fall, and frequency of flood pulses, which are natural disturbances that stimulate productivity and provide lateral connections between rivers and their floodplains (Junk et al*.* 1989). Complex interactions between geomorphology and the temporal and spatial variability of flood pulses produce a dynamic and diverse range of habitats across river and wetland systems (Ward et al*.* 1999). Drying disturbances that intervene in flood pulses are also ecologically significant as they can be perceived as 'resetting' a system before the next flood pulse (Stanley et al. 1997). The temporal and spatial variability of water within river and wetland systems is increasingly recognised as the primary driver of freshwater ecosystem structure and function (Stanley et al. 1997; Ward et al. 2002). Variability and unpredictability of flows and flooding creates a greater diversity of habitats for organisms on floodplains compared to their main river channels (Ward et al*.* 1999; Sheldon et al*.* 2002; Pinder et al. 2010) and this is often reflected by higher species richness and abundances among biological communities of floodplains and wetlands (Ward et al. 1999). Food-web structure also tends to exhibit greater complexity in such heterogeneous habitats as well as in natural ones, as opposed to modified, habitats (Power et al. 1995).

Many Australian wetlands, particularly those of the arid and semi-arid inland that covers a high proportion of the continent, display patterns of flooding and drying that are neither seasonal nor annual but are rather highly erratic as a result of unpredictable rainfall and river flows (Puckridge et al*.* 1998). Floods, driven by periods of heavy rainfall, are followed by droughts and these shifting conditions create dramatic expansions and contractions of wetland area. Waterbird populations in drylands respond strongly to these changes in wetland area and connectivity with impressive and characterised fluctuations in waterbird abundance and productivity, often referred to as 'boom and bust' cycles (Kingsford et al. 1999b, 2010).

The high level of natural variability in wetland area and waterbird populations inherent over much of Australia makes the detection of trends in waterbird population sizes and relationships between these and rainfall, river flows and wetland extent, difficult to analyse robustly without sufficient long-term data. The Eastern Australian Aerial Waterbird Survey has been conducted every October between 1983 and 2009 within 10 survey bands stretching across eastern Australia between northern Queensland (20°30'S) and the southern part of the Victorian mainland (38°30S; Figure 2). Since the same survey methods have been employed across this survey period and area (see Section 1.1.4), the data generated provides a unique opportunity to assess long-term trends in wetland extent and waterbird populations in this diverse and variable region.

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This chapter provides an overview of the assessment of long-term trends in waterbird populations of eastern Australia conducted during this project, which specifically aimed to:

- describe long-term trends in wetland area, waterbird abundance and breeding at a regional scale across eastern Australia
- determine long-term trends in waterbird abundance, breeding and community composition in key wetlands of eastern Australia
- determine relationships between wetland area, rainfall, river flow and waterbird abundance and breeding in key wetlands across eastern Australia.

3.2. Methods

3.2.1. Data collection

Waterbird counts for eastern Australia were obtained for this part of the project from the Eastern Australian Aerial Waterbird Survey database (see Section 1.1.4) covering the full spatial extent of the survey area and spanning the period from 1983 to 2009. The last three surveys (i.e. 2007–09) were conducted as part of this project. The indices extracted from the database for each date included the number of wetlands surveyed, total number of waterbirds and number of breeding waterbirds and breeding species. Data on waterbird community composition was also extracted for 11 selected wetlands that were identified as particularly important for waterbirds (see Section 3.2.2).

Data was also obtained from the Eastern Aerial Waterbird Survey database about wetland area at each survey time. Observers recorded wetland area during surveys as a proportion of each wetland that was filled with water at the time, measured as a percentage of the total area of a wetland when full (according to the 1:250 000 national waterbody layer; Geoscience Australia 2006). Where wetlands were not mapped, observers directly estimated the area of water within the wetland at the time of the survey.

Annual rainfall (mm) and river flow (ML) data for 11 selected wetlands (see Section 3.2.2) for the period 1983–2009 were obtained from the PINEENA river flow and height database for New South Wales (NSW DECCW 2009) and the Bureau of Meteorology (BOM <*www.bom.gov.au/hydro/wr/agency_data.shtml*>, accessed 19/5/11). Where no river flow data was available (e.g. Lake Galilee), nearby rainfall stations were identified that would provide an index of run-off since these wetlands tended to rely on local run-off, rather than river flow, to fill (see Table 11).

3.2.2. Data analyses

Regional trends

Trends in the total area of surveyed wetlands and total abundances of waterbirds were initially analysed across the entire eastern Australian survey region using all surveyed wetlands. Relationships were explored between waterbird numbers and the number and area of wetlands surveyed at each survey time. Model effectiveness was assessed as a percentage in relation to the model's measure of how well it explained the data it was trying to predict or its 'goodness of fit'. Time was also included as an independent variable in this model to examine temporal trends in the data. Further dependent variables modelled at the regional scale included the total number of breeding waterbirds and breeding species.

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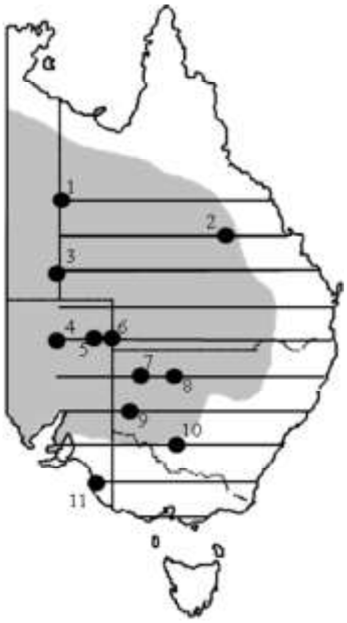
Individual wetland trends

All wetlands surveyed under the Eastern Australian Aerial Waterbird Survey were ranked by their mean abundance of waterbirds as counted in the 27-year survey period to identify wetlands with the highest concentrations of waterbirds. Ten wetlands were identified that usually supported more than 10 000 waterbirds each year and that were consistently important each year. Six of the ten occurred in the Lake Eyre drainage division and four in the Murray–Darling division (Table 11, Figure 23). An additional wetland, the Macquarie Marshes, also in the Murray–Darling division, was included because of its importance during early survey dates as well as its conservation values as a protected area and Ramsar wetland that receives environmental water (Table 11). Detailed modelling of waterbird communities and wetland area, rainfall and river flows were then conducted for these 11 wetlands.

Figure 23: Ten key wetlands identified with the highest abundance of waterbirds and the Macquarie Marshes along the 10 east–west survey bands for annual aerial surveys of waterbirds across eastern Australia, 1983–2009.

(See Table 11 for names of wetlands matching the numbers).



The 11 selected wetlands were characterised by their drainage division, source and type of inflows (i.e. local rainfall and run-off versus river flows) and their regulation status (i.e. regulated or unregulated). Regulated wetlands comprised those where there was substantial water resource development upstream in the catchment, i.e. large dams (>1 000 000 ML) and diversions exceeding 200 000 ML (Kingsford 2000). Unregulated wetlands included those fed by rivers with minimal or no regulation or upstream diversions, e.g. Cooper Creek (Kingsford et al. 1998, Kingsford 2000). Apart from Lake Moondara (defined here as regulated), the selected wetlands were easily categorised as regulated or unregulated.

Similar modelling was conducted at a wetland scale as was undertaken for the entire region (see above), with dependent variables modelled, including total numbers of waterbirds and breeding waterbirds and number of breeding species, and independent variables, including time and wetland area. Annual river flow (ML), where available, and rainfall (mm) were also included as explanatory variables in the models of individual wetlands. A more detailed description of these analyses is provided in Appendix C.

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Finally, changes in waterbird community composition for each of the selected wetlands were examined using multivariate techniques, including multidimensional scaling (MDS) and analysis of similarities (ANOSIM; Clarke 1993; Clarke & Warwick 1994, Clarke & Gorley 2006). A detailed explanation of these methods is provided in Appendix C. The relative abundance of different waterbird functional groups (i.e. ducks, herbivores, large waders, piscivores and shorebirds: see Appendix A) was also assessed for each wetland across the survey period.

Wetlands of the Timor Sea division in the Northern Territory were particularly important in terms of abundance and diversity of waterbirds. (Photo: RT Kingsford)

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Table 11: Ten highest-ranked wetlands by abundance of waterbirds (1983–2009) and the Macquarie Marshes based on data from Eastern Australian Waterbird Surveys

Note: source of inflow (river or creek), locations of rainfall stations (R) or flow gauges (F) used for annual modelling and regulation status: unregulated (unreg., limited diversions) or regulated (reg. upstream dams >1 000,000 ML storage capacity and >200 000 ML of diversions) of the wetlands (see Figure 23 for locations).

Wetland (type)	*Source of inflow*	*Rainfall (R) or flow (F)*	*Regulated (reg.) or unregulated (unreg.)*	*Location of rainfall station or flow gauge*
1. Lake Moondarra	Leichhardt River	R	Reg.	Lake Moondarra (–20.58, 139.58), Mt Isa Aero (–20.68, 139.49), Mt Isa Mine (–20.74, 139.48), West Leichhard Station (–20.60, 139.70)
2. Lake Galilee	Local creeks	R	Unreg.	Jochmus (–22.32, 145.99), Ulcanbah (–22.02, 145.98) Eastmere (–22.50, 139.59)
3. Lakes Torquinie & Mumbleberry	Mulligan River	R	Unreg.	Kamaran Downs (–24.34, 139.28), Bedourie (–24.36, 139.47), Cluny (–24.51, 139.59), Sandringham (–24.05, 139.06).
4. Lake Eyre	Cooper Creek, Warburton River	R	Unreg.	Boulia Airport (–22.91, 139.90), Bedourie (–24.36, 139.47), Mt Isa Mine (–20.74, 139.48), Winton Post Office (–22.39, 143.04), Birdsville (–25.90, 139.35), Linda Downs (–22.2, 138.69), Glenormiston (–22.91, 138.80), Marion Downs (–23.37, 139.66)
5. Cooper Creek	Cooper Creek	F	Unreg	Cullyamurra (F,–27.70, 140.84)
6. Lake Hope	Cooper Creek	F	Unreg	Cullyamurra (F,–27.70, 140.84)
7. Paroo & Cuttaburra Channels	Paroo River	F	Unreg	Caiwarro (F,–28.78, 144.68)
8. Macquarie Marshes	Macquarie Marshes	F	Reg.	Warren Weir (F,–31.70, 147.84)
9. Menindee Lakes	Darling River	F	Reg.	Menindee (F,–32.39, 142.42)
10. Lowbidgee	Murrumbidgee River	F	Reg.	Maude (F,–34.48, 144.30)
11. Naracoorte dune swamps	Local creeks and rainfall	R	Unreg.	Avenue Downer (–36.94, 140.24), Lucindale Post Office (–36.97, 140.37) Naracoorte Bettws (–36.92, 140.58), Padthaway (–36.60, 140.50)

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3.3. Results

3.3.1. Regional trends

All of the indices considered at a regional scale (i.e. wetland area, number of wetlands, total number of waterbirds and number of breeding waterbirds and breeding species) declined over the 27-year survey period from 1983 to 2009 (Figures 24 to 28, Table 12). Overall, there was a significant reduction in wetland area across the survey region during this period, with consistent decline after 1999 below the long-term mean, i.e. the mean wetland area recorded over the 27-year period (Figure 24**Error! Reference source not found.**, Table 12). Wetland area was greatest from 1983–1984, followed by 1990–1991, 1997 and 2000 (Figure 24). A reasonable goodness of fit was achieved in the explanatory model for wetland area, which was significantly related to the number of wetlands and the year (Table 12).

The number of wetlands counted was highly variable and was greatest in periods in which wetland area was highest (Figure 25). The number of wetlands also declined significantly over time (Table 12) but no clear reduction in the number of wetlands surveyed occurred until after about 1988, after which time the number of wetlands counted was consistently below the long-term mean, i.e. the mean number of wetlands recorded over the 27-year period (Figure 25, Table 12). In the last two years of the survey (2008 and 2009), numbers of wetlands increased but remained below the long-term mean (Figure 25). A reasonable goodness of fit was provided by the explanatory model and the number of wetlands was significantly related to wetland area (Table 12, Figure 29).

Waterbird abundance also declined significantly at a regional scale over the 27-year period (Table 12, Figure 26). Waterbird numbers estimated in 1984 were particularly high and have not been observed again since this time (Figure 26). A statistically significant decline in waterbird abundance was still detected if the 1984 point was excluded from analyses (Table 12). Waterbird numbers fell below the long-term mean—i.e. the mean number of waterbirds recorded in each year for the whole region over the 27-year period—in 1998 and have remained below this value since then, although a small rise in total waterbird numbers was recorded in 1990 (Figure 26). The explanatory model had a high goodness of fit and waterbird abundance was significantly related to wetland area and number of wetlands (Table 12, Figure 29).

There has been a highly significant decline in the number of breeding waterbirds estimated over time at the regional scale (Table 12, Figure 27). There has been considerable variation in the numbers of breeding waterbirds counted with high counts occurring approximately every 2–3 years and typically followed by periods of low counts (Figure 27). Only three counts of the number of breeding waterbirds (i.e. 1998, 2000 and 2005) have exceeded the long-term mean, i.e. the mean number of breeding waterbirds recorded in each year for the whole region over the 27-year period (Figure 27). A reasonable goodness of fit was given by the explanatory model and the number of breeding waterbirds was significantly related to the number of wetlands and wetland area at a regional scale (Table 12, Figure 29).

Finally, the number of different breeding species showed a significant decline over the 27-year period (Table 12, Figure 28). There were peaks in the number of breeding waterbird species in 1984, 1990 and 1998, but after 2000 numbers declined below the long-term mean, i.e. the mean number of breeding species recorded in each year for the whole region over the 27-year period (Figure 28). A model with high goodness of fit indicated that the number of different breeding waterbird species was significantly related to wetland area and less so to the number of wetlands (Table 12, Figure 29).

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Table 12: Goodness of fit for generalised additive modelling (GAM) investigating relationships between wetland area, number of wetlands and year and total number of waterbirds and breeding waterbirds and number of breeding species of waterbirds over 27 years of aerial survey of eastern Australia (1983–2009).

Non-parametric chi-square test p-values given for each covariate and their significance in parentheses are included in each of the models. Trends in waterbird abundance for each of the wetlands was also tested using Mann-Kendall trend test with the test statistic tau on the actual data and its probability (P).

Variable	Wetland Area	No. of wetlands	Goodness of fit (%)	tau	P	trend
Total area of wetlands	NA	17 710(<0.0001)	74.9	–0.493	<0.0001	decline
No. of wetlands surveyed	112.3(<0.0001)	NA	72.5	–0.436	<0.0007	decline
Total number of waterbirds	2 023 194(<0.0001)	135 370(<0.0001)	96.9	–0.516	<0.0001	decline
Total number of waterbirds (excluding 1984)	123 257(<0.0001)	288 743(<0.0001)	80.8	–0.483	0.0003	decline
Total number of breeding waterbirds	49 209(<0.0001)	14 464(<0.0001)	78.4	–0.407	0.0014	decline
Number of breeding species	11.2(0.0159)	8.1(0.0584)	95.8	–0.523	<0.0001	decline

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Figure 24: Assessments of total wetland index (ha) during annual aerial surveys of waterbirds across eastern Australia, 1983–2009, showing changes relative to long-term mean.

(The long-term mean area is represented by the dashed line in the figure below, at 267 827 ha).

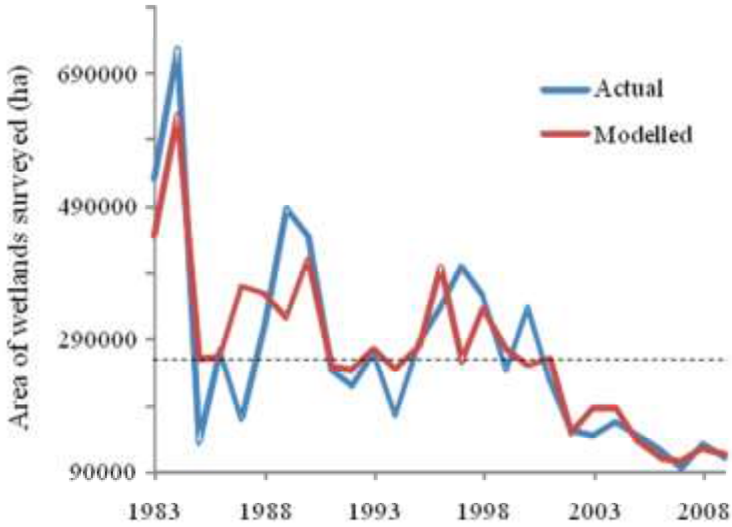

Figure 25: Number of wetlands counted during annual aerial surveys of waterbirds across eastern Australia, 1983–2009, showing changes relative to long-term mean.

(The long-term mean number of wetlands is represented by the dashed line, at 867).

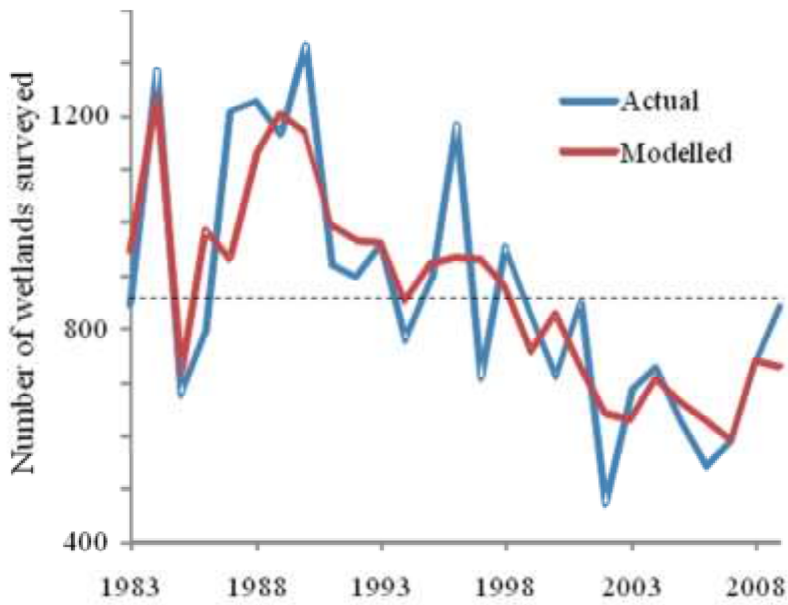

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Figure 26: Total waterbird abundance during annual aerial surveys of waterbirds across eastern Australia, 1983–2009, showing changes relative to long-term mean.

(The long-term mean total waterbird numbers is represented by the dashed line, at 443 857).

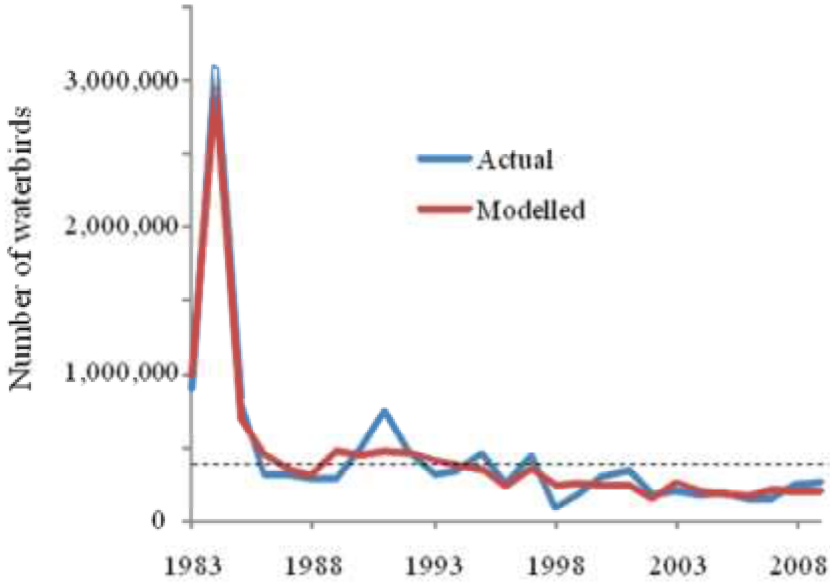

Figure 27: Total number of breeding waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia, 1983–2009, showing changes relative to long-term mean.

(The long-term mean total number of breeding waterbirds is represented by the dashed line at 4503).

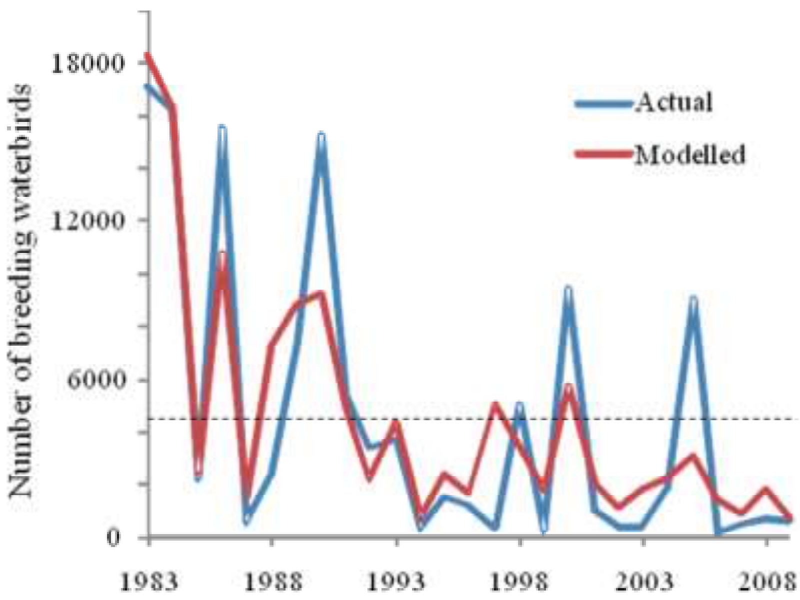

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Figure 28: Total number of breeding species of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia, 1983–2009, showing changes relative to long-term mean

(The long-term mean total number of breeding species of waterbirds is represented by the dashed line at 12.8).

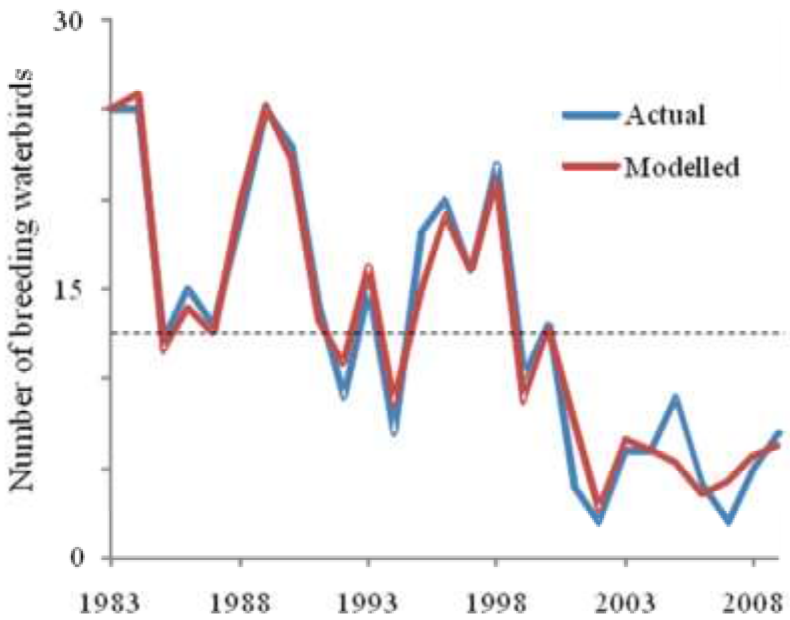
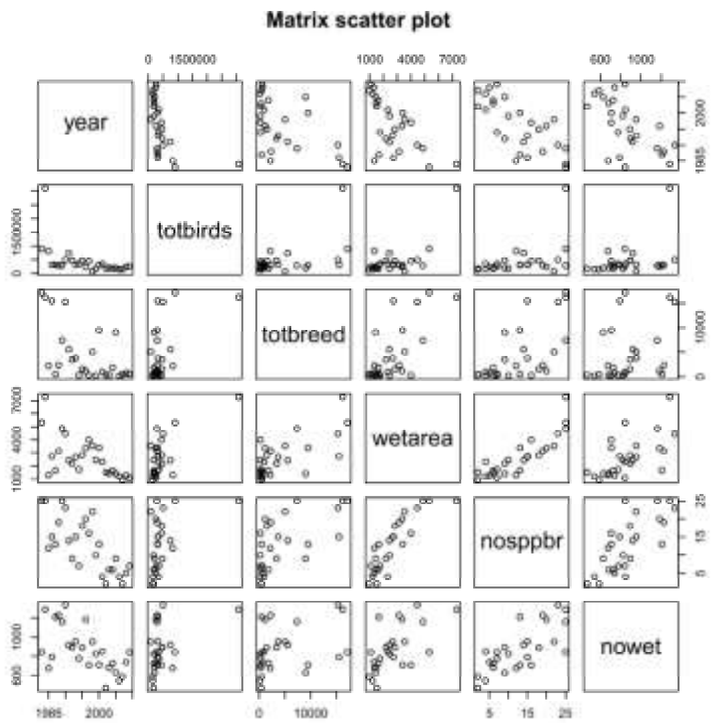


Figure 29: Matrix scatter plot showing relationships among year, total number of waterbirds (totbird), total number of breeding waterbirds (totbreed), wetland area (wetarea), number of species of breeding waterbirds (nosppbr) and number of wetlands (nowet) during annual aerial surveys 1983–2009.

(The name on the row serves as the y axis for that row while the name in a column serves as the x axis for that column).



3.3.2. Individual wetland trends

There was considerable variation in wetland area and the mean abundance and density of waterbirds recorded across the 11 selected wetlands over the 27-year survey period (Table 13). The number of years that each wetland was surveyed also varied since not all wetlands held water in every year during this period (Table 13). Many of the unregulated wetlands were dry in many years. Lake Eyre, for example, held water in only three years during the survey period (Table 13). In general, the regulated wetlands held water more often than the unregulated wetlands (Table 13).

Table 13: Mean (±SE) waterbird abundance, mean density and number of years surveyed, on the 10 highest ranked wetlands by abundance of waterbirds (1983–2008) and the Macquarie Marshes from Eastern Australian Waterbird Surveys. Area corresponds to mean area flooded. (For locations see Figure 23 and Table 11).

Wetland (type) [a]	*n* [b]	*Mean abundance*	*SE*	*Area* [c] *(ha)*	*Density* [d]
Lake Moondarra (R, LEB)	26	12 082	2135	1715	7.04
Lake Galilee (U, LEB)	18	116 883	81 341	14 845	7.87
Lakes Torquinie & Mumbleberry (U, LEB)	7	88 319	22 595	3709	23.81
Lake Eyre (U, LEB)	3	49 918	36 222	203 021	0.25
Cooper Creek (U, LEB)	13	33 670	9879	318 277	0.11
Lake Hope (U, LEB)	12	21 343	7376	3164	6.75
Paroo & Cuttaburra Channels (U, MDB)	24	32 574	8749	43 288	0.75
Macquarie Marshes (R, MDB)	26	8829	3302	8480	1.04
Menindee Lakes (R, MDB)	26	17 975	6395	25 713	0.70
Lowbidgee (R, MDB)	26	45 437	10 034	102535	0.44
Naracoorte dune swamps (U, MDB)	26	37 572	18 026	32 636	1.15

Notes:

[a]U = unregulated; R = regulated; LEB–Lake Eyre Division, MDB – Murray–Darling Division

[b]Number of years of survey data; wetlands with <26 were dry in some years

[c]Area of wetland counted within the survey band (may differ from total wetland area)

[d]Relative to mean abundance

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There was high goodness of fit for most of the explanatory models calculated using time, wetland area, annual river flow and/or annual rainfall to determine waterbird abundances for the 11 wetlands (Table 14). Among these wetlands, waterbird abundances declined over the survey period on seven wetlands, including two in the Lake Eyre drainage division (Cooper Creek and Lake Eyre) and all of the wetlands in the Murray–Darling division (Menindee Lakes, Lowbidgee, Macquarie Marshes, Naracoorte, and the Paroo–Cuttaburra) (Table 14). No trend in overall waterbird abundance was identified in the other four wetlands—Lake Galilee, lakes Torquinie and Mumbleberry, Lake Hope and Lake Moondarra (Table 14).

Waterbird numbers declined significantly in all wetlands that were regulated, apart from Lake Moondarra (Table 14). There were also significant differences in the composition of waterbird communities found between the regulated and unregulated wetland systems examined here (R = 0.166, P<0.001). Overall, waterbird communities of regulated wetlands were relatively distinct from those on unregulated wetlands, although there was clearly some overlap (Figure 30).

Figure 30: Multidimensional scaling ordination plot of waterbird community composition (1983–2008) on important regulated and unregulated wetlands using annual aerial survey data collected from waterbirds across eastern Australia.

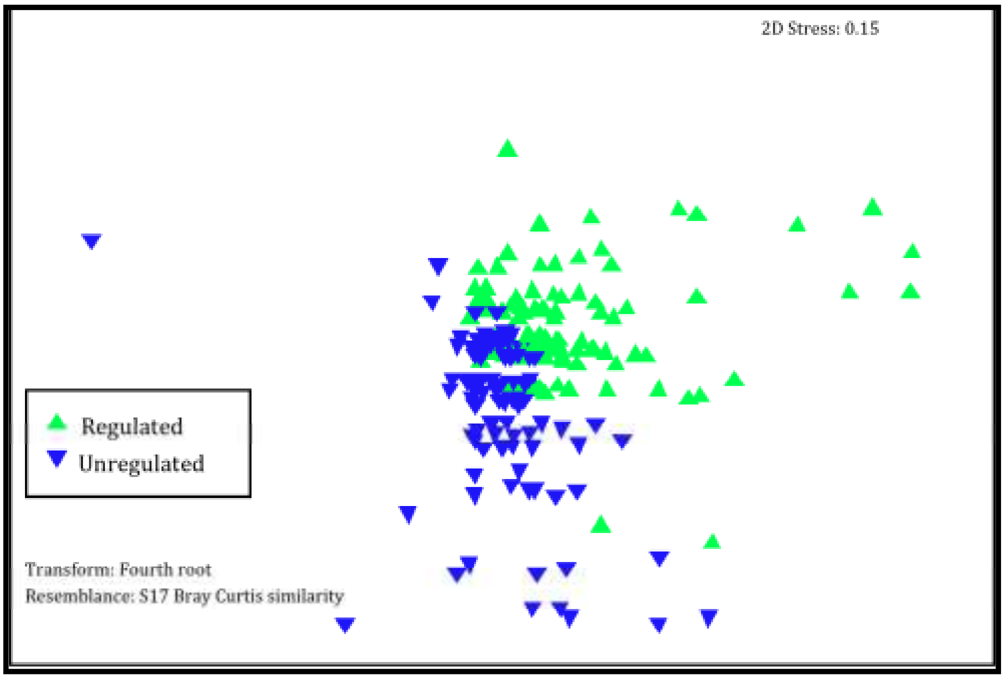

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Table 14: Goodness of fit for generalised additive modelling (GAM) investigating relationships between annual waterbird abundance, annual flows and/or rainfall and wetland area in relation to time (trend).

Non-parametric chi-square test p-values given for each covariate and their significance in parentheses; flow data was not always available (NA) and so rainfall was used. Non-significant variables were identified (NS). Trends in waterbird abundance for each of the wetlands were also tested using Mann-Kendall trend test on the actual count data, with the test statistic tau.

Wetlands[a]	Wetland area	Flow	Rainfall	Goodness of fit (%)	tau	p	trend
Lake Moondarra (R, LEB)	14.6 (0.0029)	NA	NS	50.5	0.022	0.4387	NS
Lake Galilee (U, LEB)	309.7 (<0.0001)	NA	33.7 (<0.0001)	99.6	0.023	0.4377	NS
Mumbleberry/Torquinie (U, LEB)	81.5 (<0.0001)	NA	NS	99.9	0.017	0.2479	NS
Lake Eyre (U, LEB)	NS	NA	NS	99.9	–0.314	0.0274	decline
Cooper Creek (U, LEB)	1279.1 (<0.0001)	528.7 (<0.0001)	64.6 (<0.0001)	99.8	–0.36	0.0106	decline
Lake Hope (U, LEB)	164.3 (<0.0001)	228.0 (<0.0001)	-	98.1	0.094	0.2656	NS
Paroo–Cuttaburra Channels (U, MDB)	84.7 (<0.0001)	66.1 (<0.0001)	-	80.7	–0.314	0.0123	decline
Macquarie Marshes (R, MDB)	20.0 (0.0001)	22.1 (0.0002)	-	95.8	–0.569	<0.0001	decline
Menindee (R, MDB)	8.7 (<0.042)	66.1 (<0.0001)	-	98.3	–0.467	0.0015	decline
Lowbidgee (R, MDB)	197.8 (<0.0001)	143.2 (<0.0001)	-	93.3	–0.563	<0.0001	decline
Naracoorte wetlands (U, MDB)	122.6 (<0.0001)	NA	258.8 (<0.0001)	97.7	–0.415	0.0015	decline

Note:[a]U = unregulated; R = regulated; LEB–Lake Eyre Division, MDB – Murray-Darling Division

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Analyses of the overall composition of waterbird communities in the selected wetlands indicated that there was a difference in the responses of regulated and unregulated wetlands over the 27-year survey period (Table 15). All of the regulated wetland systems—Lowbidgee, Macquarie Marshes, Menindee Lakes and Lake Moondarra—displayed significant changes in overall species abundances over time. In contrast only two of five unregulated wetland systems (Naracoorte and Paroo/Cuttaburra) showed significant changes in waterbird communities (Table 15). There was insufficient data for two unregulated wetlands to allow for analysis. Among these wetlands, which had globally significant differences in species abundances, the largest contrasts were between 1983–1989 and 2000–2009, suggesting a long-term shift in species composition in these wetlands. Compositional changes were particularly pronounced in the Macquarie Marshes and Lowbidgee where there were changes over time in the community composition, reflecting differences between later periods and earlier periods of the survey (See Figures 53 and 59).

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Table 15: An analysis of changes in waterbird community composition using global (across all wetlands) and pairwise ANOSIM comparisons of the abundance of waterbird species between years versus among (decades) within 11 selected wetlands, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008, and significant differences among years.

Some wetlands held water infrequently and decadal comparisons were not possible.

Wetland[a]	*Levels*	*R Statistic*	*P*
Naracoorte (U, MDB)	all	0.056	0.164
	1983–89, 1990–99	–0.045	0.651
	1983–89, 2000–08	0.236	0.002*
	1990–99, 2000–08	0.028	0.263
Lake Galilee (U, LEB)	all	0.035	0.194
	1983–89, 1990–99	0.046	0.182
	1983–89, 2000–08	0.100	0.080
	1990–99, 2000–08	–0.068	0.812
Mumbleberry & Torquinie	all	0.389	0.057
(U, LEB)	1983–89, 1990–99	-	-
	1983–89, 2000–08	-	-
	1990–99, 2000–08	-	-
Lake Eyre (U, LEB)	all	0	0.667
	1983–89, 1990–99	-	-
	1983–89, 2000–08	-	-
	1990–99, 2000–08	-	-
Cooper Creek (U, LEB)	all	0.217	0.092
	1983–89, 1990–99	0.241	0.171
	1983–89, 2000–08	0.259	0.143
	1990–99, 2000–08	0.259	0.200
Lake Hope (U, LEB)	all	0.272	0.053
	1983–89, 1990–99	0.636	0.095
	1983–89, 2000–08	0.364	0.190
	1990–99, 2000–08	0.108	0.175
Paroo & Cuttaburra	all	0.072	0.124
(U,MDB)	1983–89, 1990–99	0.027	0.335
	1983–89, 2000–08	–0.017	0.540
	1990–99, 2000–08	0.153	0.050*
Macquarie Marshes	all	0.235	0.003*
(R, MDB)	1983–89, 1990–99	0.173	0.051
	1983–89, 2000–08	0.356	0.005*
	1990–99, 2000–08	0.214	0.01*
Menindee Lakes	all	0.185	0.002*
(R, MDB)	1983–89, 1990–99	0.030	0.316
	1983–89, 2000–08	0.197	0.057
	1990–99, 2000–08	0.311	0.002*
Lowbidgee (R, MDB)	all	0.169	0.018*
	1983–89, 1990–99	0.017	0.510
	1983–89, 2000–08	0.429	0.004*
	1990–99, 2000–08	0.097	0.120
Lake Moondarra (R, LEB)	all	0.174	0.004*
	1983–89, 1990–99	0.214	0.012*
	1983–89, 2000–08	0.191	0.008*
	1990–99, 2000–08	0.091	0.087

Note:[a]U = unregulated; R = regulated; LEB–Lake Eyre Division, MDB – Murray–Darling Division

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Table 16: Functional group relative abundance and variability within key wetland systems using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2009.

(See Appendix A for composition of different functional groups. CV = coefficient of variation).

Wetland	*Ducks*		*Herbivores*		*Large wading birds*		*Piscivores*		*Shorebirds*	
	range	*CV%*	*range*	*CV%*	*range*	*CV%*	*range*	*CV%*	*range*	*CV%*
Lake Moondarra	278–24 264	107	35–24 532	118	11–615	98	218–2541	57	0–1055	114
Lake Galilee	0–1 098 345	306	0–358 860	291	0–7515	206	0–6150	129	0–23 385	182
Mumbleberry & Torquinie	4043–136 957	66	0–20 220	119	0–1096	68	25–5982	105	516–48 052	101
Lake Eyre	0–14 915	115	0–39	173	0–0	0	491–23 279	160	2160–92 922	143
Cooper Creek	1806–69 208	96	173–30 754	125	0–740	203	222–7710	106	25–8674	114
Lake Hope	45–88 633	180	0–11 968	132	0–114	188	0–19218	199	0–3921	128
Paroo & Cuttaburra	125–60 531	109	7–16 901	136	0–7945	163	0–9354	151	10–14 785	165
Macquarie Marshes	0–52 214	266	0–3976	164	1–24 973	167	0–2860	175	0–2242	223
Menindee Lakes	0–100 737	224	0–30 004	185	0–1034	138	4–15 401	129	0–9023	349
Lowbidgee	103–112 108	130	129–55 104	169	16–47 575	176	163–23 342	136	0–26 654	229
Naracoorte	211–305 408	264	58–115 561	277	0–8078	236	1–19 075	179	23–10 159	130

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Lake Moondarra

Waterbird numbers in Lake Moondarra, in north-western Queensland, tended to oscillate around the long-term mean for this site, although high numbers were particularly evident during early years of the survey period (Figure 31). There was no evidence of a temporal trend in waterbird abundance in this wetland and waterbird numbers were poorly explained by the model developed using wetland area during the survey period (Table 14, Figure 31). In terms of waterbird community composition, there was considerable clustering over the survey period, reflecting the similarity of the waterbird community of Lake Moondarra over the 27-years (Figure 32). There were some outliers to this pattern, including the years 1986, 1988, 1989 and 2008 (Figure 32). There was considerable variation in the functional composition of the waterbird community at Lake Moondarra, although ducks tended to dominate in most years, followed by herbivores and piscivores (Figure 33, Table 16).

Figure 31: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Lake Moondarra, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

The long-term mean total waterbird numbers is represented by the dashed line, at 30 068. Modelled data represent a Poisson GAM model of waterbird counts on Lake Moondarra, based on relationship with inundated area in relation to actual counts.

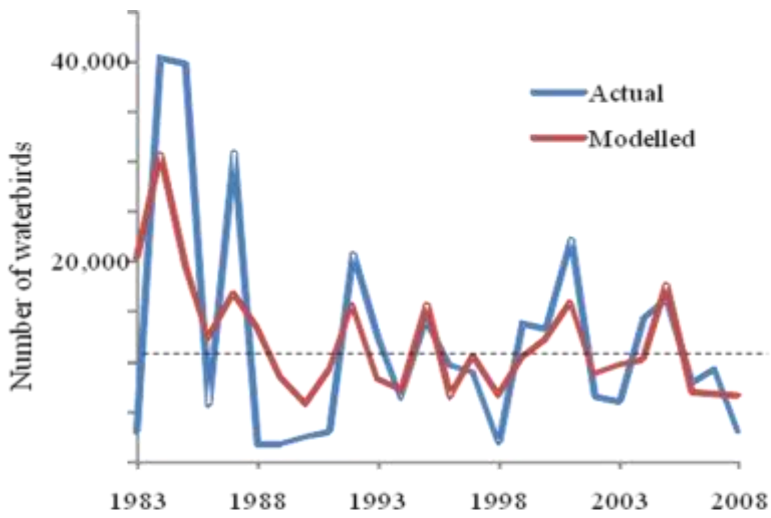

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Figure 32: Multidimensional scaling showing changes in the waterbird community from aerial surveys of eastern Australia, 1983–2008, on Lake Moondarra.

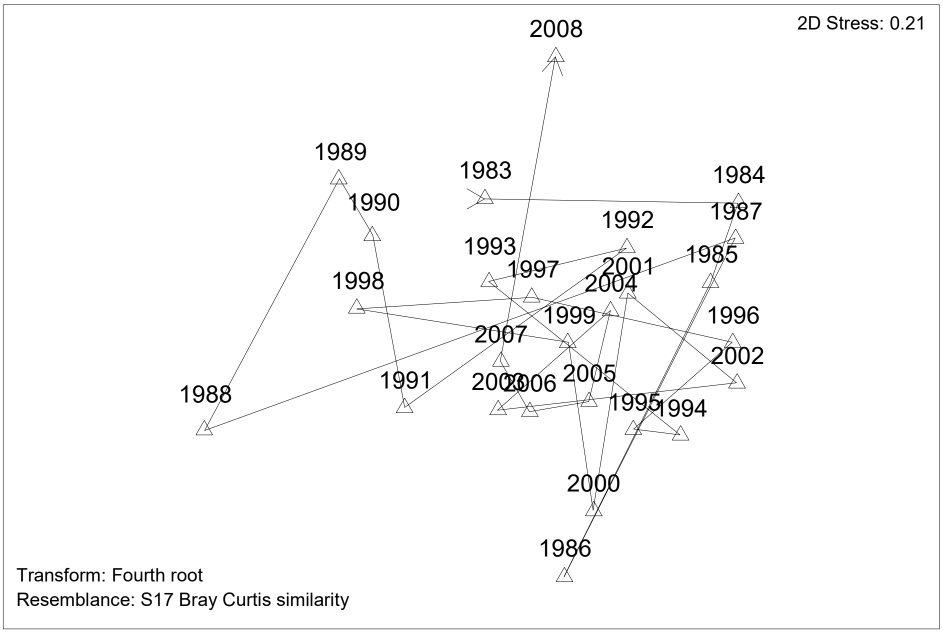
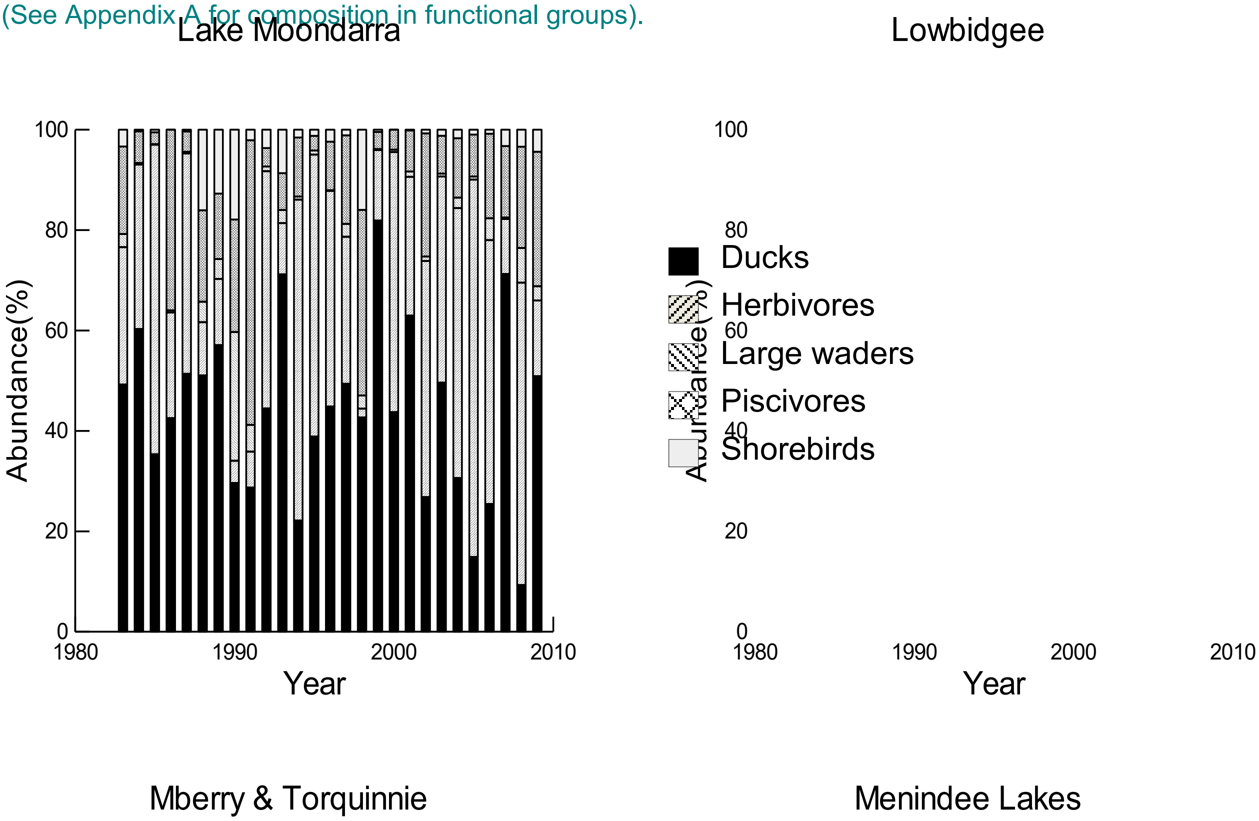


Figure 33: Relative abundance of waterbird functional groups within Lake Moondarra using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008. (See Appendix A for composition in functional groups).



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Lake Galilee

Lake Galilee holds considerable concentrations of waterbirds when it is inundated. (Photo: RT Kingsford)

There was a reasonable relationship between wetland area and rainfall for Lake Galilee, a saline temporary wetland that fills from local creek systems (Figure 34) and this was reflected by the high goodness of fit for the explanatory model of waterbird abundance developed using wetland area and rainfall over the survey period for this wetland (Figure 34, Table 14). No evidence of a trend over time was detected, however, (Table 14) although annual counts were dominated by an extremely large count in 1984 that resulted in most other years being below the long-term mean for waterbird numbers at this site (Figure 35). 1984 was also a clear outlier in terms of the composition of waterbird communities at Lake Galilee over the survey period (Figure 36) as were 1987 and 1988 although in these cases this was due to low waterbird abundance. In other years, waterbird community composition appeared to be relatively similar (Figure 36). Ducks also dominated the functional composition of the Lake Galilee waterbird community during the survey period (Figure 37, Table 16).

Figure 34: Relationship between rainfall and wetland area estimated for Lake Galilee during annual aerial surveys of waterbirds across eastern Australia, 1983–2009.
(Dashed lines indicate 95% CI).

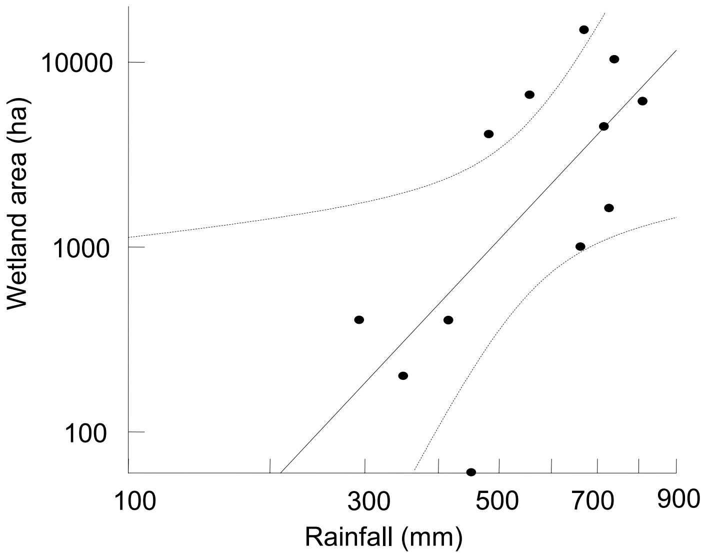

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Figure 35: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Lake Galilee, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

The long-term mean total waterbird numbers is represented by the dashed line, at 116 883. Counts of zero birds show when the wetland was dry. Modelled data represent a Poisson GAM model of waterbird count in Lake Galilee based on relationship with rainfall and inundated area in relation to actual counts.

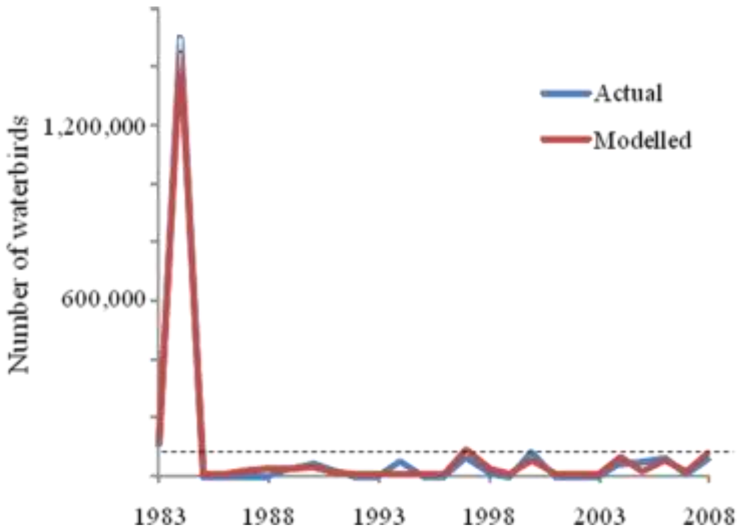
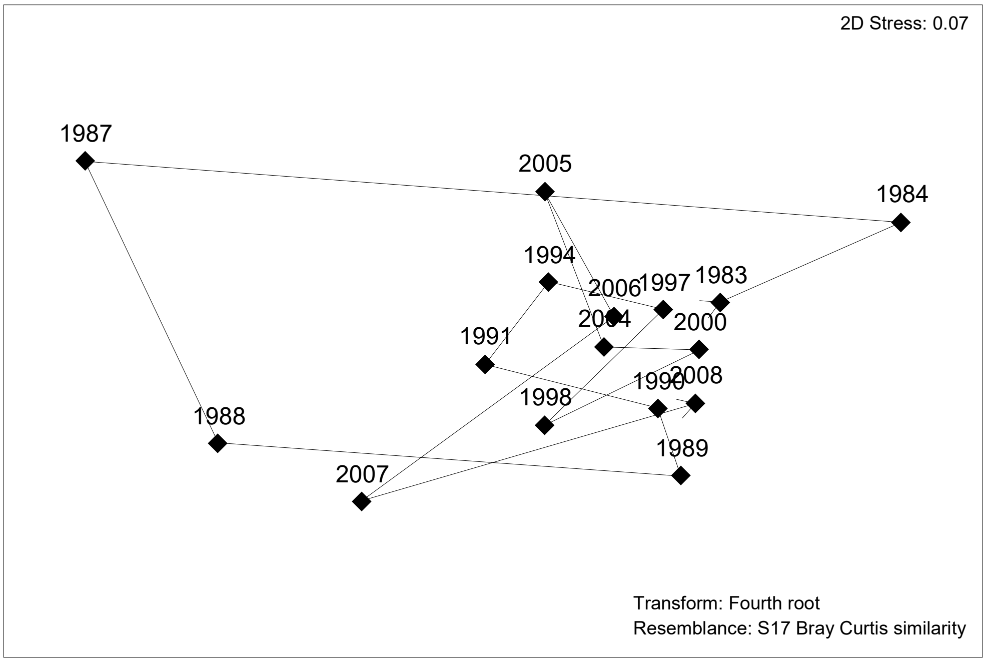


Figure 36: Multidimensional scaling showing changes in the waterbird community using Lake Galilee over time during aerial surveys of waterbirds across eastern Australia, 1983–2008.



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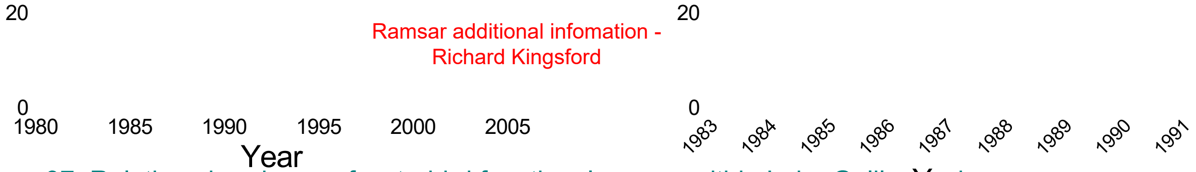
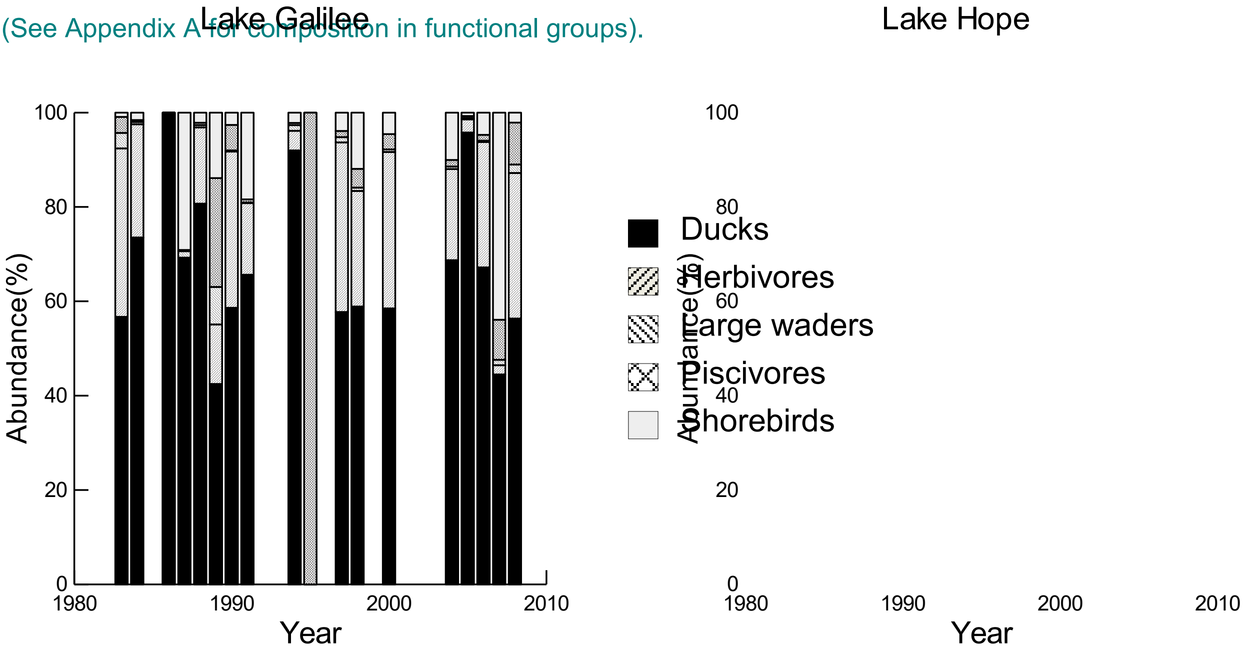


Figure 37: Relative abundance of waterbird functional groups within Lake Galilee, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



Lakes Mumbleberry and Torquinie

Lakes Mumbleberry and Torquinie in north-western Queensland are temporary saline lakes that fill from local rainfall and flows from the Mulligan River, and were dry in most years during the survey period (Figure 38). Consequently, these lakes had relatively few counts (i.e. n = 7) during the 27-year period (Figure 38). Waterbird abundance was well explained, however, by the model developed using wetland area although there was no evidence of any temporal trend (Table 14, Figure 38). Two extreme years exerted considerable influence on the patterns of waterbird community composition on these lakes, due to dry conditions and low waterbird abundances in 2005 and, to a lesser degree, in 2007 (Figure 39). During the years when there was sufficient water in these lakes, however, waterbird community composition was relatively similar (Figure 39). Ducks comprised up to 80% of the waterbird community in these lakes but in some years, e.g. 1995, a large shorebird community was also present (Figure 40, Table 16).

Figure 38: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on lakes Mumbleberry and Torquinie, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

The long-term mean total waterbird numbers is represented by the dashed line, at 37 572. Modelled data represent a Poisson GAM model of waterbird counts on Lakes Mumbleberry and Torquinie, based on relationship with rainfall in relation to actual counts.

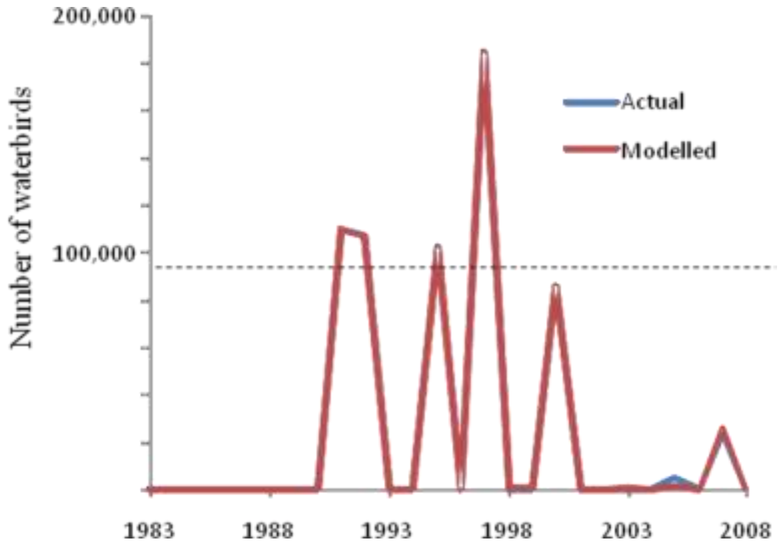


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Figure 39: Multidimensional scaling showing changes in the waterbird community using lakes Torquinie and Mumbleberry during aerial surveys of eastern Australia, 1983–2008.

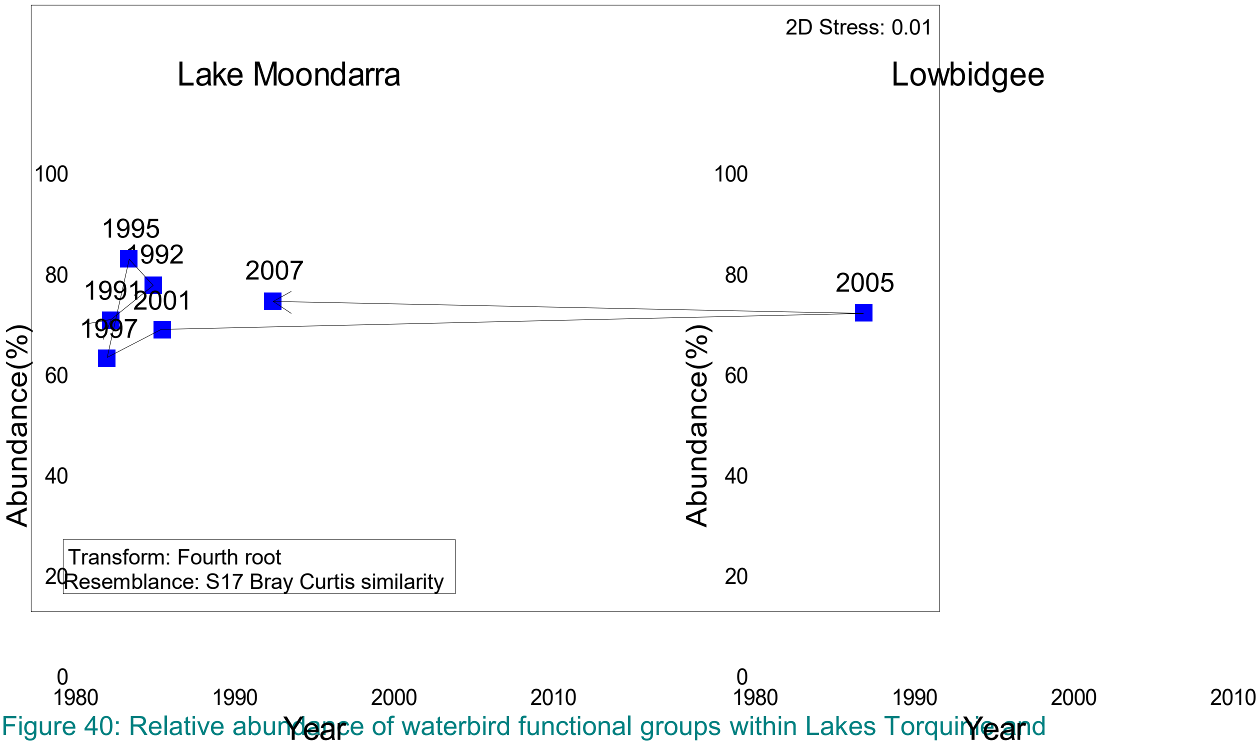
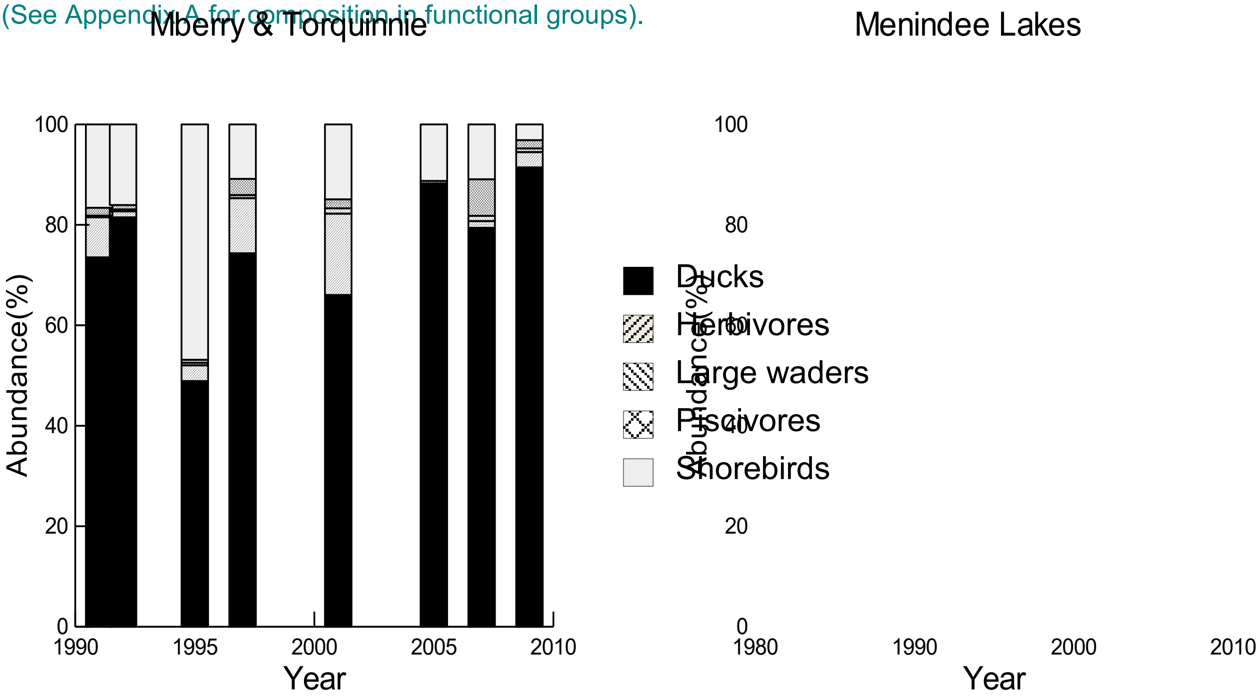


Figure 40: Relative abundance of waterbird functional groups within Lakes Torquinie and Mumbleberry, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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Lake Eyre

Lake Eyre supports large concentration, including breeding birds, but only when there is sufficient water for salinity to be reduced (Photo: RT Kingsford)

Lake Eyre was dry in most years but was notable for supporting very high numbers of waterbirds when water was present (Figure 41). No significant relationships were detected between wetland area, rainfall and waterbird numbers although the explanatory model developed had an overall high goodness of fit (Table 14). Identification of long-term trends was difficult because of the low number of data points (i.e. n = 3) although there was a tendency for waterbird numbers to decline over the survey period (Figure 41). Shorebirds formed a relatively high component of the Lake Eyre waterbird communities though ducks and piscivores were also relatively important in some years (Figure 42, Table 16). Given the limited dataset, composition patterns in waterbird communities were not further examined.

Figure 41: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Lake Eyre, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

The long-term mean total waterbird numbers is represented by dashed line, at 49 918. Counts of zero birds show when the wetland was dry. Modelled data represent a Poisson GAM model of waterbird count in Lake Eyre based on relationship with rainfall and inundated area in relation to actual counts.

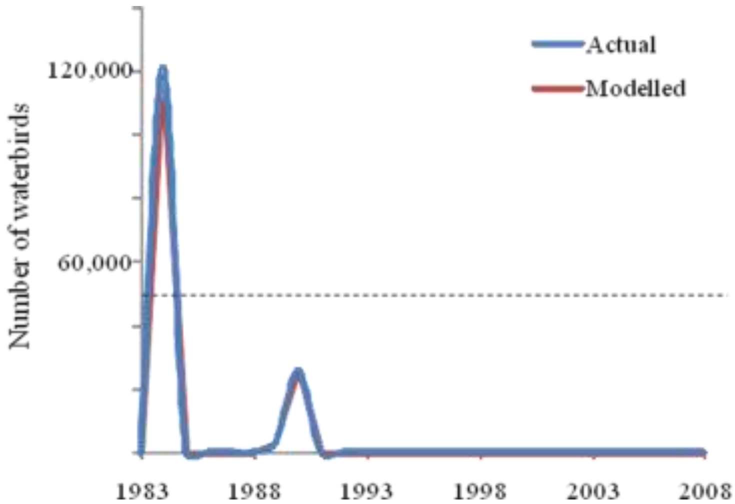

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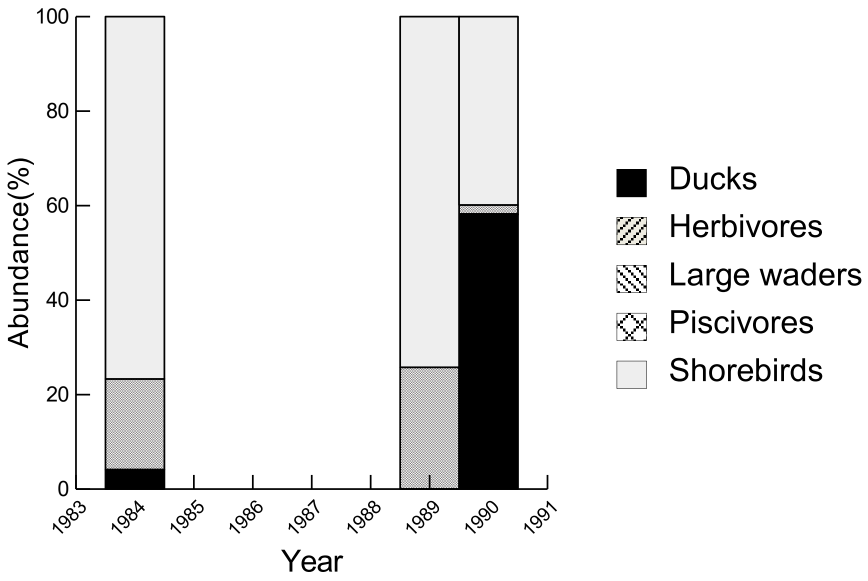
Figure 42: Relative abundance of waterbird functional groups within Lake Eyre, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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Cooper Creek

The Cooper Creek wetlands, in north-eastern South Australia, fill only occasionally, although waterbird abundances can be substantial during these periods (Figure 43). Waterbird abundances were well explained by the model developed using wetland area, flow and rainfall over the 27 year survey period (Table 14). The analyses also indicated a decline in waterbird numbers over time during this period (Table 14). In the Cooper Creek wetlands there was little similarity of waterbird community composition between flood periods (Figure 44). Duck species dominated the waterbird community, however, followed by herbivores and piscivores (Figure 45, Table 16).

Figure 43: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Cooper Creek wetlands, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

Long-term mean total waterbird numbers is represented by the dashed line, at 33 670. Counts of zero birds show when the wetlands were dry. Modelled data represent a Poisson GAM model of waterbird count in the Cooper Creek based on relationship with flow, rainfall and inundated area in relation to actual counts.

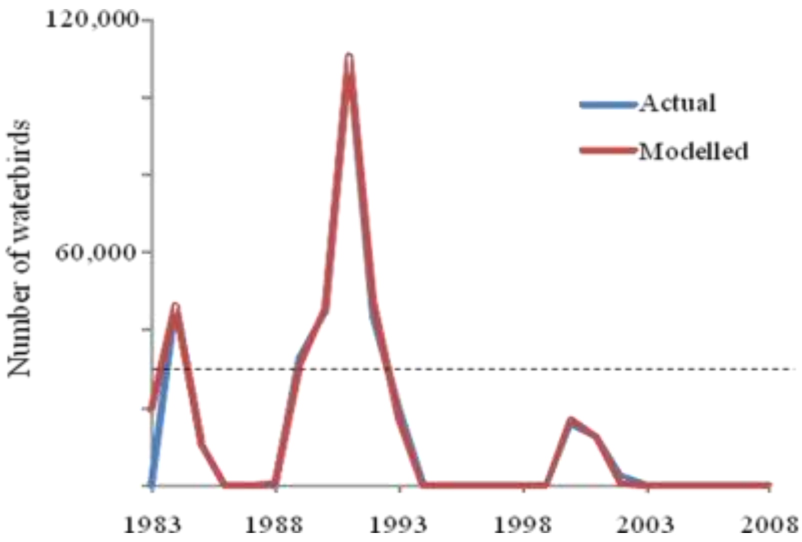

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Figure 44: Multidimensional scaling showing changes in the waterbird community using Cooper Creek wetlands from aerial surveys of eastern Australia when the wetland had water, 1983–2008.

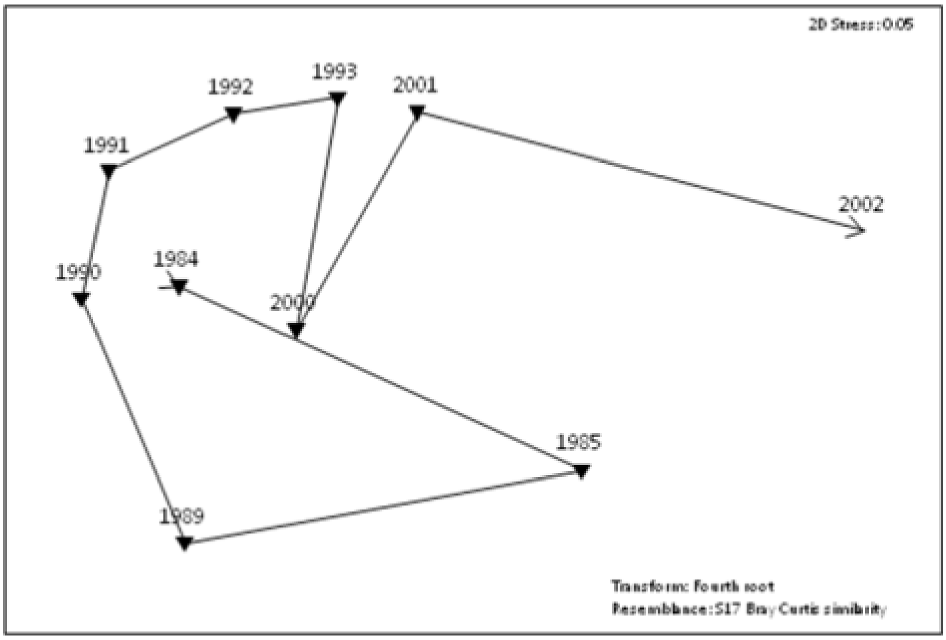
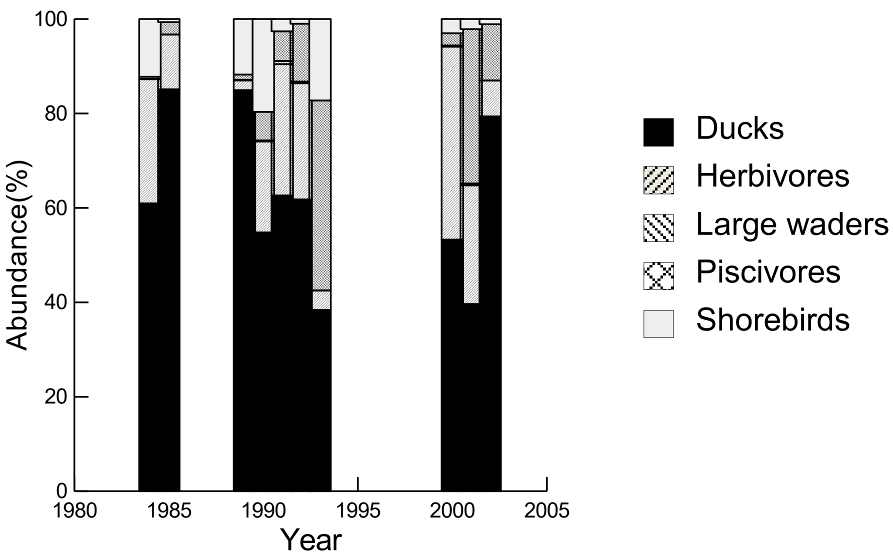


Figure 45: Relative abundance of waterbird functional groups within Cooper Creek wetlands using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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Lake Hope

Lake Hope, in north-eastern South Australia, also receives water from Cooper Creek and waterbird abundances at this wetland over the survey period were well explained by the model developed using wetland area and flow (Table 14, Figure 46). There were clear peaks in waterbird abundance during periods when the lake held water and waterbird numbers declined as the lake dried (Figure 46). No overall long-term trends in waterbird numbers were detected (Table 14). Waterbird community composition tended to be relatively similar in all years that the lake held water, although consecutive years were often more closely related (Figure 47). Overall, the most abundant functional groups contributing to the waterbird community on Lake Hope during the survey period were ducks, herbivores and piscivores (Figure 48, Table 16). In some years, ducks dominated but there was also a significant shorebird component in other years (Figure 48).

Lake Hope will hold water up to four years once it has filled, providing waterbird habitat when many other wetlands have dried up in the Cooper Creek system (Photo: RT Kingsford)

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Figure 46: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Lake Hope, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

Long-term mean total waterbird numbers is represented by the dashed line, at 21 343. Modelled data represent a Poisson GAM model of waterbird counts on Lake Hope, based on relationship with rainfall, flow and inundated area in relation to actual counts.

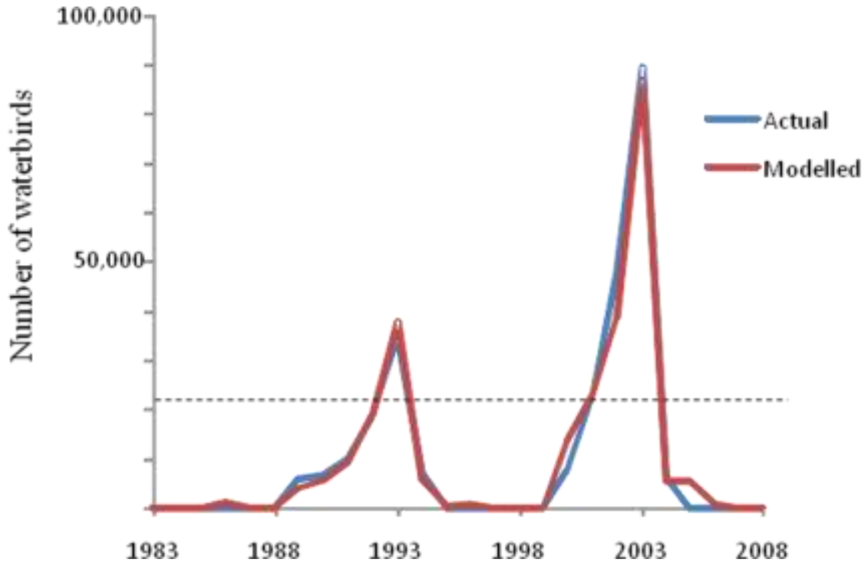


Figure 47: Multidimensional scaling showing changes in the waterbird community from aerial surveys of eastern Australia, 1983–2008 on Lake Hope.

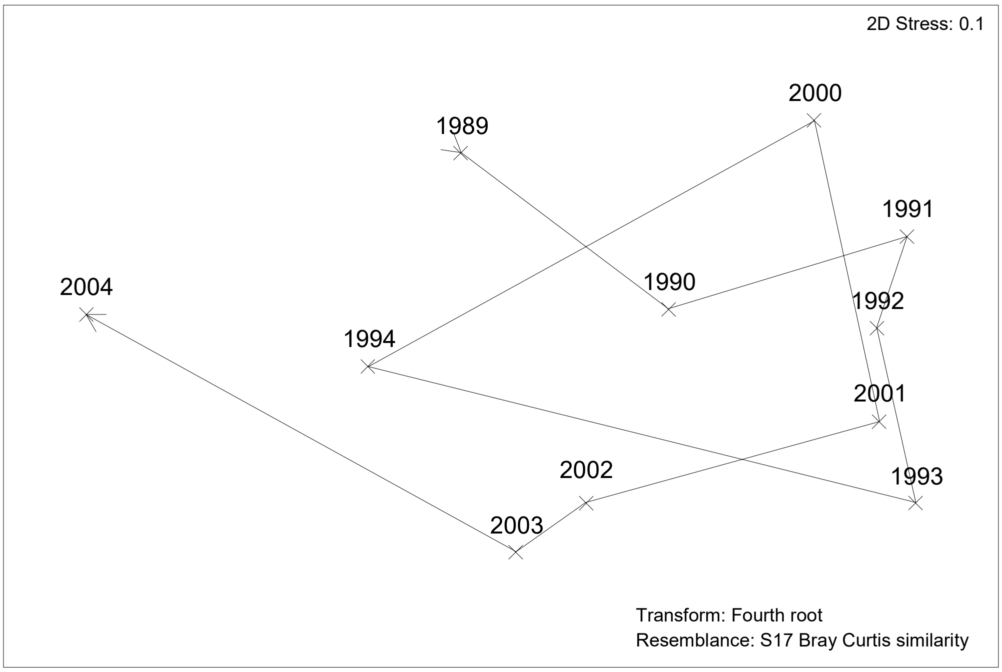
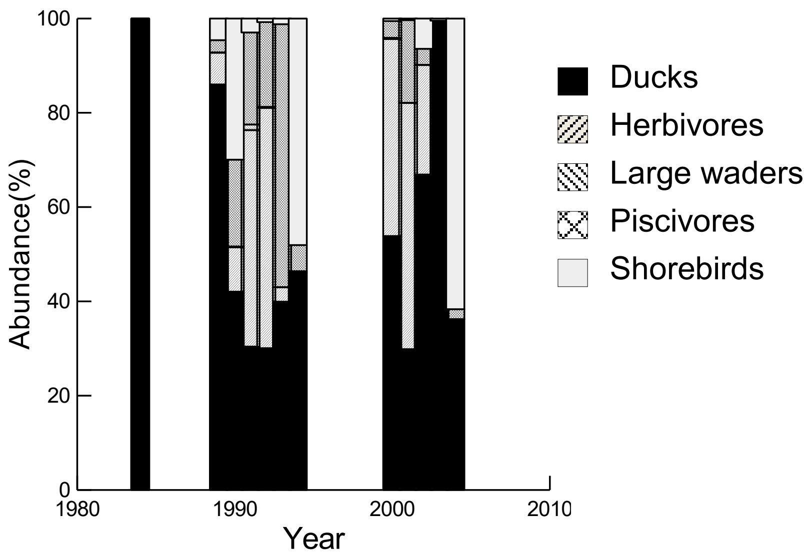


Figure 48: Relative abundance of waterbird functional groups on Lake Hope, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008

(See Appendix A for composition in functional groups).



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Paroo and Cuttaburra Channels

Extensive lake systems can be filled by the Paroo River when it floods, providing habitat for waterbirds for a few years (Photo: RT Kingsford)

Waterbird abundance over the survey period in the Paroo and the Cuttaburra Channels of far western New South Wales, which rely on flows from the Paroo River, were reasonably well explained by the model developed using wetland area (Table 14, Figure 49). Furthermore, there was evidence of a decline in waterbird numbers in the 27-year period, although this related primarily to the first data point in 1983 (Table 14, Figure 49. There were relatively few clear temporal changes in the composition of the waterbird community of this wetland system over time although there were a few years in which community composition differed particularly from others, i.e. 1986, 1996 and 2005 (Figure 50). All of the functional groups were generally represented in the waterbird community of this wetland system (Figure 51, Table 16). Ducks dominated in some years but herbivores and piscivores were more prevalent in other years (Figure 51).

Figure 49: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Paroo–Cuttaburra wetlands, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

Long-term mean total waterbird numbers is represented by the dashed line, at 30,068. Modelled data represent a Poisson GAM model of waterbird counts on Paroo–Cuttaburra wetlands, based on relationship with rainfall, flow and inundated area in relation to actual counts.

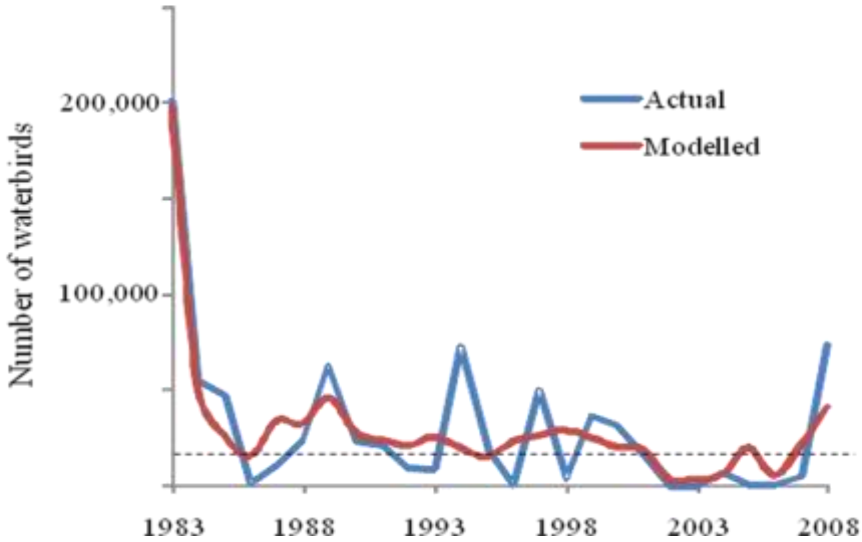

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Figure 50: Multidimensional scaling showing changes in the waterbird community from aerial surveys of eastern Australia, 1983–2008, on Paroo River and Cuttaburra Channel wetlands.

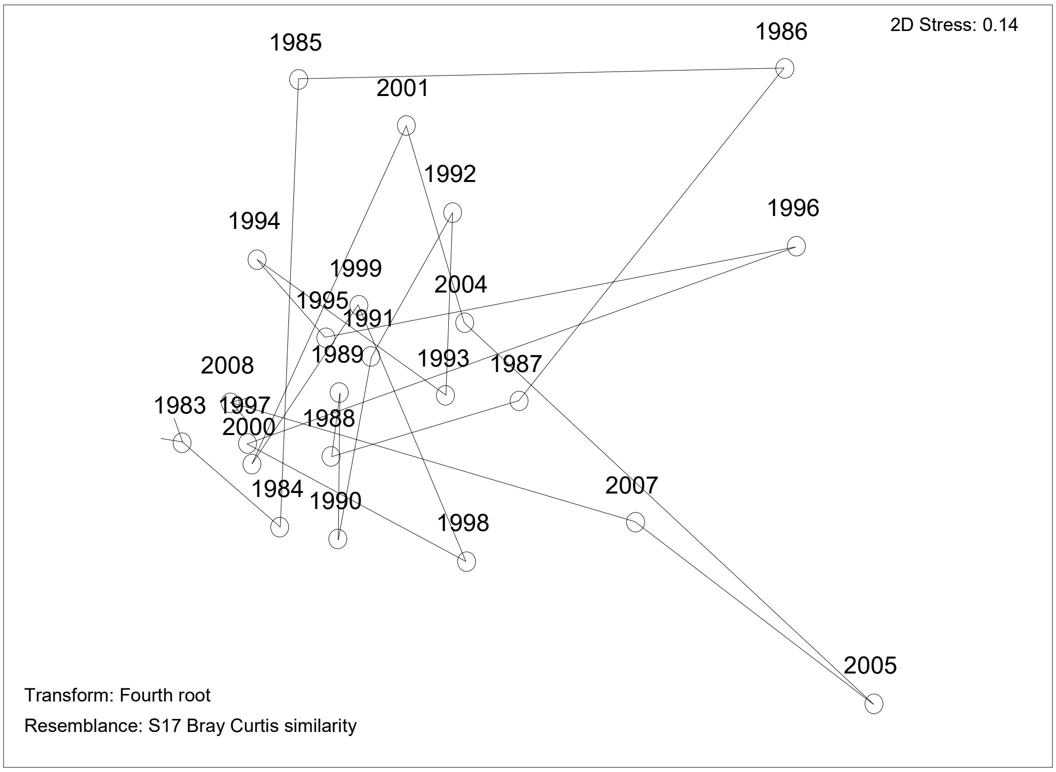
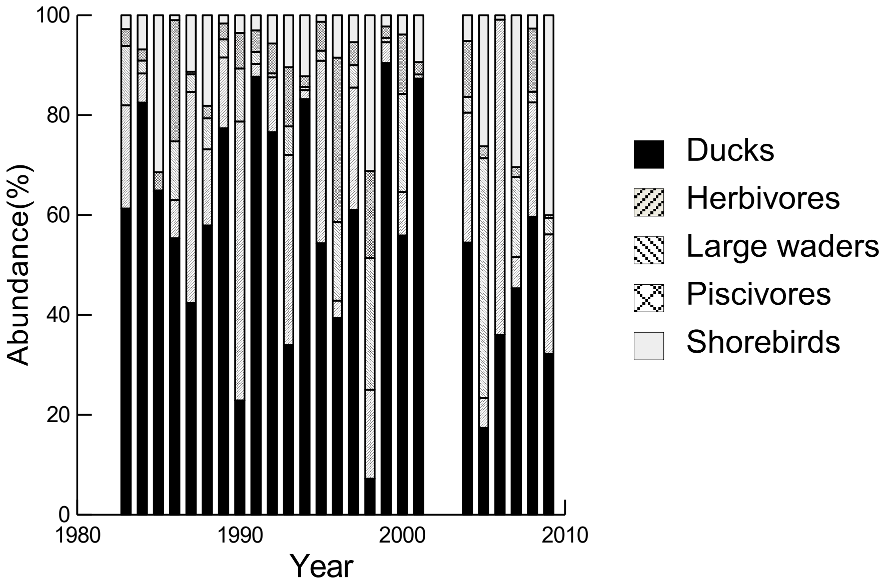


Figure 51: Relative abundance of waterbird functional groups within Paroo and Cuttaburra Channels, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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Macquarie Marshes

Floodplains of the Macquarie Marshes where water of the Macquarie River spreads out over extensive areas (Photo: RT Kingsford)

The Macquarie Marshes include temporary floodplain and semi-permanent riverine wetlands on the lower floodplain of the Macquarie River in New South Wales. Waterbird abundance in this wetland system over the survey period was reasonably well explained by the model using wetland area and flow (Table 14, Figure 52). There was evidence of a significant decline in waterbird numbers over time here with few recent counts exceeding the long-term mean of waterbird abundance over the 27-year survey period for this wetland (Table 14, Figure 52). This long-term decline in abundance was also reflected in patterns of waterbird community composition, which tended to be relatively similar in the 1980s and 1990s but has changed considerably since 2000 (Figure 53). Duck, herbivore and large wading birds were all reasonably important in the waterbird community of this wetland systems but there were relatively few piscivore or shorebird species represented (Figure 54, Table 16).

Figure 52: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Macquarie Marshes, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

Long-term mean total waterbird numbers is represented by the dashed line, at 8 209. Modelled data represent a Poisson GAM model of waterbird counts on Macquarie Marshes, based on relationship with rainfall, flow and inundated area in relation to actual counts.

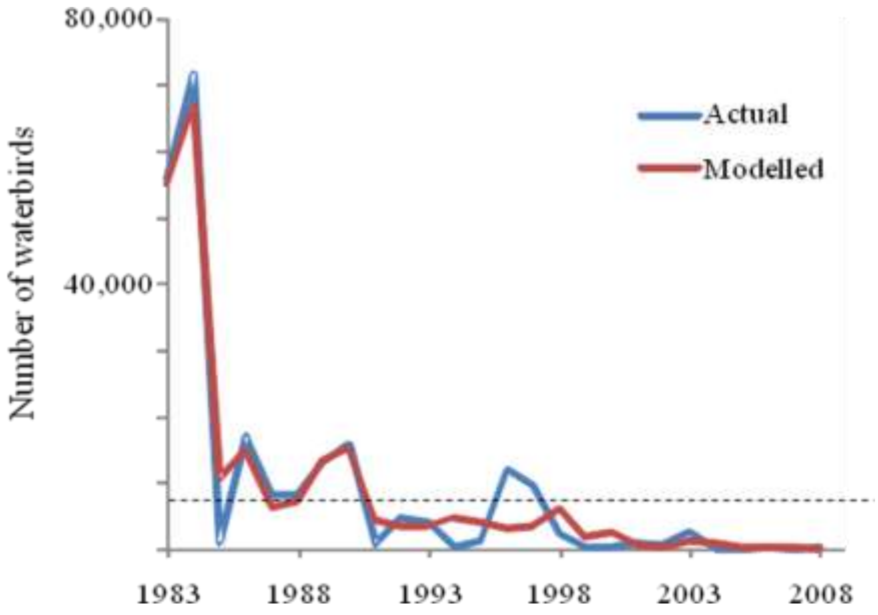

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Figure 53: Multidimensional scaling showing changes in the waterbird community from aerial surveys of eastern Australia, 1983–2008, for the Macquarie Marshes.

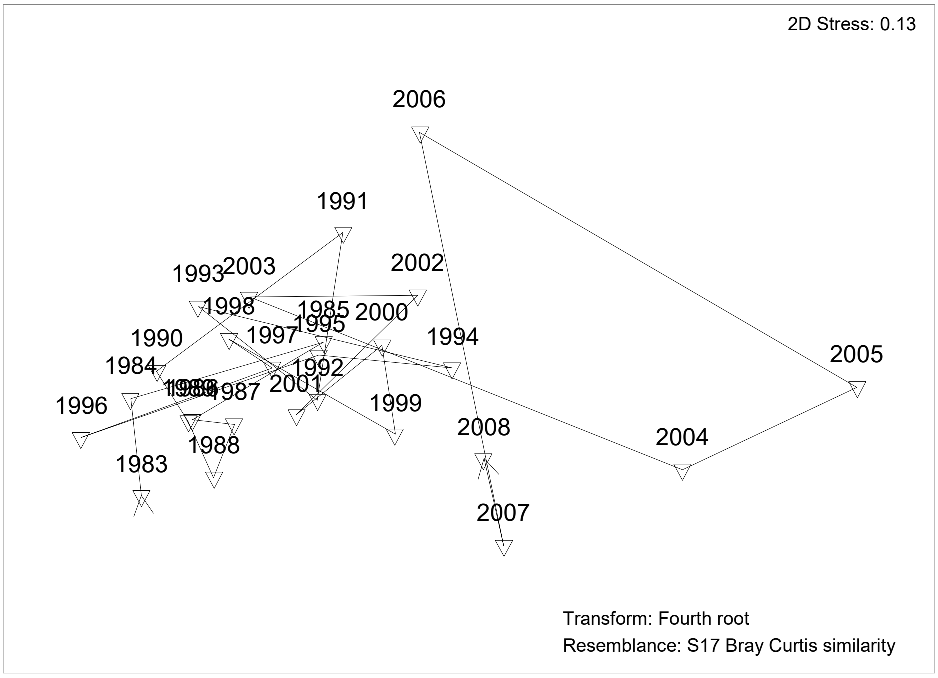
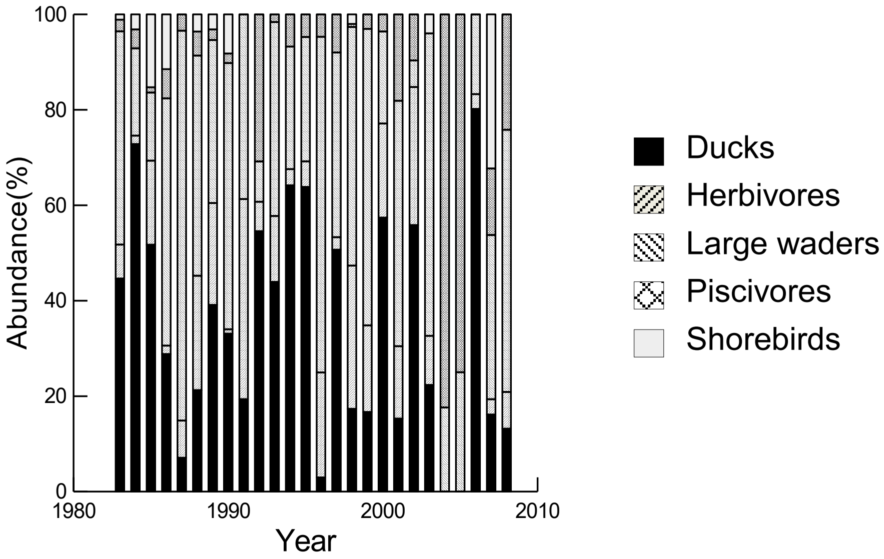


Figure 54: Relative abundance of waterbird functional groups within Macquarie Marshes, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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Menindee Lakes

Menindee Lakes, in far western New South Wales, receive flows from the Darling River. Waterbird abundance in this wetland system over the survey period was well explained by the model developed using wetland area and flow (Table 14, Figure 55). A significant decline in waterbird numbers was detected in this wetland over the survey period with a large peak at the beginning of the period and another in the mid-1990s, after which time, abundances have remained below the long-term mean for this site despite a small increase in the early 2000s (Figure 55). Temporal patterns in waterbird community composition in the Menindee Lakes reflected this long-term trend in waterbird numbers (Figure 56) with waterbird communities surveyed during the 1980s and 1990s being relatively distinct from those surveyed during the 2000s (Figure 56). Ducks, piscivores and shorebirds were the most abundant functional groups on the Menindee Lakes during the survey period though most groups exhibited considerable variability in relative abundance among years (Figure 57, Table 16).

Figure 55: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Menindee Lakes, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

Long-term mean total waterbird numbers is represented by the dashed line, at 13 567. Counts of zero birds show when the wetlands were dry. Modelled data represent a Poisson GAM model of waterbird counts on Menindee Lakes, based on relationship with rainfall, flow and inundated area in relation to actual counts.

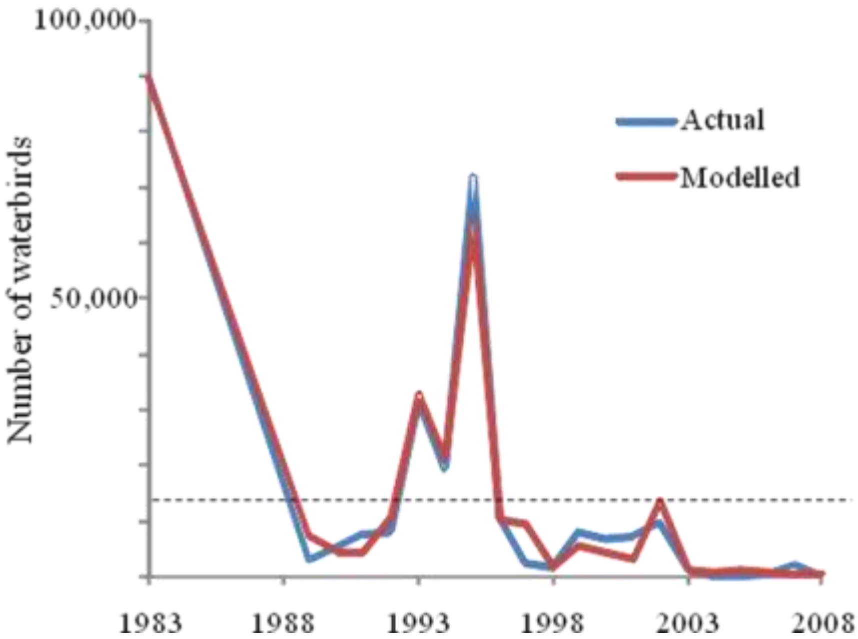

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Figure 56: Multidimensional scaling showing changes in the waterbird community from aerial surveys of eastern Australia, 1983–2008 on Menindee Lakes.

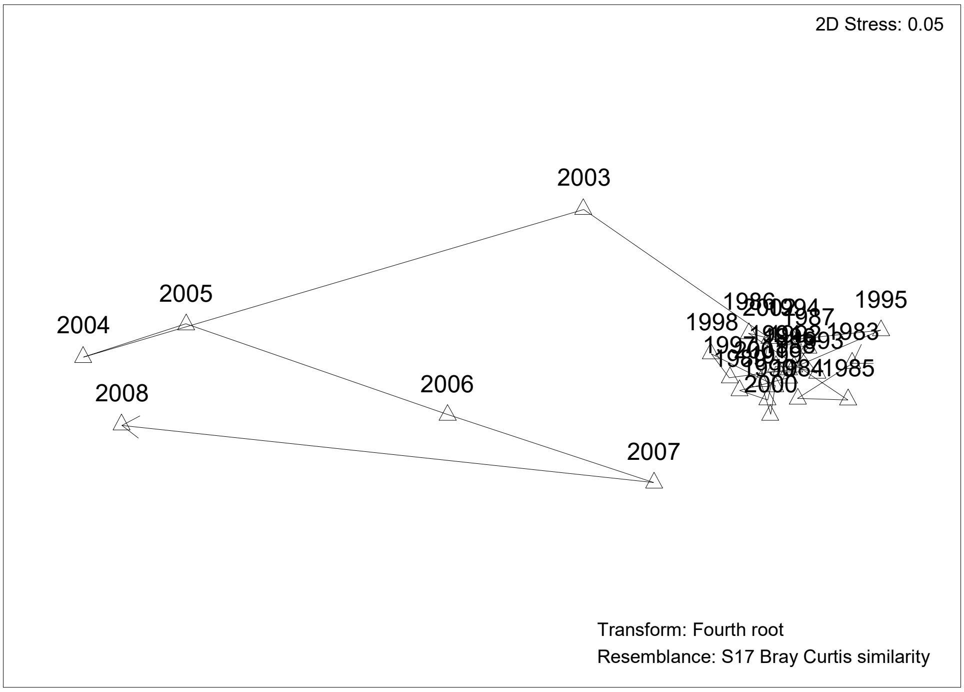
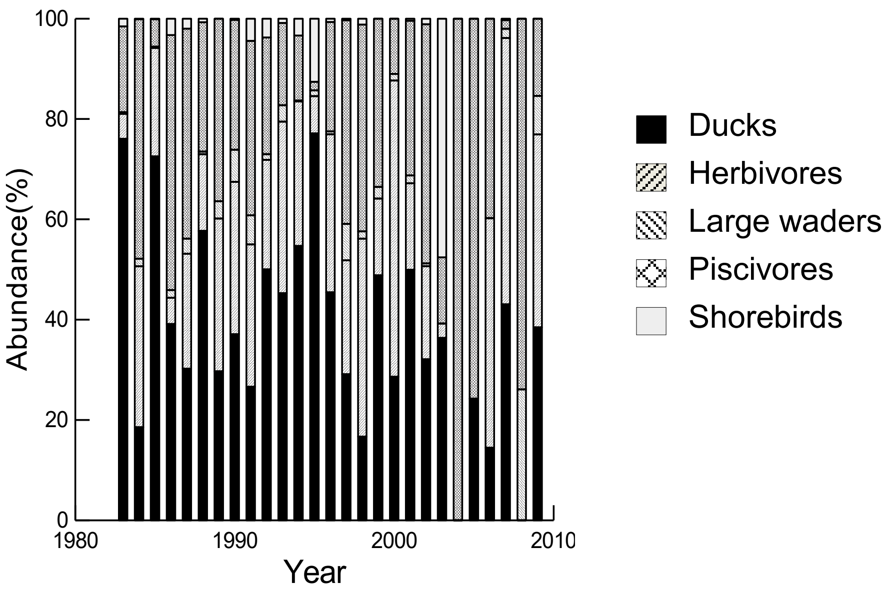


Figure 57: Relative abundance of waterbird functional groups within Menindee Lakes, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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Lowbidgee wetlands

Lowbidgee wetlands are an important area, particularly for breeding ibis species, such as the straw-neck ibis (Photo: RT Kingsford)

The Lowbidgee wetlands include temporary floodplain and semi-permanent riverine wetlands on the lower floodplain of the Murrumbidgee River in New South Wales. Waterbird abundance in this wetland system was reasonably well explained by the model developed using wetland area and flow over the survey period (Table 14, Figure 58). There was evidence of a significant decline in waterbird numbers in the Lowbidgee wetlands over the survey period, despite variability (Table 14, Figure 58).

This steady decline in overall waterbird abundance was reflected by significant changes over time in the waterbird community composition, which included a general clustering of waterbird communities over recent years (Figure 59). The functional composition of the waterbird community also varied considerably among years with ducks dominating in some years and herbivores, piscivores and large wading birds were important in others (Figure 60, Table 16).

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Figure 58: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Lowbidgee wetlands, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

Long-term mean total waterbird numbers is represented by the dashed line, at 49 918. Modelled data represent a Poisson GAM model of waterbird counts on Lowbidgee wetlands, based on relationship with rainfall, flow and inundated area in relation to actual counts.

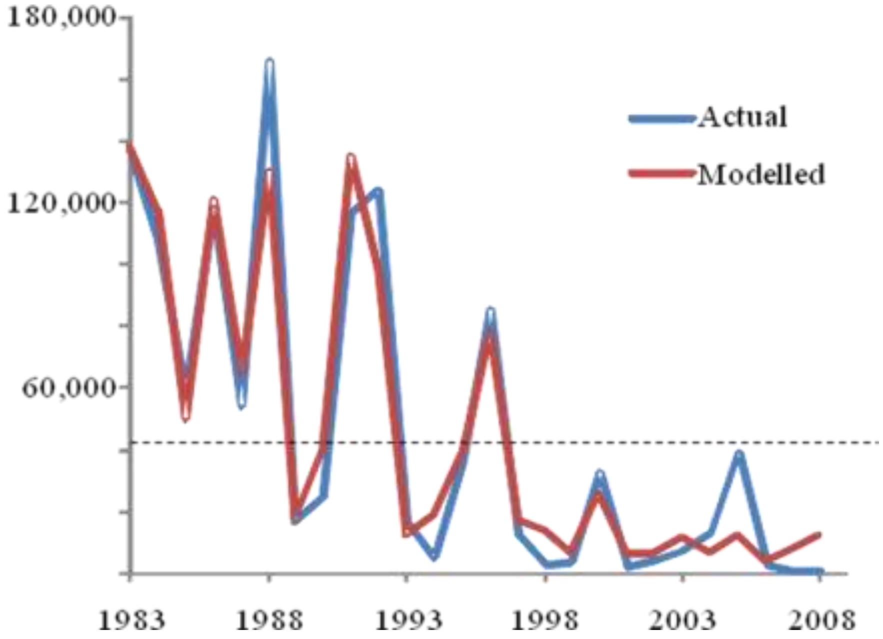

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Figure 59: Multidimensional scaling showing changes in the waterbird community using Lowbidgee waterbird data from aerial surveys of eastern Australia, 1983–2008.

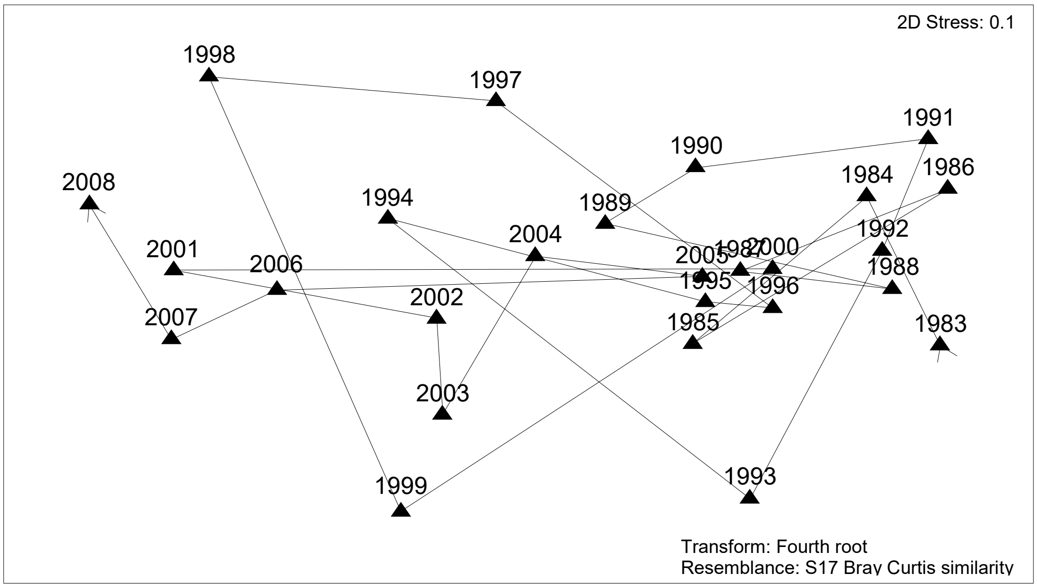
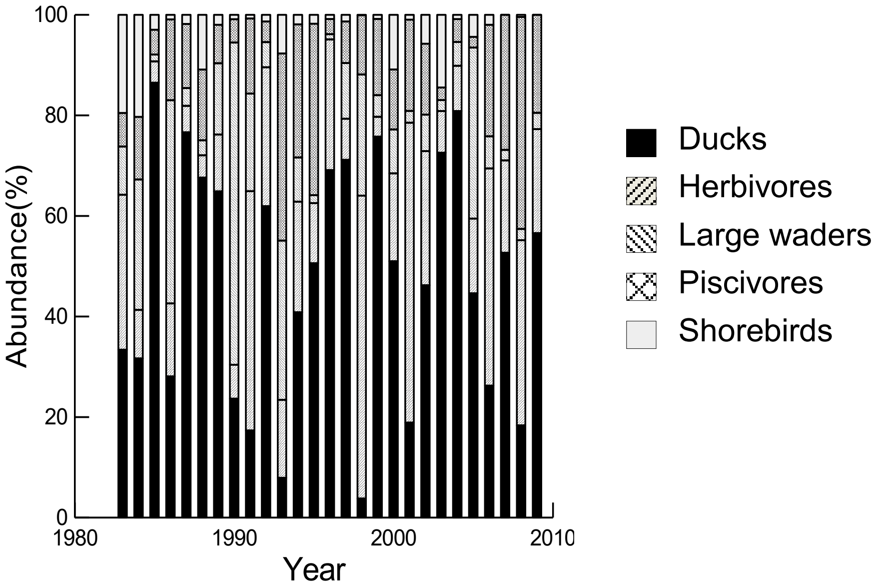


Figure 60: Relative abundance of waterbird functional groups within Lowbidgee, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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Naracoorte wetlands

The Naracoorte wetlands, south of the Coorong in South Australia, fill from local rainfall and waterbird abundance here was explained reasonably well by the model developed using wetland area and local rainfall over the survey period (Table 14, Figure 61). There was also evidence of a significant decline in waterbird numbers in this wetland system over the survey period (Table 14, Figure 61). No clear patterns in community composition were evident, however, although there was some slight clustering during the 1980s (Figure 62). Duck species were generally the dominant functional group, although there was considerable variability in the relative abundance of functional groups between years (Figure 63, Table 16). Herbivores were also numerous in some years and shorebird important in others (Figure 63).

Figure 61: Total number of waterbirds estimated during annual aerial surveys of waterbirds across eastern Australia on Naracoorte wetlands, 1983–2008, showing changes relative to long-term mean when water was in the wetland.

Long-term mean total waterbird numbers is represented by the dashed line, at 37 572. Modelled data represent a Poisson GAM model of waterbird counts on Naracoorte wetlands, based on relationship with rainfall and inundated area in relation to actual counts.

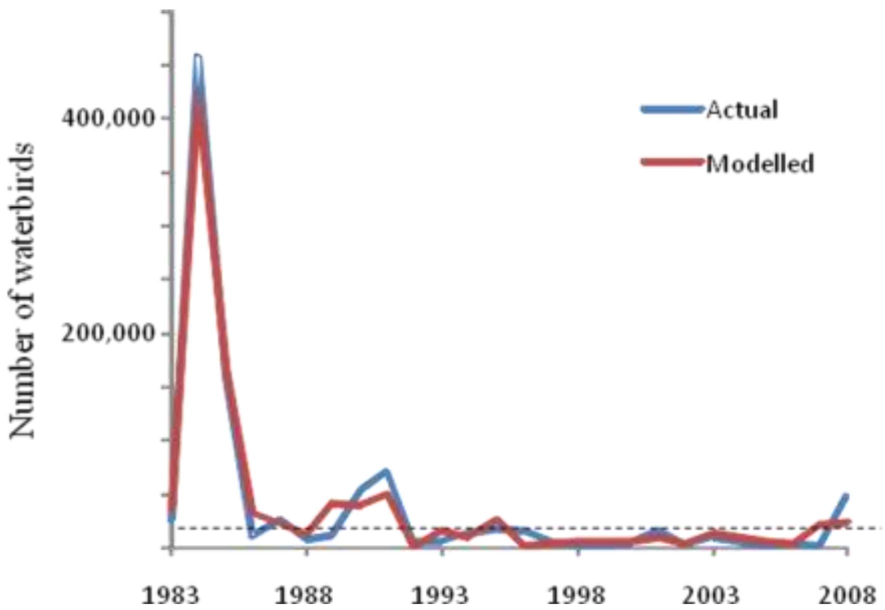

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Figure 62: Multidimensional scaling showing changes in the waterbird community using Naracoorte waterbird data from aerial surveys of eastern Australia, 1983–2008.

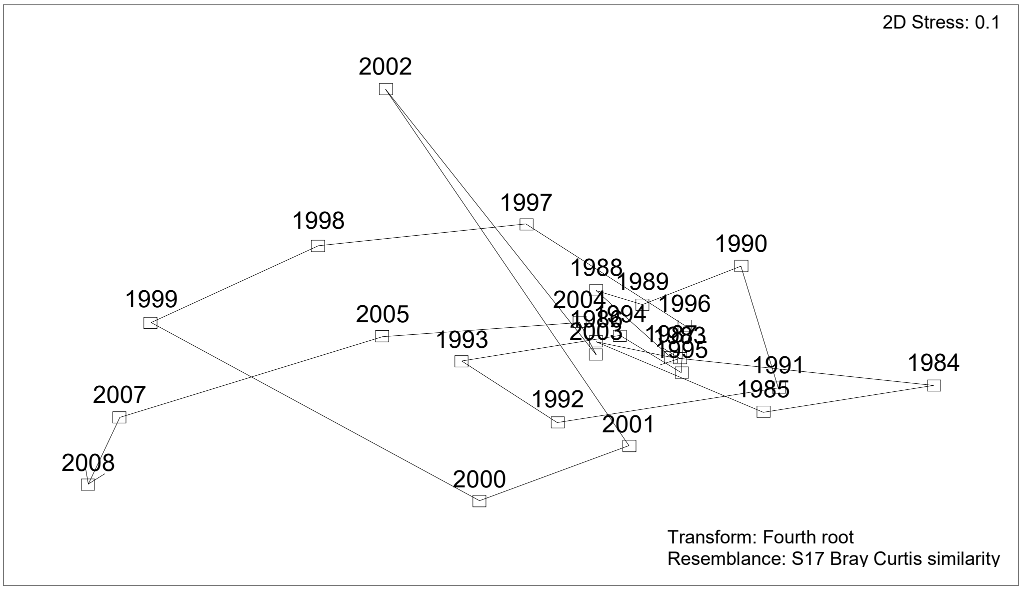
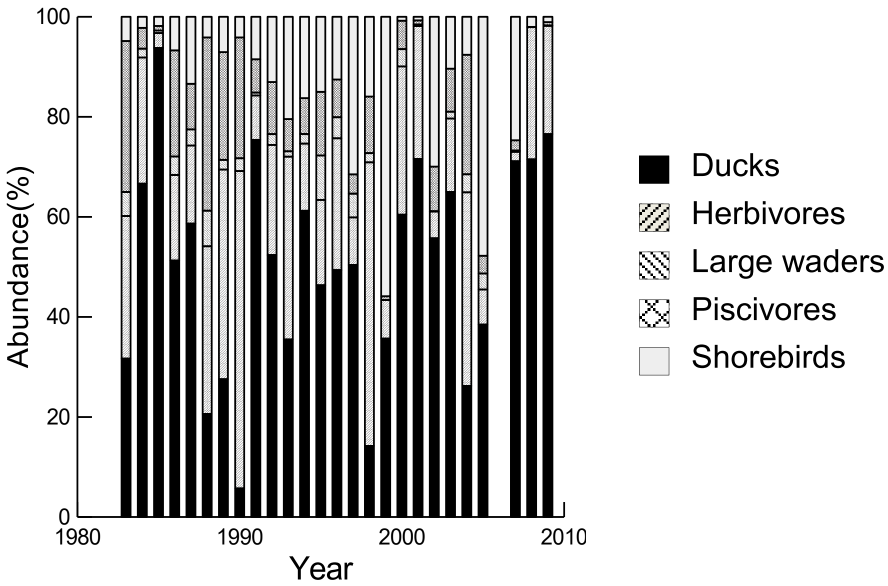


Figure 63: Relative abundance of waterbird functional groups within Naracoorte wetlands, using annual aerial survey data collected from waterbirds across eastern Australia, 1983–2008.

(See Appendix A for composition in functional groups).



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3.4. Discussion

This chapter presents the results of an assessment of long-term trends in waterbird numbers in eastern Australia using the results of the Eastern Australian Aerial Waterbird Survey which has surveyed wetlands in approximately one-third of the continent for 27 years between 1983 and 2007. The specific aims of this assessment were to:

- describe long-term trends in wetland area, waterbird abundance and waterbird breeding at a regional scale across eastern Australia
- determine long-term trends in waterbird abundance, breeding and community composition in key wetlands of eastern Australia
- determine relationships between wetland area, rainfall, river flow and waterbird abundance and breeding in key wetlands across eastern Australia.

Long-term trends across eastern Australia

There was a significant decline in the total numbers of waterbirds counted across eastern Australia over the 27-year survey period from 1983 to 2009. Particularly high numbers of waterbirds were recorded early in this period, i.e. in 1984, but a significant long-term decline in abundance was still apparent when this date was excluded from analyses.

Both wetland area and number of wetlands surveyed fell during the survey period and contributed to the observed reductions in waterbird numbers. Wetland area in the eastern Australian survey region declined significantly from 1983–1984 and then again from 2000 to 2009, the latter period demonstrating the effects of the long dry period that, until recently, had affected eastern Australia since early this century. In contrast, the number of wetlands was highly variable between 1983 and 1999 after which time wetland number declined significantly until 2009 when numbers rose again, almost reaching the long-term mean.

Numbers of breeding waterbirds recorded each year during the survey period exhibited considerable highs and lows that generally corresponded to periods of flooding and drying. Waterbirds typically breed during flood periods, rapidly building up numbers before dispersing during dry times (Frith 1982, Kingsford and Norman 2002; Kingsford et al. 2010) and this pattern was reflected by survey observations. There was evidence, however, of long-term decline in both the number of waterbirds breeding and breeding species in the eastern Australia region over the survey period.

Long-term trends in individual wetlands

Long-term trends were also examined within 10 selected wetlands within the survey region that were identified as being of high importance to waterbirds, based on their overall waterbird numbers during the survey period, as well as for the Macquarie Marshes, which have considerable conservation significance (i.e. as a Ramsar site) and had high waterbird numbers during early survey dates. There was substantial variation in wetland area, waterbird abundance and density across these individual wetlands during the survey period. The number of times each wetland was surveyed also differed since not all of the wetlands held water during each survey date. In general, the regulated wetlands considered have more frequent low flows through regulation than natural wetlands, but have a reduced flood extent and frequency (Kingsford and Thomas 1995).

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Significant long-term decline in waterbird abundance over the 27-year survey period was evident in seven of the 11 individual wetlands considered. These included all of the wetlands within the Murray–Darling drainage division (i.e. Menindee Lakes, the Lowbidgee, Macquarie Marshes, the Naracoorte wetlands and the Paroo–Cuttaburra Channels) as well as two wetlands within the Lake Eyre drainage division (i.e. Lake Eyre and Cooper Creek wetlands). No long-term trends in waterbird abundance were apparent in the other four wetlands, all of which were within the Lake Eyre drainage division (i.e. Lake Galilee, lakes Torquinie and Mumbleberry, Lake Hope and Lake Moondarra).

Waterbird numbers declined in the majority of both regulated (3 of 4) and unregulated (4 of 7) wetlands. All of the regulated wetlands examined here, except Lake Moondarra, displayed significant long-term declines in waterbird abundance. Significant shifts in the composition of waterbird communities were also apparent over the 27-year survey period in all of the regulated wetlands, including Lake Moondarra, and particularly in the Lowbidgee and Macquarie Marshes. In comparison, waterbird community composition in unregulated wetlands exhibited fewer significant changes, in two of five wetlands where analyses could be performed. Waterbird community composition also showed considerable overall differences between unregulated and regulated wetlands, although some overlap was also evident. Further analysis of the long term and 2008 survey data would yield more in-depth knowledge of compositional change, however this analysis was not undertaken as part of this project.

Relationships between waterbird numbers, rainfall, flow and wetted wetland area

At a regional scale, both waterbird abundance and the number of breeding waterbirds were strongly explained by wetland area and the number of wetlands, which were significantly correlated. The number of breeding waterbird species was also well explained by wetland area but less so by the number of wetlands.

There was also a high goodness of fit for the explanatory models developed for waterbird abundance in the individual wetlands considered, except for Lake Moondarra. Wetland area was a highly significant factor explaining variance in abundance of waterbirds in all cases and river flow in all cases where this data was available. Rainfall was also a significant predictor of waterbird numbers in two wetlands that fill from local runoff, Naracoorte and Lake Galilee, as well as in the Cooper Creek wetlands for which flow was also highly significant.

Implications

The long-term trends detected here in waterbird abundance, numbers of breeding waterbirds and breeding species across the eastern Australia survey region reflect both a long-term decline in wetland area as well as the effects of the recent dry period. Changes in climate are clearly implicated in the trends identified here, particularly with respect to reductions in rainfall and river flow that have occurred over most of eastern Australia over the last decade of the survey period and will have contributed to reductions in wetland area.

Long-term declines in wetland area throughout much of the Murray–Darling drainage division, however, can be also be attributed to reductions in the number and frequency of end-of-system floods that have occurred on many of the regulated rivers of this system (CSIRO 2008). Consequently, the results of this assessment particularly emphasise the need for improved water management practices in regulated systems of the Murray–Darling.

Reductions in wetland area in the individual regulated wetlands considered here may be partially attributed to river regulation and diversions. In the Macquarie Marshes, for instance, river regulation and upstream diversions have reduced the frequency of flows and flooding in

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the wetland (Kingsford and Thomas 1995, Herron et al. 2002, Ren et al. 2010, Thomas et al. in press, Ren and Kingsford 2011), affecting the viability of floodplain vegetation (Thomas et al. 2011) and reducing opportunities for breeding among waterbirds (Kingsford and Johnson 1998). Similarly, river regulation and upstream diversions have reduced flows to the Lowbidgee floodplain by up to 60%, significantly reducing the wetland area, which has been further impacted by floodplain development, including irrigation bays, channels and levee banks (Kingsford and Thomas 2004). A significant decline in waterbird numbers and a shift in composition over the survey period was also detected in a third regulated wetland, the Menindee Lakes in the Murray–Darling division. This wetland comprises a regulated lake system in which water is kept artificially high to supply downstream human needs. Such regulation reduces productivity and alters the ecology of wetlands, favouring piscivores over small and large wading birds, herbivores and duck species (Kingsford et al. 2004a). Instigating a more variable flooding regime could therefore improve the habitat value of this wetland to waterbirds.

Declines in waterbird numbers were also detected in a further four of the unregulated wetlands examined: the Paroo and Cuttaburra Channels and the Naracoorte wetlands in the Murray–Darling division and the Cooper Creek and Lake Eyre in the Lake Eyre division. These trends were influenced in the Murray–Darling by high counts in 1983 and 1984 and, in the Lake Eyre Basin, exhibited considerable variability in relation to episodic flooding– the cycles of dry periods and wet periods. It is possible that river regulation has also contributed to the reductions in waterbird numbers observed in these wetlands since waterbirds appear to move regularly both within and between the Murray–Darling and Lake Eyre drainage divisions (Roshier et al. 2002; Kingsford et al. 2010).

This assessment of data from the Eastern Australian Aerial Waterbird Survey (1983–2009) provides a strong demonstration of relationships between waterbird numbers, breeding and community composition and wetland area, rainfall and flow, as well as significant evidence of declines in waterbird numbers in eastern Australia over the 27-year period considered, particularly in wetlands and drainage divisions subjected to river regulation. Future surveys will enable a similar assessment with a focus on the recovery of waterbird populations and communities after the long dry period and responses to improved land and water practices, including the delivery of environmental flows.

Analyses in this study were restricted to long-term patterns in total waterbird numbers, as well as in the overall composition of waterbird communities. A more in-depth analysis of which species are contributing to the variation observed in the long-term and 2008 survey data sets, might shed light on the mechanisms driving the variation and the role that river regulation plays in this.

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4. National Waterbird Database

4.1. Introduction

There is considerable value in collecting and analysing waterbird data to determine changes in waterbird populations and communities in different wetland systems, as demonstrated by this project. This has particular relevance to the management of rivers, wetlands and water resources but also to obligations the Australian Government and the state and territory jurisdictions have for protecting and conserving wetlands under the Ramsar Convention, various migratory bird treaties and the *Environment Protection and Biodiversity Conservation Act 1999*.

There is a substantial and growing amount of data on waterbirds in Australia (Figure 1, Table 1) but the variety of waterbird surveys that have been conducted around the country often makes it difficult to compile this data—a difficulty that is likely to grow over time without a nationally coordinated effort to organise, store and disseminate waterbird data. Consequently, a third major objective of this project was to develop a rigorously constructed database to be a repository of such data at a national scale to ensure past investments can easily be built upon. Furthermore, the database was designed to store and enable analyses across both large-scale aerial and more targeted, localised ground surveys.

This chapter provides an overview of the design of the National Waterbird Database (Section 4.3) as well as how this was approached (Section 4.2) and a brief discussion of its future (Section 4.4).

4.2. Approach

A workshop was held in July 2007 with representatives of all jurisdictions to determine the most effective structure for the National Waterbird Database. Proposed data fields were discussed as well as database structure, data entry, licensing, hosting, maintenance and QA/QC. It was recognised that a spatially referenced database was essential, requiring a unique identifier and centroid for each wetland. It was also agreed that naming conventions follow the *National gazetteer*, a nationally recognised standard source. Appropriate fields that adequately define both the wetland area sampled as well as the total wetland area were considered important inclusions in the database. The importance of a fully developed metadata standard was also deemed critical, with the use of the ANZLICC metadata template suggested as a minimum requirement.

The recommended general approach to construction of the National Waterbird Database was to put the 2008 National Waterbird Survey data into a new custom-made database. This would be followed by the addition of data from the Eastern Australian Aerial Waterbird Survey, and then other major waterbird databases and 'freestanding' or supplementary waterbird data could be added should resources be available in the future. Given that the rigorous field structure of the National Waterbird Database would not always be complied with, it was recognised that the entry of future data would require resources to ensure quality.

Initial work was done on the development of the Australian Waterbird Survey of Eastern Australia Database (AWSEAD), which holds data from the Eastern Australian Aerial Waterbird Survey. The existing eastern Australian database has been developed over 24 years and was a valuable resource when designing and assembling the national database, providing a preliminary structure.

4.3. Database design

The National Waterbird Database is a relational database management system, constructed in Microsoft Access and using structured query language (SQL) to link with GIS software and deliver the database online via a server.

The database is designed for storing and handling large and complex datasets consisting of waterbird count data. Waterbird survey data encompasses both spatial (i.e. unique wetlands) and temporal (i.e. different years) dimensions and it is assumed that each wetland has been surveyed for waterbird abundance, species composition and breeding (i.e. nests and broods). The database was designed to enable flexible retrieval of temporal and spatial dimensions of the data and these two dimensions are accessible concurrently in the database so that temporal information can be accessed via a spatial unit (the wetland) or for a point in time (the year).

Relational database systems are characterised by their simplicity in that all the data is stored as tables of rows and columns with each table representing a set of records. The principal features of a relational database are the record key and the relational joins (Healey 1991). The record key serves as the row identifying mechanism in the relational database, which links data from different tables. Record matching is frequently based on the record key in one table linked to a column in the second, referred to as the foreign key. The advantage of a relational database is that all database structures can be reduced to a set of tables that allow for easy modification.

4.3.1. Wetland base layer

A base layer of spatial information on wetlands was created for the National Waterbird Database using information from the *National gazetteer* and 1:250 000 national waterbody GIS layer from Geoscience Australia. Each wetland was assigned a unique spatial identifier, based on the currently available *National gazetteer*, that included wetland name, GIS boundary (shape file, obtained from the 1:250 000 national waterbody layer), entroid location or sampling boundary (e.g. 6-minute longitude interval). Wetland area was also derived from the 1:250 000 national waterbody layer for all wetlands >1ha in size. Small creeks, streams and drainage lines were represented as polylines rather than polygons, so these features could not be assigned a defined area. A software routine was also written that allowed for easy look-up of gazetteer details for any wetland in Australia during data entry.

4.3.2. Data tables and links

The key data tables included in the National Waterbird Database are:

- the ‘wetlands’ table: spatial wetland information, including links to GIS data
- the ‘surveys’ table: temporal information about the year of the survey
- the ‘counts’ table waterbird counts: the waterbird counts collected in the year and on the particular wetland (Figure 64, Table 17).

A collection of separate tables was also used to store other relevant information, including: the survey’s waterbird species coding system (‘Duck Codes’ table), the survey observer’s details (‘recorders’ table), the relevant topographic maps (‘maps’ table) and the waterbird species taxonomy and conservation status (*Census of Australian vertebrate species* (‘Cavs’) table, which is sourced from the online Cavs database administered by the Australian Government Department of Sustainability, Environment, Water, Population and Communities <*www.environment.gov.au/biodiversity//abrs/online–resources/fauna/cavs/index.html*>, accessed 19/5/11).

The connectivity of information flow between the data tables is shown in Figure 64 and names and description of all data fields are provided in Table 17.

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Figure 64: Structure of the relational National Waterbird Database built in MS Microsoft Access software and migrated into a web environment (MYSQL), showing the links between different tables to the main data set.

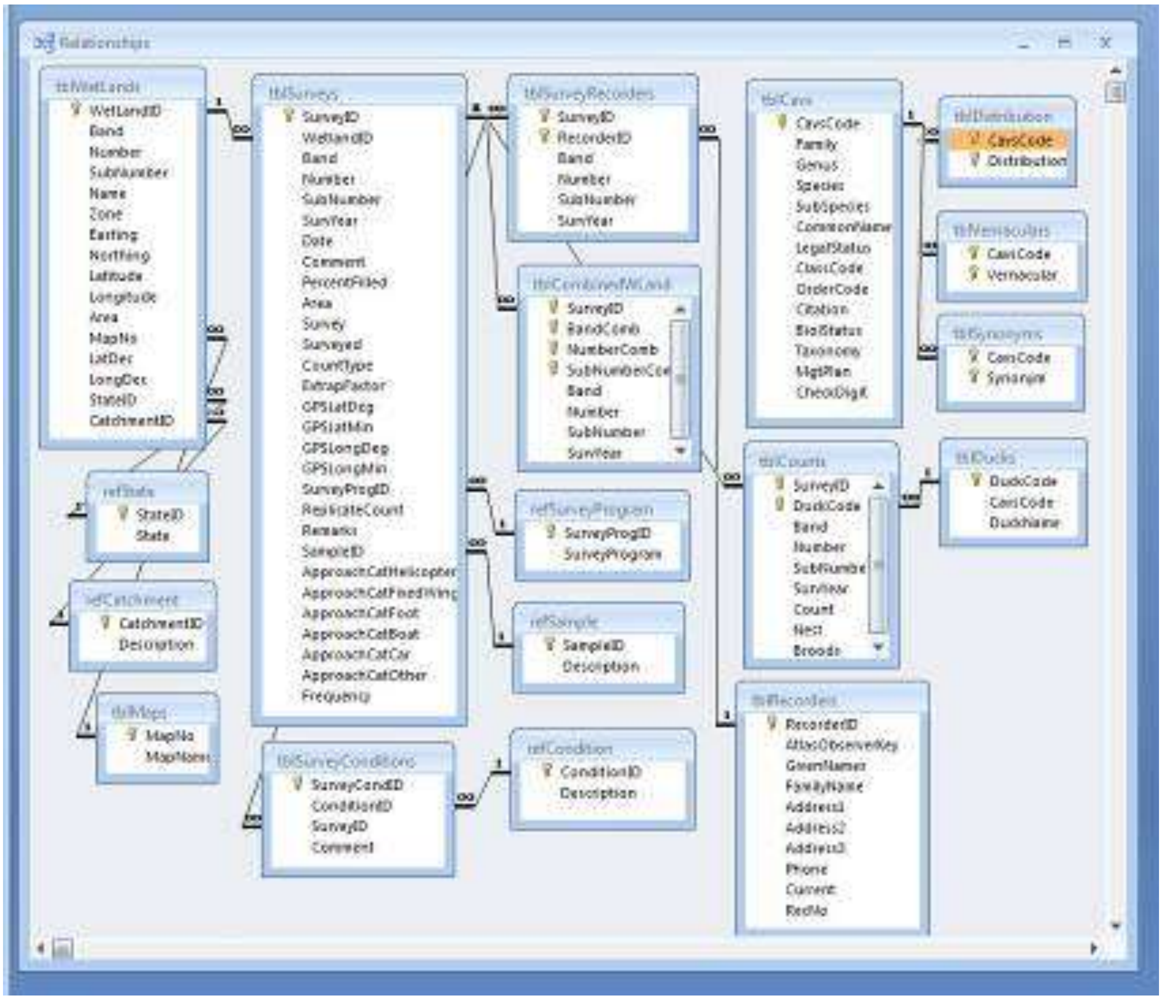

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Table 17: The main data contents of the relational database describing the different database tables and the fields within each table

Also refer to Figure 64. Reference tables (ref_) are self-explanatory and are not included. Some fields are repeated in linked tables.

Database table	*Database field*	*Description*
Wetlands (tblWetlands)	WetlandID	This is a unique identifier for each wetland surveyed on the National Aerial Survey of Waterbirds, Murray Icon site surveys or the Eastern Australian Waterbird Survey. It is compiled from the *National gazetteer* to ensure that it can be linked to GIS systems.
	Band	Identifies the 30 km-wide survey band used in aerial surveys of waterbirds in eastern Australia. There are ten surveys, numbered from north to south (1 to 10).
	Number	Systematic number allocated to each wetland within a 30 km-wide survey band in aerial surveys of waterbirds in eastern Australia. Numbering begins in the west and progresses east.
	Subnumber	A systematic subnumber allocated within a 30 km-wide survey band in aerial surveys of waterbirds in eastern Australia and linked to a wetland number.
	Name	This is the name identified from the *National gazetteer*. For wetlands identified in the aerial surveys of waterbirds in eastern Australia, descriptors are also used that describe the type of wetland unit (e.g. dam, swamp, lake) and the direction it is from the nearest landmark published on the most recent 1:250 000 topographic map sheet. (e.g. Smith Town Swamp Nth.).
	Zone	Describes the Australian Metric Grid (AMG) Zone.
	Easting	Six-digit number for AMG easting, taken from the *National gazetteer*. Some wetlands have no unique identifier and so have to be ascribed this.
	Northing	Seven-digit number for AMG northing.
	Latitude	Relevant degrees and minutes.
	Longitude	Relevant degrees and minutes.
	Area	Maximum extent of the wetland from the 1:250 000 waterbody layer (measured in hectares). This is used to gauge fullness of a wetland during the survey.
	Map number	Number and name of the 1:250 000 topographic map sheet on which the wetland is located (only for Eastern Australia Waterbird Survey data).
	LatDec	Decimal conversion of latitude.

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Database table	*Database field*	*Description*
	LongDec	Decimal conversion of longitude.
	StateID	Jurisdiction in which the wetland is located.
	CatchmentID	Catchment in which the wetland is located.
Surveys	SurveyID	Name and identification of survey.
(tblSurveys)	Year	Year of the survey.
	Date	Date of the survey.
	Comment	Opportunity to describe the type of survey.
	PercentFilled	Estimated percentage of water in wetland at the time of survey (assessed against the high-water mark).
	Area	Estimated area of water surveyed at the time of survey. The area of the wetland was measured from a 1:250 000 topographic map (tblWetLands) and then the area surveyed was estimated using the percent filled estimate.
	Survey	Surveyed wetlands with a zero count of waterbirds. A ‘Y’ for yes is entered here. If the wetland was dry the percentage filled is zero
	Count type	The type of count method performed on the survey for the specified wetland. The options are: total count 1), transect count 2) and proportion count 3). In total count, all the waterbirds of the wetland were counted. In transect count, all waterbirds were counted in a transect 100 m-wide on either side of aircraft and flying time was recorded to determine area of water within the transect. This was then extrapolated, after calculating area of the wetland, to determine a total count for all waterbirds. In a proportion count, a proportion of the wetland is surveyed and then extrapolated depending on the size and proportion of the wetland counted.
	ExtrapFactor	This factor was based on the area of the wetland surveyed and the proportion of the wetland surveyed and then this was extrapolated.
	GPSLatDeg	The GPS latitude in degrees is recorded for each survey as this may differ to the centroid that provides data for the location of a wetland.
	GPSLatMin	The GPS latitude in minutes is recorded for each survey as this may differ to the centroid that provides data for the location of a wetland.
	GPSLongDeg	The GPS longitude in degrees is recorded for each survey as this may differ to the centroid that provides data for the location of a wetland.

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Database table	*Database field*	*Description*
	GPSLongMin	The GPS longitude in minutes is recorded for each survey as this may differ to the centroid that provides data for the location of a wetland.
	SurveyProgID	Each survey program will have a separate ID number with a more detailed description of the type of survey (see refSurveyProgram, Figure 2).
	ReplicateCount	Sometimes a replicate count will be required for a survey, so this will need to be recorded to ensure calculation of mean numbers and errors of survey.
	Remarks	Allows for commentary about particular surveys at a particular time.
	SampleID	Used where multiple samples make up a single count. For example. different parts of a lake may be sampled to make up a total count for the lake.
	ApproachCatHelicopter	Refers to the counting platform and technique employed to survey waterbird populations—helicopter aerial surveys.
	ApproachCatFixedWing	Refers to the counting platform and technique employed to survey waterbird populations—fixed-wing high-winged aircraft surveys.
	ApproachCatFoot	Refers to the counting platform and technique employed to survey waterbird populations—ground surveys done by foot.
	ApproachCatBoat	Refers to the counting platform and technique employed to survey waterbird populations—surveys done by boat.
	ApproachCatCar	Refers to the counting platform and technique employed to survey waterbird populations – surveys done by car.
	ApproachCatOther	Refers to the counting platform and technique employed to survey waterbird populations—surveys done by other means not covered in categories above. Or it may be a combination of categories.
	Frequency	Records the frequency with which counts of this type for a particular survey are done.
Survey Recorders (tblSurveyRecorders)	RecorderID	Each observer used on aerial surveys has their details recorded in a separate table to differentiate them from other recorders (tblRecorders, see Figure 2). Each observer receives a number of identification in the primary field linked to look-up tables. 'Current' (see Figure 2) identifies if a particular observer is involved in surveys.
Combined wetlands (tblCombinedWLand)	All fields	As a result of flooding, unique wetland systems that are usually separated can become combined and surveyed together. This table allows this issue to be dealt with. This occurs when widespread flooding joins two or a series of wetlands, making it impossible to survey them separately. A wetland record key is entered in this field (band/number/subnumber). Waterbird counts for a combined wetland can be incorporated into the current survey record.

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Database table	*Database field*	*Description*
Counts (tblCounts)	DuckCode	Three-letter code used in the aerial survey to identify each species or group of species of waterbirds (see Appendix A) in a particular count. This is linked to the CavsCode (see below) with the taxonomic name and the name used in aerial surveys (DuckName).
	Count	Total number of the particular species counted during a survey of a wetland.
	Nest	Total number of nests of a particular species counted during a survey of a wetland.
	Broods	Total number of broods of a particular species counted during a survey of a wetland.
Census of Australian vertebrate species (CavsCode) (tblCavs)	All fields	Each species of waterbird has a three-letter code used in the aerial survey to identify each species or group of species of waterbirds that is then linked to the *Census of Australian vertebrate species* (CavsCode). This list has links to current taxonomic and legal status and distribution information (see Figure 2). There are a range of linked tables (Figure 2Figure 2) providing information on distribution (tbl Distribution), vernacular names (tbl Vernaculars) and synonyms used (tblSynonyms). These could be linked to BirdLife Australia codes with simple look-up tables.

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4.3.3. Data entry and validation

Initially, data from the 2008 National Waterbird Survey (see Chapter 2) was entered into the database. Digital audio recordings of waterbird counts from the survey were transcribed to data sheets (Appendix C) then entered into Microsoft Excel spreadsheets. Quality control and assurance routines to check data columns and identify potential errors resulting from transcription errors were conducted in Excel since large datasets are more easily managed within Excel before importing into the database. Excel spreadsheets were imported in the same format into the National Waterbird Database in sections matching the major survey regions. Once a dataset was imported, a series of quality assurance routines was used to check that names of wetlands were compatible between observers; that times of survey matched between observers; observer numbers matched; that the count type was appropriate and that there was a matching estimation of the proportion counted if it was required or the area was covered by a transect (see Section 2.2.3); and finally, the three-letter codes used by the transcriber were correct.

Magpie gees in flight over wetlands in the Northern Territory (Photo: RT Kingsford)

The National Waterbird Database has a user interface with administration functions and routines to assist with these data import and validation functions. After the validation routines systematically checked all data, a transcription error report was produced, indicating in which records and fields errors had been identified. If the initial correction failed rechecking, errors could be easily corrected on the Excel spreadsheet and the dataset reimported and validated again. Eventually this quality assurance and control cycle ensured that all known errors were corrected in the dataset and produced a validation report free of errors. Aerial survey data for the 2008 National Waterbird Survey was collected following this strict protocol which allowed for structured entry and error checking before incorporation into the national database (see Chapter 2).

Data can also be entered directly into the database with administrator rights—for instance, where minor corrections might be required. Database users can access the data entry component of the database in which there are six data entry windows that display each record

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within a data field. Data is entered or modified from the keyboard following the fields set up in the National Waterbird Database. Users need to be aware of the hierarchical nature of the three main datasets of the database: the wetlands, surveys and counts database, because it imposes an order of data entry into the database, i.e. the wetland identification key becomes part of the survey record key and this then becomes part of the counts record key. A record in the count dataset cannot exist therefore without a survey record and a survey record cannot exist without a wetland record. Therefore, a wetland record must be entered before a survey record is entered and then a count record can be entered. If there is a wetland record without a corresponding survey or count record the wetland has never been surveyed, usually because no water has been present at the time of survey.

4.3.4. Database reports and queries

The tabular storage of datasets in the database is transparent to the user. Each record of data can be displayed to the user and accessed via the menu and window structure of the relational database. Reports, which are queries resulting in data table outputs, can be produced from the database and, if the user wishes to produce specific reports, the 'report' item is selected from the main menu and the reporting submenu is subsequently displayed. Again, different options are available to the user.

The flexibility of the database also allows for a variety of queries to be made using the internal query language. A query is usually a two-step process: data selection and a report list. A selection filters the dataset allowing the user to use a subset of data for further processing. The specified fields of data can be reported as a tabulated list. The command line interface (a TCL window (the command level), allows the user to select the required file and to construct a comparison clause using key words (e.g. select, with, comparison operators (e.g. =, >, <) or multiple comparisons using logical expressions (e.g. AND, OR). Queries can use combinations of known wetland(s), a survey year(s) or a waterbird species. Typically, the database is queried to determine the abundance of waterbirds, species richness and species composition of a specific wetland. A query first allows identification of availability of data for a particular wetland and this can be followed by a query of actual waterbird counts for a particular year.

There is a flexible reporting system within the National Waterbird Database that produces reports from the specified files in the program, and a series of frequently used queries that can be accessed when required. These queries have been specifically written to reflect the most often asked questions from users. Data from these queries can easily be exported into Excel data sheets or GIS programs for further analyses:

Total numbers above a threshold on a wetland. This query selects wetlands in a user-determined area that support more than the specified number of waterbirds. This is particularly important when identifying high conservation value wetlands for waterbirds. A report is produced listing the wetland record key, the geographic position of a wetland as zone, easting, northing and the frequency of years surveyed which meet the selection condition.

Selected number of species on a wetland. These queries select wetlands in a user-determined area that have more than a specified number of a particular species. A report is produced listing the wetland record key, the geographic position of a wetland as zone, easting, northing and the frequency of years surveyed that meet the selection condition.

Retrieval of all data for a particular wetland. These queries would allow users to select a particular wetland and obtain longitudinal temporal data for it.

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4.3.5. Trial web version

A major aim of developing the National Waterbird Database is to extend the accessibility of waterbird survey data by making it publicly available via the internet. This will involve development of agreements with those jurisdictions whose data is incorporated into the trial version, and with the Commonwealth, to allow for release of the data and capture appropriate intellectual property arrangements. To enable web deployment and assist in linking to GIS software the database has been converted to structured query language (SQL) format with Navicat software with an interface allowing access, by password, to the database. While the 'front end' of this initial web version—i.e. web graphics interface and associated query forms—has limited functionality because the database conversion process does not automatically include these elements, testing has indicated that all data structure and linkages have been preserved and data integrity maintained. A range of MS Access queries has been separately converted into SQL format as well and these 'stored procedures' are available via a drop-down menu in the trial web version database .

The trial web version of the database can be accessed by contacting the Australian Wetlands and Rivers Centre at the University of New South Wales via email: *awrc@unsw.edu.au*.

4.4. Future of the National Waterbird Database

The National Waterbird database currently contains the results of four large survey programs:

- the National Waterbird Survey (see Chapter 2)
- the Eastern Australian Aerial Waterbird Survey database (72 524 records from 1983–2008)
- Northern Murray–Darling Surveys (5655 records)
- Murray Icon Surveys (MIS) (4157 records 2007 and 2008).

This represents a significant depository of temporal and spatial waterbird and wetland data for anyone interested in quantitative, spatially explicit information on the distribution and abundance of Australian waterbirds and the condition of their wetland and river habitats. Previously, information on waterbirds was patchy and difficult to access by land and water managers. The development of the national database has provided a comprehensive assemblage of waterbird data, supporting BirdLife Australia's *Atlas of Australian birds* (Barrett et al. 2003), and bringing together a wide range of existing expertise to develop a coordinated and consistent approach to the acquisition and storage of waterbird data.

Information from the database will be of use at national and jurisdictional levels in assisting governments to meet their obligations under international and national agreements and legislation. In particular, this information will help implement the National Water Initiative, which commits all Australian governments to identify high conservation value aquatic ecosystems. Additionally, the database will aid government organisations involved in water management by providing information about essential environmental assets on river systems.

The database can also be used to assess developments that might affect waterbirds and their habitat such as those that may impact on migratory waterbirds or Ramsar sites. All governments in Australia have responsibilities for managing migratory waterbird populations and their habitats and data from the National Waterbird Database could be integrated with ground counts of shorebirds that are available through other organisations. Information in the database is also potentially relevant to assessment of species conservation status (i.e. threatened or vulnerable) at different jurisdictional levels.

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Adding past survey data

Ground survey results were not available for inclusion at the time of writing this report because they had not been validated owing to time constraints. They will however be included in the future as validation processes are completed. Other past waterbird surveys, including aerial surveys (see Figure 1, Table 1) were also assessed for possible inclusion in the National Waterbird Database but considerable resources would be required for quality control and development of metadata to ensure that these surveys could be included appropriately.

Past surveys represent a significant resource that would considerably enhance the utility of the National Waterbird Database for land and water resource management across jurisdictions. Availability and format of other waterbird databases were discussed during the national waterbird workshop in 2007 but a number of constraints were identified that precluded routine importation of this data into the national database, including data accessibility, potential custodian and licensing constraints, and a series of issues associated with metadata.

A data-suitability framework is needed to guide decisions about which datasets can be brought into the national database, e.g. those with adequate metadata following ANZLICC specifications. With some other datasets, further involvement from different jurisdictions is required to develop licensing procedures for data before its release for inclusion in the national database.

Adding new survey data

The database has been collaboratively set up to ensure good coordination among jurisdictions and other groups collecting waterbird data in the future. By establishing a standardised methodology, future waterbird surveys at any scale, from local to continental, can allow regional groups, non-government organisations, e.g. BirdLife Australia and the Australian Wader Studies Group, as well as governments concerned about key environmental assets, to develop focused aerial or ground surveys of waterbird populations that can contribute to the ongoing development of this significant national knowledge base.

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5. Key findings and recommendations

The National Water Resource Assessment Using Waterbirds: Ecosystem Health and Conservation Importance of Water Dependent Ecosystems and Rivers project addressed three major objectives:

- completion of a national survey of waterbirds in all major wetlands of Australia holding water in 2008
- assessment of long-term changes in waterbird numbers in relation to flow in key wetlands of eastern Australia
- establishment of a national waterbird database for storing and accessing waterbird survey data.

The key findings of each of these components are synthesised here along with major recommendations arising from these findings for policy and management and future research.

5.1. Key findings

5.1.1. The 2008 National Waterbird Survey

Distribution of wetlands

- The 2008 National Waterbird Survey covered 3.8 million ha of wetlands comprising 4858 wetlands.
- Mean wetland size was 333.4 ha (± 4.52 standard error) and the most frequently encountered wetland sizes were in the 0–1 ha and 10–200 ha size classes. The largest individual wetland was the Diamantina River floodplain in the Lake Eyre drainage division at 440 625 ha.
- The majority of wetlands holding water during the 2008 survey period occurred in coastal regions. The Timor Sea drainage division had the highest number of wetlands (20.5%), followed by the South-west Coast (15.3%) and the Gulf of Carpentaria (13.8%) divisions.
- The largest percentage of wetland area occurred within the Lake Eyre Basin drainage division (33.1%), followed by the Gulf of Carpentaria (16.4%), Timor Sea (8.8%) and Indian Ocean (8.7%) drainage divisions.
- There were relatively few wetlands and low percentage wetland area in the Bullo–Bancannia, South Australian Gulf, Tasmania and Western Plateau drainage divisions.

Key wetlands for waterbirds

- Waterbirds were not observed in around 40% of surveyed wetlands and most of the other 60% of wetlands supported fewer than 100 waterbirds.
- Very few wetlands had high waterbird concentrations and 39% of all recorded waterbirds occurred on the top 20 wetlands, as ranked by waterbird abundance, with over 6% occurring in the highest ranked wetland alone, Eighty Mile Beach. Around 50% of all waterbirds surveyed occurred on just 41 wetlands or 1.1% of all wetlands surveyed.

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- Four of the top five wetlands ranked in terms of waterbird abundance were in northern Australia, i.e. Eighty Mile Beach, lakes Gregory and Argyle, and Roebuck Bay. The Coorong and Lower Lakes wetland complex at the mouth of the Murray–Darling drainage division was also among the top five, supporting over 100 000 waterbirds at the time of the survey.
- The top 20 ranked wetlands in terms of waterbird abundance were distributed around the country and included wetlands in southern and inland Australia, e.g. Dumbleyung Lake and the Cuttaburra Channels.
- Overall, 106 species of waterbirds were recorded but the species richness of individual wetlands exhibited a much lower range than waterbird abundance. Species richness was significantly correlated with abundance, with high species numbers generally occurring on wetlands supporting high numbers of waterbirds.
- A few wetlands with high abundances were dominated by particular species or functional groups of waterbirds. In particular, magpie geese dominated Nanjbagu Billabong in Kakadu National Park and migratory shorebirds dominated Eighty Mile Beach and Roebuck Bay.

Key regions for waterbirds

- The tropical drainage divisions, especially Timor Sea, were clearly more important to waterbirds in terms of abundance and density at the time of the survey, largely due to the inclusion of many of the top-ranked wetlands, e.g. Eighty Mile Beach and Roebuck Bay.
- High waterbird abundance, density and species richness also occurred in some inland wetlands, e.g. Lake Galilee and Cuttaburra Channels, and the Bulloo–Bancannia drainage division in particular supported a relatively high density of waterbirds.
- Wetlands with high waterbird species richness occurred in all drainage divisions except Tasmania, which supported considerably fewer species.
- Waterbird community composition varied among drainage divisions, primarily reflecting distributions of tropical, e.g. magpie geese and plumed whistling-duck, versus temperate species, e.g. grey teal and small waders.
- The Indian Ocean and Western Plateau drainage divisions were particularly important for migratory shorebirds, emphasising the significance of north-western Australia as a staging area and over-wintering sites for these species.
- Duck species dominated the Lake Eyre and Bulloo–Bancannia drainage divisions reflecting their ability to capitalise on productive ephemeral wetlands in these regions.

Waterbird population sizes

- The number of waterbirds recorded during the 2008 National Waterbird Survey was 4.55 million. An estimate of the true number of waterbirds at the time, extrapolating from randomly surveyed wetlands, is calculated to be 4.65 million. These estimates are considerably lower than an estimate of 9 million made in 1998 based on data from the late 1980s to mid-1990s. The discrepancy probably reflects both a degree of underestimation in the current national survey due to a lack of small wetlands surveyed, as well as a decline in waterbird numbers corresponding with that observed in eastern Australia, including among shorebirds, over the past 20 years.
- The most abundant functional group of waterbirds was the herbivore group, which included Australian shelduck, Eurasian coot and black swans.

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- The most abundant species recorded were magpie geese, accounting for almost 21% of all waterbirds counted, followed by small waders, plumed whistling-duck, grey teal, large waders, egrets, banded stilt, wandering whistling-duck, pink-eared duck, terns, black swan and Eurasian coat. These top 12 ranked species accounted for over 82% of all waterbirds counted. In contrast, the 43 least abundant species comprised less than 1% of all waterbirds surveyed.

- Population sizes of several abundant species from the 2008 National Waterbird Survey are comparable to past estimates. For example, a national magpie goose population size of around 900 000 compared with past estimates of around 1 million (although one regional estimate suggested a population size of 1.6 million). Banded stilt are also estimated here to have a population size of about 200 000 which is comparable to a past estimate of 206 000 in 2006.

- Grey teal are estimated to have a current (i.e. 2008) population size of around 320 000 which is considerably lower than past estimates of over 1 million. Furthermore, counts of 150 000 in eastern Australia and 135 000 in south-western Australia alone in the early 1990s suggest that this species may have undergone a significant decline of up to 80% in population size.

5.1.2. Long-term changes in waterbirds in eastern Australia

Long-term trends across eastern Australia

- A significant decline is evident in the total numbers of waterbirds counted across eastern Australia over a 27-year survey period from 1983 to 2009. While particularly high numbers of waterbirds were recorded early in this period, i.e. in 1984, a significant long-term decline in waterbird abundance remains apparent when this date is excluded from analyses.
- Wetland area and the number of wetlands surveyed (i.e. holding water) in the eastern Australia survey region fell between 1983 and 2009. Wetland area declined significantly from 1983 to 1984 and again from 2000 to 2009, the latter period demonstrating the effects of the recent drought. In contrast, the number of wetlands varied considerably between 1983 and 1999 then declined significantly until 2009, when numbers rose again, almost reaching the long-term mean.
- Numbers of breeding waterbirds have exhibited considerable highs and low over the survey period, generally corresponding to periods of flooding and drying. Long-term decline in both the number of waterbirds breeding and the number of breeding species is evident, however, over the survey period.

Long-term trends in individual wetlands

- There was considerable variation in wetland area, waterbird abundance and density across 11 selected wetlands within the survey region, including 10 wetlands identified as being of high importance to waterbirds based on their overall waterbird numbers during the survey period, and the Macquarie Marshes, which is a Ramsar site and had high waterbird numbers during early survey dates. Not all of the wetlands held water during each survey date, although regulated wetlands typically held water more frequently than the unregulated wetlands investigated.

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- Significant long-term declines in waterbird abundance were evident over the 27-year survey period in seven of these wetlands, including all of the wetlands within the Murray–Darling drainage division (i.e. Menindee Lakes, the Lowbidgee, Macquarie Marshes, the Naracoorte wetlands and the Paroo–Cuttaburra Channels) and two wetlands in the Lake Eyre drainage division (i.e. Lake Eyre and Cooper Creek wetlands).
- No long-term trends in waterbird abundance were apparent in the other four wetlands, all in the Lake Eyre drainage division (i.e, Lake Galilee, lakes Torquinie and Mumbleberry, Lake Hope and Lake Moondarra).
- Waterbird community composition exhibited considerable differences between unregulated and regulated wetlands over the survey period, although some overlap was also evident.
- Significant long-term declines in waterbird abundance were evident in all of the regulated wetlands examined here, except Lake Moondarra, and significant long-term shifts in the composition of waterbird communities were also apparent in all of the regulated wetlands, including Lake Moondarra, and particularly in the Lowbidgee and Macquarie Marshes.
- Waterbird abundance also declined in four of seven unregulated wetlands but waterbird community composition in unregulated wetlands exhibited fewer significant changes during the survey period than in regulated wetlands.
- Analyses of waterbird abundance and composition were performed at the whole of community level and only a limited number of environmental variables were measured, so the mechanisms creating the differences observed in the behaviour of regulated and unregulated wetlands are unclear. River regulation and floodplain development can decrease wetland area which is strongly linked with waterbird abundance. Previous research has shown changes in flood frequency due to river regulation can reduce breeding opportunities for waterbirds and impact floodplain vegetation that waterbirds may depend upon. A more in-depth analysis of the species contributing to this variation may suggest the mechanisms driving it.

Relationships between waterbird numbers, rainfall, flow and wetland area

- At a regional scale, waterbird abundance and the number of breeding waterbirds were strongly explained by wetland area and the number of wetlands, which were significantly correlated. The number of breeding waterbird species was also well explained by wetland area but less so by the number of wetlands.
- There was a high goodness of fit for the explanatory models developed for waterbird abundance in the individual wetlands considered, except for Lake Moondarra. Wetland area was highly significant in all cases and river flow in all cases where this was available. Rainfall was also a significant predictor of waterbird numbers in two wetlands that fill from local runoff, Naracoorte and Lake Galilee, as well as in the Cooper Creek wetlands for which flow was additionally highly significant.

5.1.3. National Waterbird Database

- A national waterbird database has been designed and developed as a repository of waterbird survey data to enable improved data storage and accessibility as well as analyses across a range of spatial and temporal scales.

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- The trial web version of the database can be accessed by contacting the Australian Wetland and Rivers Centre at the University of New South Wales via email: *awrc@unsw.edu.au.*
- The database currently holds data from the:
  - 2008 National Waterbird Survey (see Chapter 2)
  - Eastern Australian Aerial Waterbird Survey database (72 524 records from 1983–2008)
  - Northern Murray–Darling Surveys (5655 records)
  - Murray Icon Surveys (MIS) (4157 records 2007 and 2008).
- The National Waterbird Database could be enhanced considerably through the inclusion of additional past survey data, including ground survey data. However, this is likely to require considerable resources for data processing and quality control. In some cases there are additional issues, e.g. accessibility, licensing and metadata, that need to be addressed before data can be included in the database.
- The structure and methodolology developed in the construction of the National Waterbird Database can be used to guide the effective collection of waterbird survey data in the future across a range of scales.

5.2. Key recommendations

5.2.1. Recommendations for policy and management

- Data from the 2008 National Waterbird Survey about individual wetlands identified as being of high national (and international) importance to waterbirds, in terms of abundance and density, including (but not limited to):
  - the top five ranked wetlands (Eighty Mile Beach, lakes Gregory and Argyle, Coorong/Lower Lakes and Roebuck Bay, which all supported over 150 000 waterbirds
  - the top 20 ranked wetlands, which together supported approximately 40% of all waterbirds counted.
- Data from the 2008 National Waterbird Survey will contribute to national and jurisdictional assessments of:
  - the existing reserve/protected area network to ensure their adequate protection and conservation
  - existing listings of wetlands under Ramsar or as important wetlands
  - high conservation value aquatic ecosystems as per the requirements of the National Water Initiative
  - development proposals that have the potential to impact on these wetlands.
- The importance of northern Australia to waterbirds in particular should be recognised at a national (and international) level. Data from the 2008 National Waterbird Survey can be used to inform critical assessments of the existing reserve/protected area network in tropical regions as well as listings of wetlands under Ramsar or as important wetlands. The information from the survey should also be used to inform planning and prioritisation of off-reserve conservation measures, e.g. corridors, development controls and climate change adaptation measures in tropical Australia.

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- The significance of ephemeral wetlands of inland Australia to waterbirds, especially duck species, even during a dry year such as 2008, should be recognised at national and jurisdictional levels. An assessment of the current reserve network and off-reserve conservation measures for dryland wetlands identified here as important to waterbirds should be conducted with particular consideration of water (e.g. limits on extraction and environmental flow allocations) and land management practices (e.g. fencing of waterbodies).
- Comparison of results from the 2008 National Waterbird Survey with past research suggests that grey teal is one common waterbird species that is likely to have undergone a significant decline in population size (up to 80%) over the past 20 years. Using the results of the current survey to inform the development of a management plan and a reassessment of conservation status for this species should therefore be a priority.
- The current project has included only preliminary analyses of the extensive dataset produced by the 2008 National Waterbird Survey and many recommendations of relevance to policy and management require further analyses and consideration in the context of specific management questions, including:
  - identification of wetlands of national importance to particular species of waterbirds to ensure these are adequately protected by the reserve network and conservation agreements, e.g. Ramsar
  - identification of wetlands of regional importance to waterbirds, both overall and to particular species (i.e. within state jurisdictions or drainage divisions and catchment), to ensure these are adequately represented by the reserve network and off-reserve conservation measures, e.g. water management and planning
  - identification of wetlands of local importance to waterbirds using data on species and functional compositions (e.g. breeding and foraging habits of community) to inform appropriate on-ground management actions, e.g. protection of nesting habitat or water level manipulation, and contribute to development of wetland-scale management plans (e.g. for national parks)
  - identification of waterbird species of potential concern for development of targeted species management plans.
- Much of the value of the National Waterbird Survey will come from repeating it over time, particularly for wetlands of high and very high importance, and supplementing it with longitudinal studies of targeted wetlands that respectively explore long-term temporal trends and finer seasonal and event-based fluctuations. The latter could be largely undertaken by skilled volunteers from organisation like BirdLife Australia.
- Given the potential decline in migratory shorebirds and because of the significance of migratory birds to many of Australia’s international agreements, e.g. JAMBA, CAMBA and ROKAMBA, there is considerable merit in extending the amount of shoreline covered in future surveys with targeted surveys of regions of known importance to improve estimates of shorebird numbers in Australia.

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- The long-term assessment of waterbird numbers in eastern Australia conducted during this project provides further evidence that wetland area, waterbird numbers and numbers of breeding waterbirds and breeding species, have all declined in this region over the past 27 years. While climate, especially the recent drought, is obviously implicated in many of these trends, changes in the composition of waterbird communities through time in regulated wetlands, indicate that river regulation is partially contributing to these declines. Detailed analyses of changes to river flow regimes, published in peer reviewed journals, support this interpretation. Other factors not measured in our study could also be contributing to reductions, particularly long, dry periods. Waterbirds could serve as a focus in addressing over-allocation and flow regime alteration in regulated systems of the Murray–Darling Basin, through the mechanism of the Murray–Darling Basin planning processes, and also serve as a baseline for protection of the mostly unregulated rivers and wetlands of the Lake Eyre Basin.
- The Eastern Australian Aerial Waterbird Survey provides a valuable long-term ecological dataset from which to examine human impacts on waterbird populations and wetland condition as well as from which to assess the efficacy of management actions, e.g. wetland restoration or rules for water planning and management. Long-term data sets (such as the aerial surveys of waterbirds) are critical for future management to ensure measurement of success for key questions, regarding the success of water management plans, ecological recovery following drought and responses to climate change. Such analyses needs to also include assessment of potential explanatory factors including changes to flow regimes and climate.
- The National Waterbird Database developed in this project is a significant resource that provides a baseline against which to comapre future data, including more recent evidence of the recovery of waterbird populations as a result of wetter years in 2010–11. The database has the potential to inform the management of Australia’s rivers and wetlands and could influence future research on Australia’s waterbirds. As a rigorously constructed platform, the database can support national waterbird data into the future, and could substantially contribute to the current strategic planning for national waterbird data requirements Continued collaboration between the Australian Government, jurisdictions, researchers, and key non-government organisations committed to bird conservation will provide the best opportunity for the development of a successful national approach to the organisation, storage and dissemination of waterbird data.

5.2.2. Recommendations for future research

- The waterbird survey data, now available via the National Waterbird Database, including the extensive spatial dataset produced by the 2008 National Waterbird Survey and the long-term dataset from the Eastern Australian Aerial Waterbird Survey, has considerable potential for generating new knowledge about the ecological structure, function and condition of Australian rivers and wetlands and waterbird populations and communities.
- Some of the key questions that might be addressed using the existing dataset include:
  - How do patterns of waterbird diversity and abundance at a national scale relate to patterns of diversity and abundance of other aquatic organisms, e.g. frogs, fish, wetland plants?
  - The mechanisms in which river regulation may affect whole ecosystems (eg food webs, feeding and nesting areas for waterbirds).

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- What spatial patterns exist in the distribution of waterbird species at a national scale and how do these relate to wetland area, wetland type, climate, hydrology, land use and landscape factors, e.g. proximity to other wetlands or urban centres?
- To what extent can the effects of climate, changes to flow (e.g. river regulation) and other landscape factors, e.g. land use, be identified in temporal and spatial patterns of waterbird abundance and community composition?
- How vulnerable, in terms of projected exposure, are wetlands of importance to waterbirds to climate change in different regions of Australia?
- How will climate change, habitat loss and flow modification interact with identified population declines and what are the implications for adequacy of the current reserve network and waterbird conservation?

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Glossary

Anatidae	A family of birds comprising ducks, geese and swans.
Evenness	Refers in ecology to the diversity of a community or a sample, including species richness and how evenly individuals are distributed among the species present.
Flight track log	A record of flight paths flown (i.e. locations and distances) and their dates and times.
Functional group	A group of species that share common functional traits, e.g. food sources.
Goodness of fit	A measure of how well a model explains the data it is trying to predict.
GPS	Global positioning system—technology used to provide locations (e.g. longitude and latitude).
Multivariate techniques	Methods of statistical analysis that examine patterns among groups of variables rather than one or two as in univariate analyses.
Piscivores	Fish-eating birds
Rarity	The degree of uncommonness (e.g. of a species).
Species abundance distributions	A graphical representation of the relationship between the number of individual organisms and the number of species recorded within a sample.
Species accumulation curves	A graphical representation of the relationship between the number of species and the area sampled (or the effort directed towards sampling).
Species richness	The number of species present.
Survey band	A strip of land within which aerial surveys of waterbirds are conducted.

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Appendix A—Waterbird species and functional groups identified during National Waterbird Survey (2008)

Duck Code used to identify each species with its matching CavsCode and aerial survey code matched to waterbird name (recorded as Duck Name in database) and specific name. Migatory shorebirds are identified (m). Some species could not be surveyed during aerial surveys or were grouped. Functional groups were ducks, small grebes and jacanans (du); herbivores (he); shorebirds (sh); piscivores (pi) and large wading birds (la).

Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
ABN	0197		Australasian bittern	*Botaurus poiciloptilus*	La
ABO	0854		Abbott's booby	*Papasula abbotti*	Pi
ACR	0049		Australian crake	*Porzana fluminea*	La
ADW	0939	LGW(m)	Asian dowitcher	*Limnodromus semipalmatus*	Sh
ALG	0061	GRE	Little (Australasian) grebe	*Tachybaptus novaehollandiae*	Du
APR	0173		Australian pratincole	*Stiltia isabella*	Sh
ASP	0170	LGW	Painted snipe	*Rostratula australis*	Sh
ATN	0952		Arctic tern	*Sterna paradisaea*	Pi
AVO	0148	AVO	Red-necked avocet	*Recurvirostris novaehollandiae*	Sh
BAG	0152	LGW(m)	Black-tailed godwit	*Limosa nebularia*	Sh
BBN	0196		Black bittern	*Ixobrychus flavicollis*	La
BBR	0046		Buff-banded rail	*Gallirallus philippensis*	Sh
BBS	0887		Buff-breasted sandpiper	*Tryngites subruficollis*	Sh
BBU	0216	BBD	Blue-billed duck	*Oxyura australis*	Du
BCR	0050		Baillons crake	*Porzana pusilla*	Sh
BCU	0174		Bush stone-curlew	*Burhinus grallarius*	La

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
BDP	0135	BDP	Banded lapwing	*Vanellus tricolor*	Sh
BDU	0208	BDU	Pacific black duck	*Anas superciliosa*	Du
BFC	0098		Black-faced cormorant	*Phalacrocorax fuscescens*	Pi
BFP	0144	SMW	Black-fronted dotterel	*Elseyornis melanops*	Sh
BGU	0856		Black-tailed gull	*Larus crassirostris*	Pi
BHE	0053		Bush hen	*Amaurornis olivaceus*	He
BKU	0206	BKU	Radjah shelduck (Burdekin duck)	*Tadorna radjah*	Du
BNH	0796		Black-crowned night heron	*Nycticorax nycticorax*	La
BNT	0119	TRN	Black-naped tern	*Sterna sumatrana*	Pi
BNY	8815		Black noddy	*Anous minutus*	Pi
BOO	0102		Brown booby	*Sula leucogaster*	Pi
BRI	8808	TRN	Bridled tern	*Sterna anaethetus*	Pi
BRL	0177	BRL	Brolga	*Grus rubicundus*	La
BSK	0127		Brown skua	*Stercorarius antarctica*	Pi
BSP	0167	SMW(m)	Broad-billed sandpiper	*Limicola falcinellus*	Sh
BST	0147	BST	Banded stilt	*Cladorhynchus leucocephalus*	Sh
BSW	0203	BSW	Black swan	*Cygnus atratus*	He
BTG	0153	LGW(m)	Bar-tailed godwit	*Limosa lapponica*	Sh
BTN	0055	BTN	Black-tailed native-hen	*Gallinula ventralis*	He
BWS	0212	BWS	Australasian shoveler	*Anas rhynchotis*	Du
CAG	0799		Canada goose	*Branta canadensis*	He

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
CAP	0894	(m)	Caspian plover	*Charadrius asiaticus*	Sh
CBG	0198	CBG	Cape Barren goose	*Cereopsis novaehollandiae*	He
CEG	0977	EGR	Cattle egret	*Ardea ibis*	La
CGA	0825		Cape gannet	*Morus capensis*	Pi
CNR	0047		Chestnut rail	*Eulabeornis castaneoventris*	Sh
CNY	8814		Common noddy	*Anous stolidus*	Pi
COS	0157	SMW(m)	Common sandpiper	*Tringa hypoleucos*	Sh
COT	0059	COT	Eurasian coot	*Fulica atra*	He
CRK	0891	SMW(m)	Common redshank	*Tringa totanus*	Sh
CSP	0161	SMW(m)	Curlew sandpiper	*Calidris ferruginea*	Sh
CST	0112	CST	Caspian tern	*Hydroprogne caspia*	Pi
CTL	0210	CST	Chestnut teal	*Anas castanea*	Du
CTN	0115	TRN	Crested tern	*Sterna bergii*	Pi
DAR	0101	DAR	Darter	*Anhinga melanogaster*	Pi
DBD	0140	SMW(m)	Double-banded plover	*Charadrius bicinctus*	Sh
DLN	0888	SMW(m)	Dunlin	*Calidris alpina*	Sh
DMG	T183		Domestic goose sp.	*Anser anser*	He
DSP	0890	SMW(m)	Baird's sandpiper	*Calidris bairdii*	Sh
DUK			Unidentified duck		Du
ECU	0149	LGW(m)	Eastern curlew	*Numenius madagascariensis*	Sh
EGR	T179	EGR	Egrets		La
EPT	0759		Eaton's pintail	*Anas eatoni*	Du
ERE	0191	EGR	Eastern reef egret (Reef heron)	*Egretta sacra*	La
FDU	0214	FDU	Freckled duck	*Stictonetta*	Du

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
				naevosa	
FGU	0885		Franklin's gull	*Leucophaeus pipixcan*	Pi
FTN	0118	TRN	Fairy tern	*Sterna nereis*	Pi
GAN	0104		Australasian gannet	*Morus serrator*	Pi
GBH	0184	GBH	Great-billed heron	*Ardea sumatrana*	La
GBT	0111	GBT	Gull-billed tern	*Sterna nilotica*	Pi
GCG	0060	GCG	Great crested grebe	*Podiceps cristatus*	Pi
GGY	0209		Garganey	*Anas querquedula*	Du
GLI	0178	GLI	Glossy ibis	*Plegadis falcinellus*	La
GNK	0158	SMW(m)	Greenshank	*Tringa nebularia*	Sh
GNT	0165	SMW(m)	Great knot	*Calidris tenuirostris*	Sh
GOD		LGW(m)	Unidentified godwit		Sh
GPG	0201	GPG	Green pygmy-goose	*Nettapus pulchellus*	Du
GPL	8006	SMW(m)	Pacific golden plover	*Pluvialis fulva*	Sh
GRC	0096	GRC	Great cormorant	*Phalacrocorax carbo*	Pi
GRE	T180	GRE	Small grebes	*Tachybaptus ruficollis*	Du
GRP	0136	SMW(m)	Grey plover	*Pluvialis squatorola*	Sh
GSK	0980		Great skua	*Stercorarius skua*	Pi
GTA	0155	SMW(m)	Grey-tailed tattler	*Tringa brevipes*	Sh
GTL	0211	GTL	Grey teal	*Anas gracilis*	Du
GYP	0835	SMW(m)	Grey phalarope	*Phalaropus fulicarius*	Sh
GYT	0982		Grey ternlet	*Procelsterna cerulea*	Pi
HHD	0215	HHD	Hardhead	*Aythya australis*	Du

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
HHG	0062	GRE	Hoary-headed grebe	*Poliocephalus poliocephalus*	Du
HPL	0138	SMW	Hooded plover	*Thinornis rubricollis*	Sh
HSG	0815	(m)	Hudsonian godwit	*Limosa haemastica*	Sh
HTN	8817	TRN	White tern	*Gygis alba*	Pi
ILD	0145		Inland dotterel	*Charadrius australis*	Sh
IMP	0970		Imperial shag	*Leucocarbo atriceps nivalis*	Pi
JAB	0183	JAB	Jabiru (Black-necked) stork	*Ephippiorhync hus asiaticus*	La
JAC	0171	JAC	Comb-crested jacana	*Irediparra gallinacea*	Du
KGU	0981		Kelp gull	*Larus dominicanus*	Pi
KNT		SMW(m)	Unidentified knot		Sh
KPL	8774	SMW(m)	Kentish plover	*Charadrius alexandrinus*	Sh
KTN	0884	TRN	Black tern	*Chlidonias niger*	Pi
LBC	0097	LBC	Little black cormorant	*Phalacrocorax sulcirostris*	Pi
LBN	8703		Australian little bittern	*Ixobrychus dubius*	La
LCT	0116	TRN	Lesser crested tern	*Sterna bengalensis*	Pi
LCU	0151	LGW(m)	Little curlew	*Numenius minutus*	Sh
LGE	0187	LGE	Great egret	*Ardea alba*	La
LGP	0141	SMW(m)	Large (greater) sand plover	*Charadrius mongolus*	Sh
LGU	0785		Laughing gull	*Larus atricilla*	Pi
LGW	T181	LGW(m)	Large waders		Sh
LHW	0966		Lord Howe woodhen	*Gallirallus sylvestris*	Sh
LNY	8021		Lesser noddy	*Anous tenuirostris melanops*	Pi

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
LPC	0100	LPC	Little pied cormorant	*Phalacrocorax melanoleucos*	Pi
LPL	0851	(m)	Little ringed plover	*Charadrius dubius*	Sh
LRA	0045		Lewins rail	*Dryolimnas pectoralis*	Sh
LSN	0168	LGW(m)	Lathams snipe	*Gallinago hardwickii*	Sh
LSP	0827	SMW(m)	Stilt sandpiper	*Calidris himantopus*	Sh
LST	0965	SMW(m)	Long-toed stint	*Calidris himantopus*	Sh
LTE	0185	EGR	Little egret	*Ardea garzetta*	La
LTN	0117	TRN	Little tern	*Calidris subminuta*	Pi
LTS	0857	SMW(m)	Little stint	*Calidris minuta*	Sh
LYL	0809	(m)	Lesser yellowlegs	*Tringa flavipes*	Sh
MAL	0948	MAL	Mallard	*Anas platyrhynchos*	Du
MBO	0105		Masked booby	*Sula dactylatra*	Pi
MDU	0217	MDU	Musk duck	*Biziura lobata*	Du
MHE	0056	MHE	Dusky moorhen	*Gallinula tenebrosa*	He
MLW	0133	MLW	Masked lapwing	*Vanellus miles*	Sh
MNH	0797		Malayan night heron	*Gorsachius melanolophus*	La
MNU	0207		Australian shelduck (Mountain duck)	*Tadorna tadornoides*	He
MOP	0139	(m)	Lesser sand (Mongolian) plover	*Charadrius mongolus*	Sh
MPG	0199	MPG	Magpie goose	*Anseranas semipalmata*	He
MSP	0159	SMW(m)	Marsh sandpiper	*Tringa stagnatilis*	Sh
MST	0110	TRN	Whiskered (marsh) tern	*Sterna hybrida*	Pi
MSW	0906		Mute swan	*Cygnus olor*	He
NIL		NIL	zero count		

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
NKE	0192	NKE	Nankeen (rufous) night heron	*Nycticorax caledonicus*	La
NPT	0800		Northern pintail	*Anas acuta*	Du
NSV	0905		Northern shoveler	*Anas clypeata*	Du
OPL	0142		Oriental plover	*Charadrius veredus*	Sh
OPR	0172		Oriental pratincole	*Glareola maldivarum*	Sh
OTN	0953	TRN	Common tern	*Sterna hirundo*	Pi
PCO	0099	PCO	Pied cormorant	*Phalacrocorax varius*	Pi
PED	0213	PED	Pink-eared duck	*Malacorhynchus membranaceus*	Du
PEL	0106	PEL	Pelican	*Pelecanus conspicillatus*	Pi
PGU	0126		Pacific gull	*Larus pacificus*	Pi
PIH	0190	PIH	Pied heron	*Ardea picata*	La
PLE	0186	EGR	Plumed (Intermediate) egret	*Casmerodius albus*	La
POC	0130	POC	Pied oystercatcher	*Haematopus longirostris*	La
PSD	0798		Paradise shelduck	*Tadorna variegata*	Du
PSN	0852		Pin-tailed snipe	*Gallinago stenura*	Sh
PSP	0978	SMW(m)	Pectoral sandpiper	*Calidris melanotos*	Sh
PTJ	0897		Pheasant-tailed jacana	*Hydrophasianus chirurgus*	Du
PWD	0205	GWD	Plumed whistling-duck	*Dendrocygna eytoni*	He
RBC	8759		Ruddy-breasted crake	*Porzana fusca*	Sh
RBO	0103		Red-footed booby	*Sula sula*	Pi
RCP	0143	SMW	Red-capped plover	*Charadrius ruficapillus*	Sh
RFF	0934	SMW(m)	Ruff (Reeve)	*Philomachus pugnax*	Sh
RKD	0132	SMW	Red-kneed dotterel	*Erthrogonys*	Sh

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
				cintus	
RLC	0900		Red-legged crake	*Rallina fasciata*	Sh
RNC	0048		Red-necked crake	*Rallina tricolor*	Sh
RNP	0932	(m)	Red-necked phalarope	*Phalaropus lobatus*	Sh
RNS	0162	SMW(m)	Red-necked stint	*Calidris ruficollis*	Sh
RNT	0164	SMW(m)	Red knot	*Calidris canutis*	Sh
RPL	0895	(m)	Ringed plover	*Charadrius hiaticula*	Sh
RSB	0181	RSB	Royal spoonbill	*Platalea regia*	La
RSP	0849	SMW(m)	White-rumped sandpiper	*Calidris fuscicollis*	Sh
RTN	0113	TRN	Roseate tern	*Sterna dougallii*	Pi
RTS	0129	SMW(m)	Ruddy turnstone	*Arenaria interpres*	Sh
RTT	0107		Red-tailed tropicbird	*Phaethon rubricauda*	Pi
SAB	0783		Sabine's gull	*Larus sabini*	Pi
SAC	0898	BRL	Sarus crane	*Grus antigone*	La
SCR	0051		Spotless crake	*Porzana tabuensis*	Sh
SCU	0175	BSC	Beach stone-curlew	*Esacus neglectus*	La
SDG	0166	SMW	Sanderling	*Calidris alba*	Sh
SGU	0125	SGU	Silver gull	*Larus novaehollandiae*	Pi
SHE	0058	SHE	Purple swamphen	*Porphyrio porphyrio*	He
SMW	T182	SMW(m)	Small waders		Sh
SNI	0180	SNI	Straw-necked ibis	*Threskiornis spinicollis*	La
SOC	0131	SOC	Sooty oyster catcher	*Haematopus longirostris*	La
SRK	0820	(m)	Spotted redshank	*Tringa erythropus*	Sh
SSN	0169	(m)	Swinhoe's snipe	*Gallinago*	Sh

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
				megala	
STS	0163	SMW(m)	Sharp-tailed sandpiper	*Calidris acuminata*	Sh
STH	0193	MHE	Striated (mangrove) heron	*Butorides striatus*	La
STN	8811	TRN	Sooty tern	*Sterna fuscata*	Pi
SWD	0745		Spotted whistling duck	*Dendrocygna guttata*	Du
TAT		SMW(m)	Unidentified tattler		Sh
TBO	5000		Tasman booby	*Sula dactylatra tasmani*	Pi
TMH	0054		Tasmanian native hen	*Gallinula mortierii*	He
TRN		TRN	Unidentified tern		Pi
TSP	0160	SMW(m)	Terek sandpiper	*Tringa terek*	Sh
TTN	0985		Antarctic tern	*Sterna vittata*	Pi
USP	0892		Upland sandpiper	*Bartramia longicauda*	Sh
WBC	0052		White-browed crake	*Porzana cinerea*	Sh
WBW	0768		White-breasted waterhen	*Amaurornis phoenicurus*	Sh
WCK	0711		Watercock	*Gallicrex cinerea*	Sh
WDU	0202	WDU	Wood (maned) duck	*Chenonetta jubata*	He
WFH	0188	WFH	White-faced heron	*Ardea novaehollandiae*	La
WHI	0179	WHI	White (sacred) ibis	*Threskiornis molucca*	La
WHS	0146	WHS	Black-winged stilt	*Himantopus himantopus*	Sh
WIM	0150	LGW(m)	Whimbrel	*Numenius phaeopus*	Sh
WLP	0886	(m)	Wilson's phalarope	*Phalaropus tricolor*	Sh
WNH	0189	WNH	Pacific (White-necked) heron	*Ardea pacifica*	La

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Duck code	*Cavs code*	*Aerial survey code*	*Duck name*	*Specific name*	*Functional group*
WPG	0200	WPG	White (cotton) pygmy-goose	*Nettapus coromandelianus*	Du
WSP	0154	SMW(m)	Wood sandpiper	*Tringa glareola*	Sh
WTA	0156	SMW(m)	Wandering tattler	*Heteroscelus incanus*	Sh
WTN	0114	TRN	White-fronted tern	*Sterna striata*	Pi
WTT	0108		White-tailed tropicbird	*Phaethon lepturus*	Pi
WWD	0204	WWD	Wandering whistling duck	*Dendrocygna arcuata*	Du
WWT	0109	TRN	White-winged tern	*Chlidonias leucopterus*	Pi
YBN	0907		Yellow bittern	*Ixobrychus sinensis*	La
YSB	0182	YSB	Yellow-billed spoonbill	*Platalea flavipes*	La

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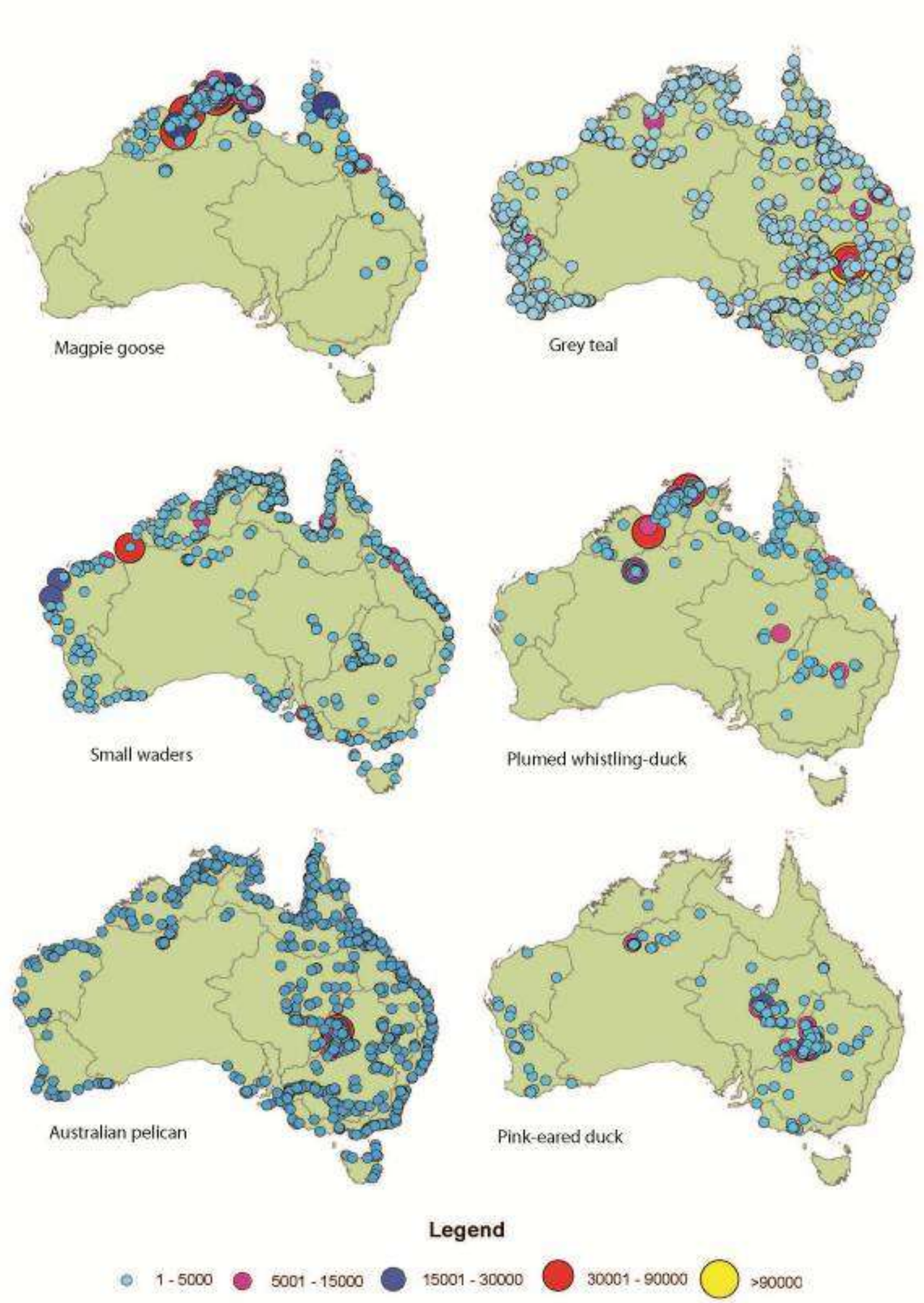
Appendix B—Distribution maps for 20 most abundant species surveyed during the aerial survey of 2008



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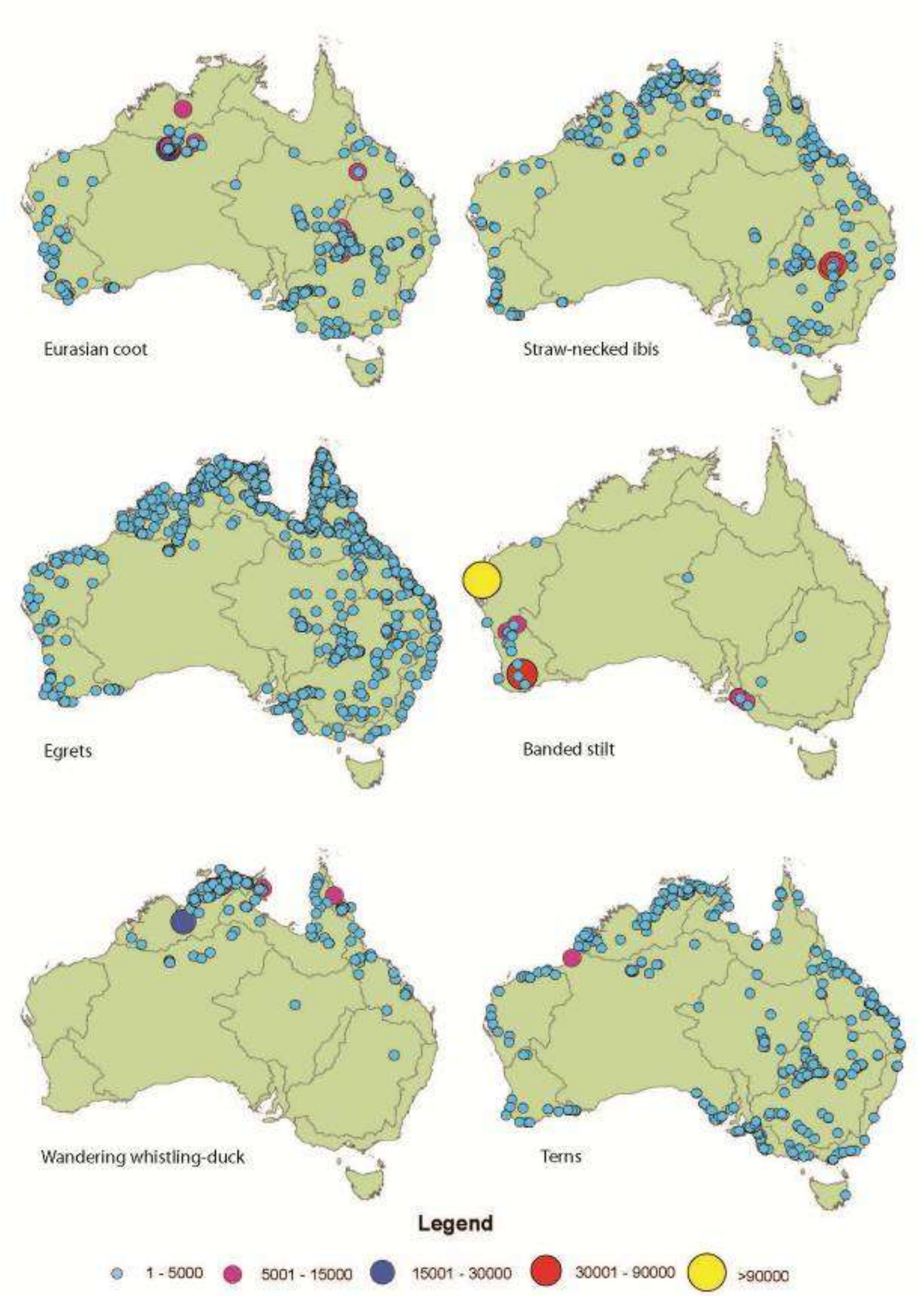
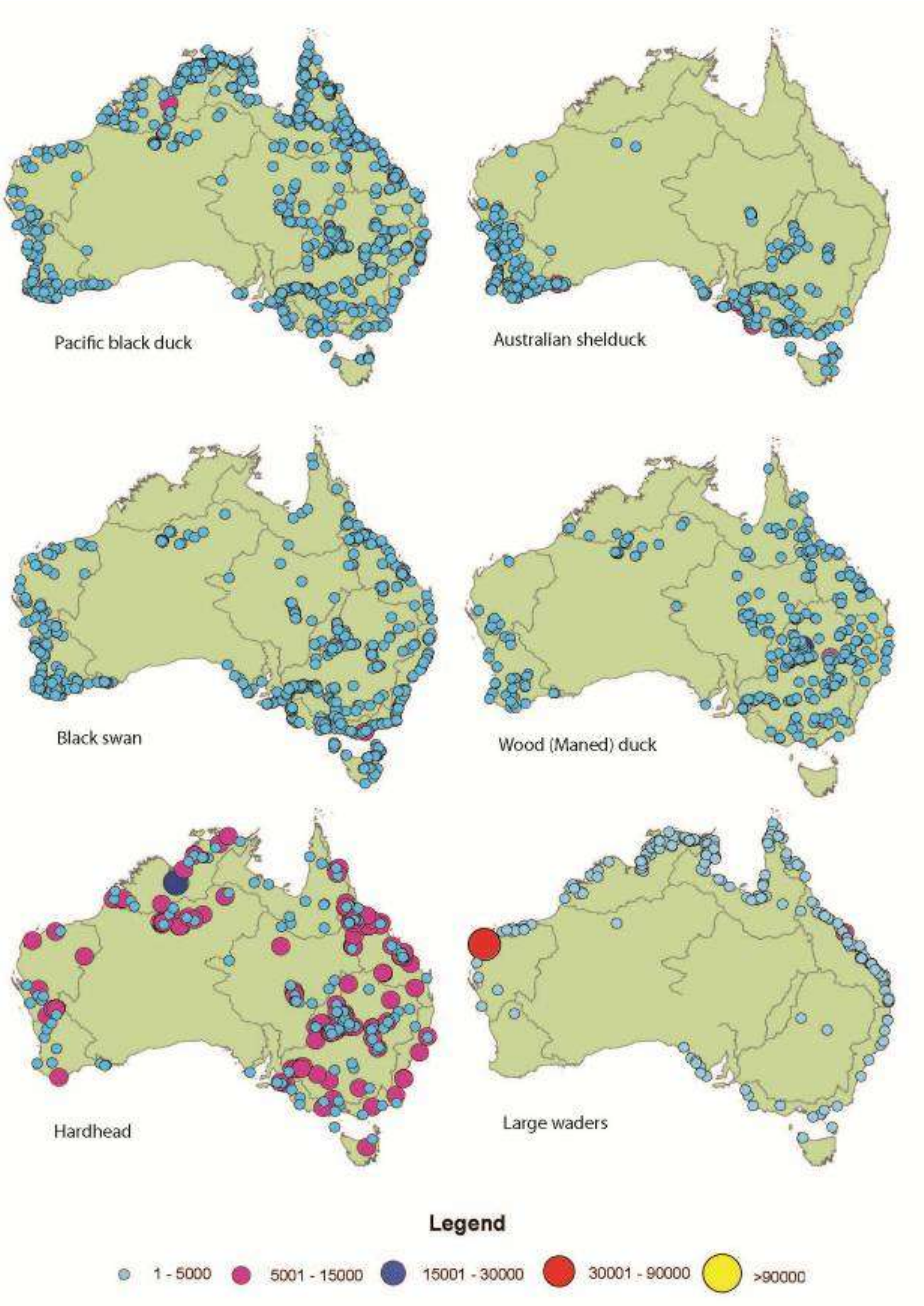

Eurasian coot
Straw-necked ibis
Egrets
Banded stilt
Wandering whistling-duck
Terns
Legend
1 - 5000
5001 - 15000
15001 - 30000
30001 - 90000
>90000



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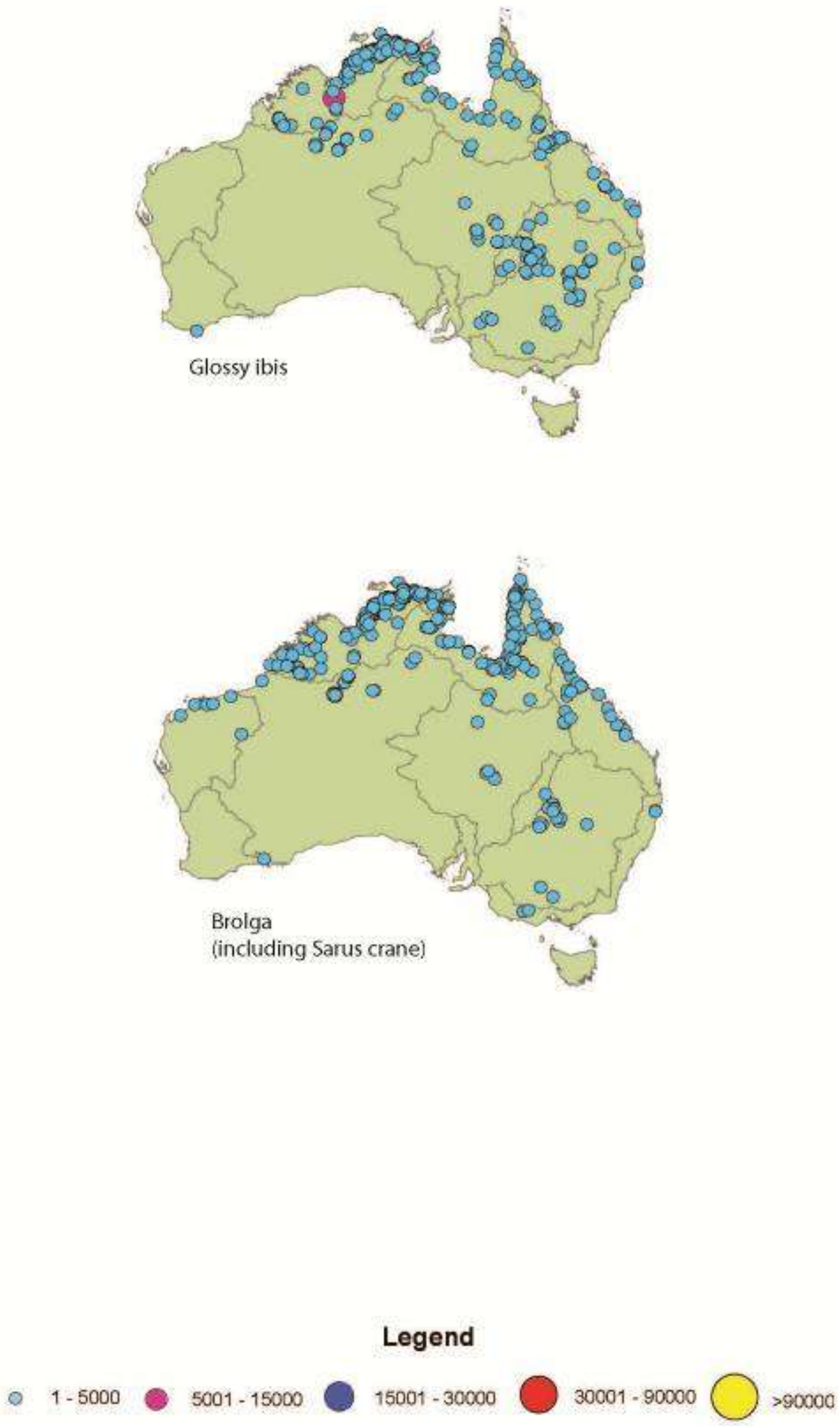

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Appendix C—Statistical analyses

Models and trends in waterbird abundance

Generalised additive modelling of waterbird abundance

Our independent variables included flow, wetland area, number of wetlands, rainfall and year (time). For total wetland area, number of wetlands, total number of birds and number of breeding species for the entire dataset, we used wetland area and number of wetlands as indices of inundation. We examined pairwise relationships among all variables using a scatter matrix plot. The scatter matrix plot can assist in examining pairwise relationships between the variables and the nature of these relationships as well as identifying any outliers. Axes labels are provided on alternate rows and columns.

To estimate the effect of flow, rainfall, inundated area and time on total waterbird abundance each wetland, we used the generalised additive models (GAM) with LOESS (locally weighted regression) smoother for Poisson distribution with log link function to develop a relationship between the waterbird abundance and these independent variables, across the entire region of eastern Australia and then separately for the 11 key wetlands. GAM is a compromise between a linear model and a smoothing function, and is a flexible tool with the fewest statistical assumptions (Hastie and Tibshirani 1990). These models could be fitted by numerical maximum likelihood using local scoring procedure, and LOESS functions could be used in the back-fitting algorithm. The package GAM (http://cran.r-project.org/web/packages/gam/index.html) in the R language (R Development Core Team 2011) was available to build these models. After we get the fitted waterbird abundance based on the above models, we compared these fitted data with the actual count data using the goodness of fit.

Mann–Kendall trend test of waterbird abundance

To determine the direction of annual waterbird abundance trends, we used the Mann–Kendall trend test (Mann 1945).

Changes in waterbird communities

We used separate one-way analyses to examine change over time in each wetland system; years were grouped into decades (1983–1989; 1990–1999; 2000–2008) for comparison. The null hypothesis of no difference in community composition between groups was tested using the global R statistic. This equals 1 when all replicates within a group are more similar to each other than any other replicate outside the group, and equals zero when dissimilarities between groups and within are the same on average (Clarke & Warwick 1994). For most wetlands, the number of comparisons was small relative to the number of replicates, significantly reducing the risk of Type I error (Clark 1993). A Bray–Curtis dissimilarity matrix of species abundance from all wetlands was calculated, after omitting samples with zero abundance across all species, and then fourth root $(x+1)^{0.25}$ transforming the data to reduce strongly heteroscedatistic variances among groups and reduce the risk of Type I error (Legendre & Legendre 1998).

Similarities and groupings among waterbird community composition over time were analysed using hybrid non-metric multidimensional scaling (nMDS). Such ordinations allowed portrayal of the entire waterbird community over time or space, allowing for comparison of wetlands or comparisons of the waterbird community on a particular wetland over time. If wetlands were clustered together, this usually indicated similar waterbird communities, while the opposite

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conclusion can be made if they were apart. Similarly for a wetland that changed over time, a clustering of points indicated that the waterbird community was reasonably stable, but if a sequence of years separated out, it was an indication of changes in the waterbird community. Ordinations were done on matrices of fourth-root transformed waterbird species abundance and environmental variables (wetland area and time) using normalised Bray–Curtis and Euclidean distance measures. Samples with low total abundance (<20) were omitted to prevent them from obscuring or distorting the ordination results. Configurations were calculated in two dimensions after 50 random starts and the configuration of Shepard diagrams examined for degenerate solutions (Legendre & Legendre 1998).

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Appendix D—Datasheets

Datasheet used for recording aerial survey counts for aerial survey of waterbirds across Australia in 2008.

Count type: 1 = tota l 2 = transect 3 = proportion

Waterbird Survey Voice Transcripts Date: Region: Sheet No:

Observer: Band: File Name : Section: Day of Survey:

Length: Min sec

Wetland Type:
1 = natural 2 =
artificial

Wtld seq	Wetland Name and or no.	Lat/Lon or Sub no. or transect no	Count type	%Prop or (t–time)	% Wtld full	% Wtld transect	Time	Species	Count	Wtld Area ha	Wtld type

Make sure all counts have a time and a sequence number

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Aircraft flying log for aerial survey of waterbirds across Australia in 2008.

UNSW
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Aircraft Log   Aircraft Callsign: UNSW Aerial Waterbird Survey   2008

Pilot:			RFO:			LBO:	
Day of Survey	Date	Take ,off Place	depart time	Landing Place	Land Time	Air Time	Cum Total

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Appendix E—Summary reports eastern aerial surveys

Summary reports of the 2007, 2008 and 2009 aerial surveys of waterbirds in eastern Australia as provided to jurisdictions.

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Department of Environment & Climate Change NSW

Aerial Survey of Wetland Birds in Eastern Australia - October 2007 Annual Summary Report

R.T. Kingsford & J.L. Porter
School of Biological, Earth and Environmental Sciences
University of New South Wales

Results summary

1. Severe and widespread drought conditions continue to affect wetlands, floodplains and rivers throughout eastern Australia. Trend analyses indicate declines in waterbird abundance, wetland area, breeding abundance and breeding species richness are significant.

2. Below average wetland area was recorded throughout most of the survey area (Fig.1). The southern Coorong was almost dry. The Macquarie Marshes, Lowbidgee and Menindee Lakes were dry or almost dry. Most rivers in the Murray-Darling Basin were also low with little water on the floodplain. Gippsland lakes in the survey band were dry.

3. Several wetlands in the Georgina-Diamantina catchment, including Lakes Torquinnie, Mumbleberry & Phillipi held water after rainfall early in 2007, and 42,000 waterbirds were recorded but these were drying back and shallow. Some of the Paroo overflow lakes also held water but relatively few birds (<4,100).

4. Wetland area index was the lowest on record (Fig. 2). Available wetland habitat was mostly (22%) distributed in the north (Band 10) and Bands 2 to 4. Band 2 contained 14% of total wetland area; Band 3 had 16% and Band 4 had 16% (Fig. 3).

5. Total waterbird abundance was low (second lowest on record; Fig. 3) and waterbirds were concentrated on a few wetlands. Six Queensland wetland systems held 41% of total abundance; Lake Torquinnie (15%, Band 8), Lake Moondarra (6%, band 10), Coolmunda Dam (6%, Band 6), Lake Phillipi and Pippagitta Waterhole (10%, Band 8) and Lake Galilee (4%, Band 9) (Fig. 4).

This survey is run by the University of NSW and the NSW Department of Environment and Climate Change, with funding contributed by the South Australian Department of Environment and Heritage, the Queensland Environment Protection Agency and the Victorian Department of Sustainability and Environment.

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Result summary continued

6. Total breeding index (all species combined) was below average, and concentrated (92%) in one location – Rhyll Swamp in Band 1 (Figs 4-6). Most birds (>99%) breeding here were White ibis. Breeding species richness was the lowest on record, with only two non-game species, White Ibis and Black Swan recorded (92% & 8%). Breeding within all survey bands was also low (Figs 7 & 8).

7. Low numbers of waterbirds and breeding on key wetland systems including Cooper Creek, Paroo overflow, Menindee Lakes, Lowbidgee and Macquarie Marshes extends a sequence of below average years (Figs 5 & 6). A combination of severe drought and long term effects of river regulation, continues to impact on wetland area, waterbird abundance and breeding.

8. Species at or near their lowest recorded numbers in 25 years included: Grey Teal, Black Swan, Australasian shoveler, Australian Shelduck, Musk Duck, Pacific Heron, Yellow-billed Spoonbill and Royal Spoonbill (Figs 9-29).

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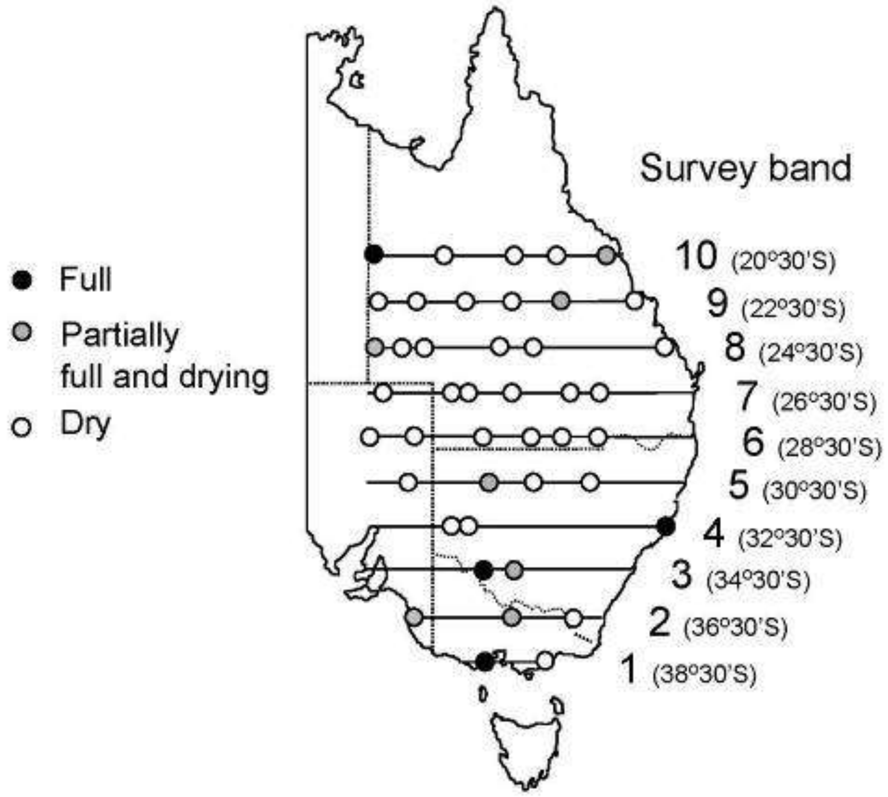
Figure 1. Wetland map 2007



Key to wetlands from W-E, by band

10 Lake Moondarra, Cloncurry River, Flinders River, Campaspe R, Burdekin R

9 Georgina R, Eyre Ck, Hamilton R, Diamantina R, Lake Galilee, Styx R

8 Mumbleberry-Torquinnie Lakes, Eyre Ck, Diamantina R, Thomson R, Barcoo R, various small coastal wetlands

7 Goyder Lagoon, Lake Yamma Yamma, Cooper Ck, Bulloo R, Paroo R, Warrego R

6 Lake Eyre, Lake Hope, Bulloo R, Paroo R, Warrego R, Balonne R,

5 Lake Frome, Paroo O'flow, Darling R, Macquarie Marshes

4 Menindee Lakes, Talyawalka Lakes, Myall Lakes

3 Murray River Lakes, Lowbidgee Swamp

2 Coorong, Cooper + Mokoan Lakes, Cooma-Monaro

1 Curdies Inlet, Jack Smith Lake

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Figure 2. Total wetland area

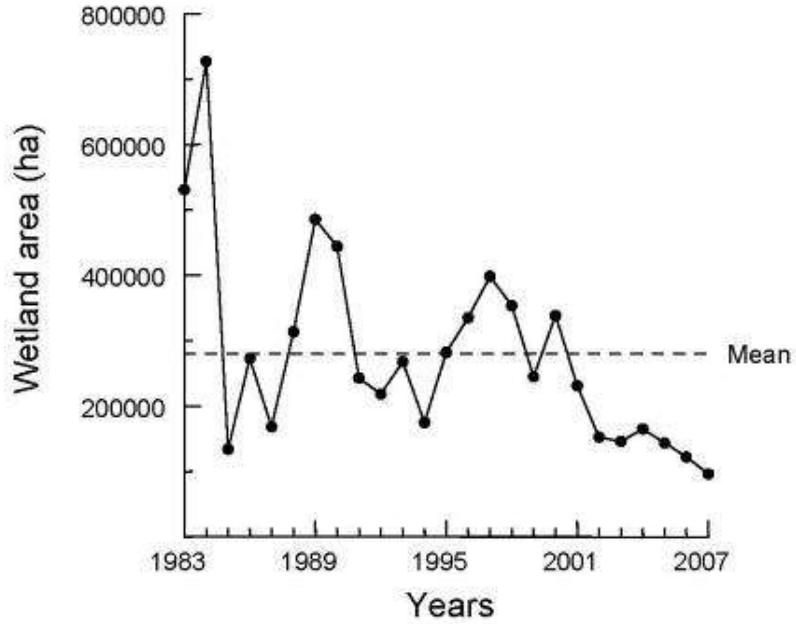

Figure 3. Total waterbirds

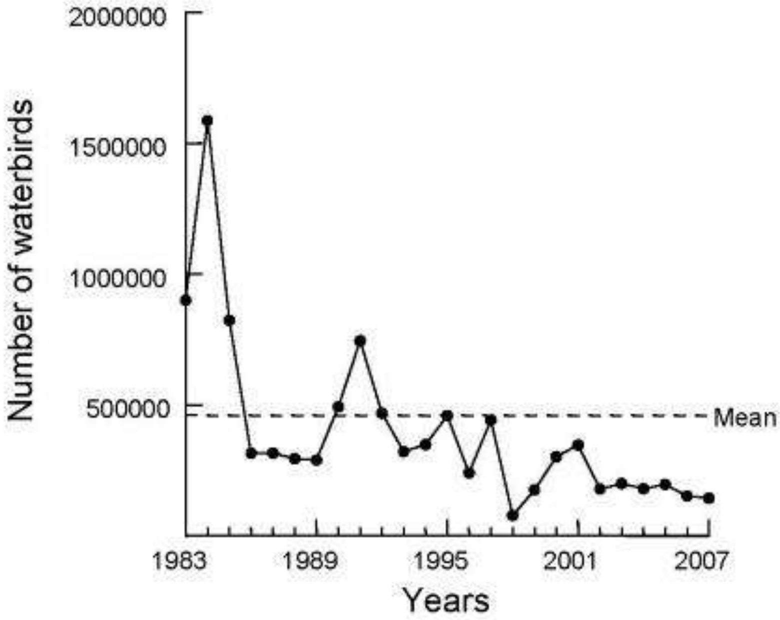

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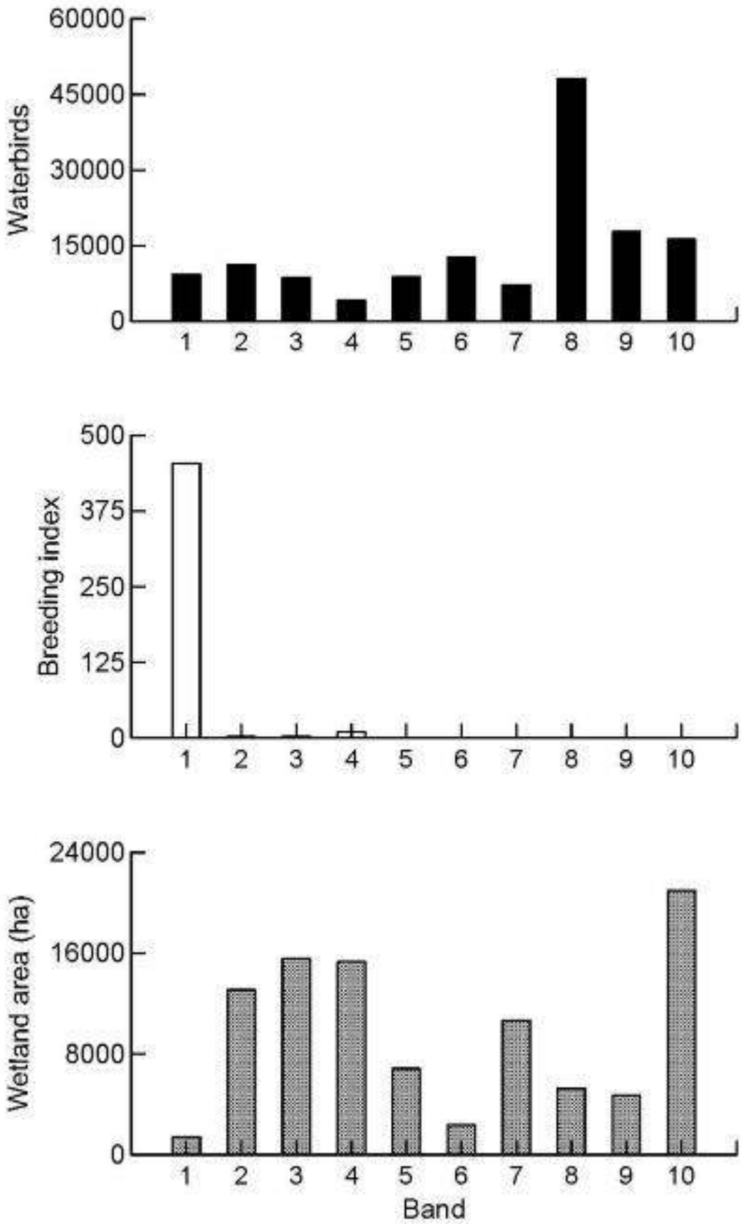
Figure 4. Band totals 2007



Scales vary on graph axes
5

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Figure 5. Breeding index (all species)

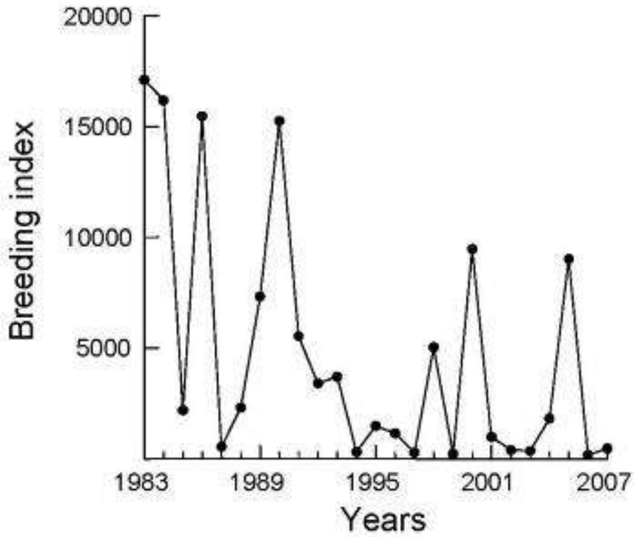
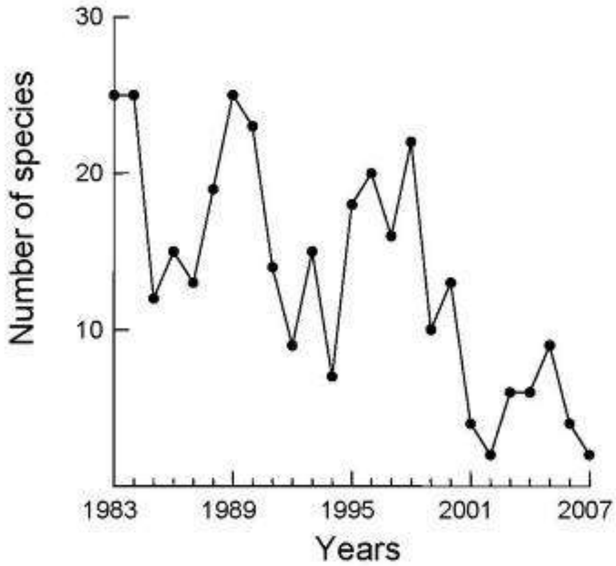


Figure 6. Number of species breeding



Scales vary on graph axes
6

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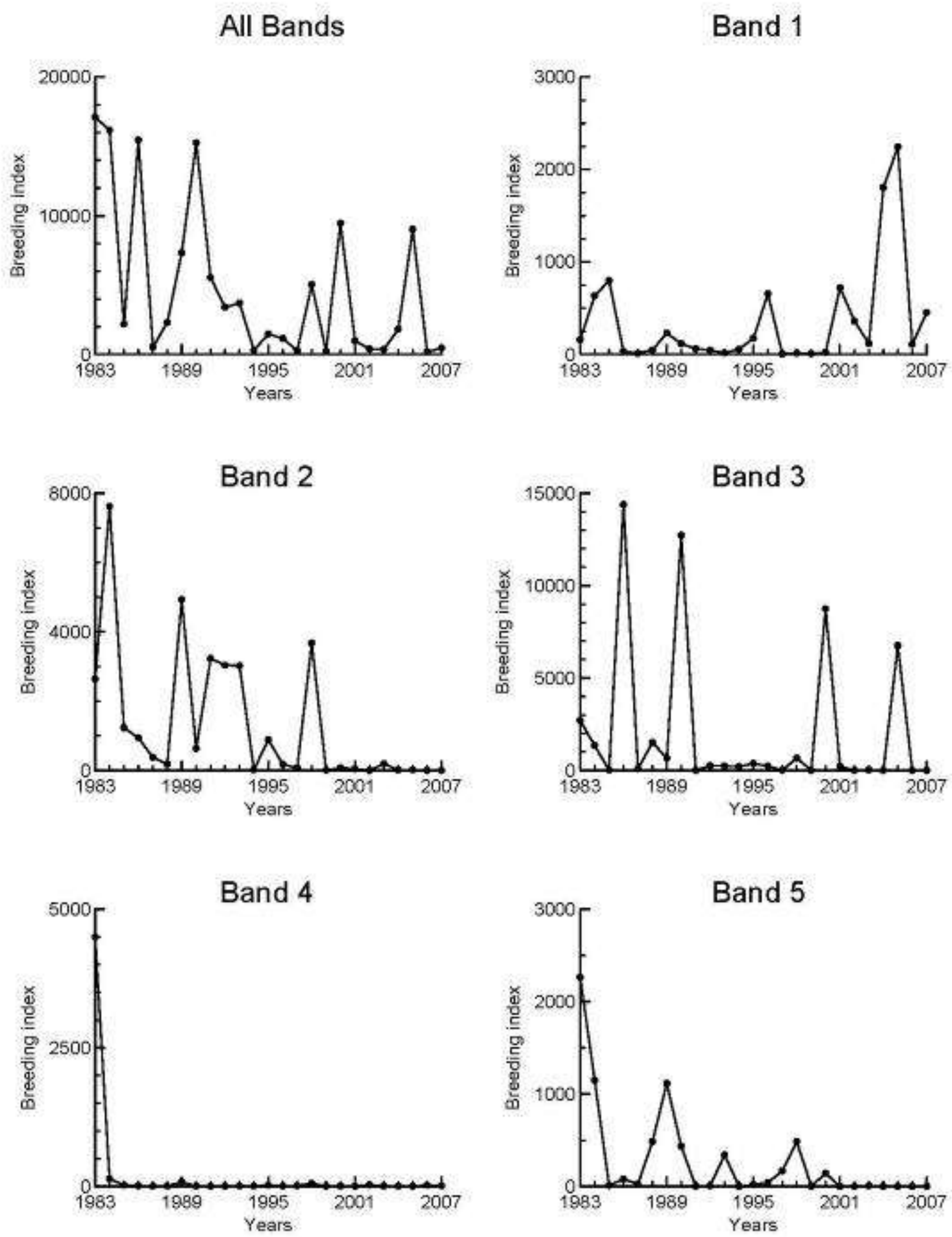
Figure 7. Breeding index (all species) 1-5



Scales vary on graphs

7

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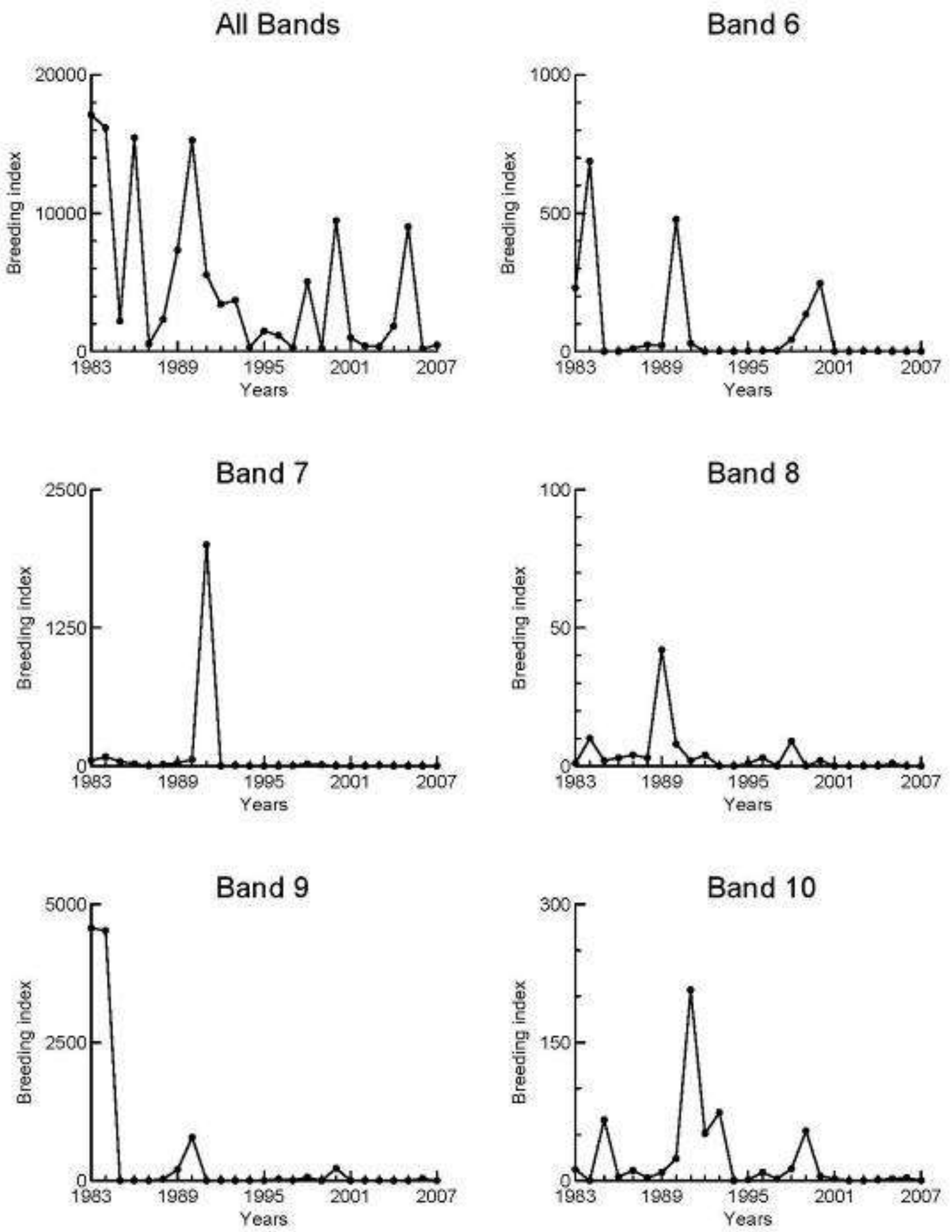
Figure 8. Breeding index 6-10



Scales vary on graphs

8

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THE UNIVERSITY OF NEW SOUTH WALES

Department of Environment & Climate Change NSW

Aerial Survey of Wetland Birds in Eastern Australia - October 2008 Annual Summary Report

J.L. Porter and R.T. Kingsford
School of Biological, Earth and Environmental Sciences
University of New South Wales

Results summary

1. The survey region experienced significant flooding in the Paroo-Warrego, Narran Lakes and Gippsland areas, early in 2008, however drought continues to affect wetlands, floodplains and rivers in much of eastern Australia. Trend analyses indicate overall declines in waterbird abundance, wetland area, breeding abundance and breeding species richness but increases in 2008 compared to previous years.

2. The Macquarie Marshes, Lowbidgee and southern Menindee Lakes were dry or almost dry. Most rivers in the Murray-Darling Basin were also low with little water on the floodplain. Wetlands in the Gippsland area in the survey band were dry, but flooded shortly afterwards (November 2008)

3. The Paroo overflow lakes and Cuttaburra channels held water after flooding in December 2007 and more than 50,000 waterbirds were recorded.

4. Total waterbird abundance was below average (Fig. 3) and waterbirds were concentrated on a few wetlands. Five wetland systems held more than 66% of total abundance; Lake Galilee (25%, Band 9), Cuttaburra Creek (17%), Paroo overflow (16%), Barwon River (6%) and Cooper Creek waterholes (Fig. 4).

5. Total breeding index (all species combined) was below average but higher than in the two previous years, and concentrated (94%) in two locations – Rhyll Swamp in Band 1, and Lake Galilee in Band 9 (Figs 4-6). Breeding species richness was low, and comprised mainly of three non-game species, White Ibis, Whiskered Tern and Black Swan (92%). Few active breeding sites were recorded elsewhere (Figs 7 & 8).

This survey is run by the University of NSW and the NSW Department of Environment and Climate Change, with funding provided by the South Australian Department of Environment and Heritage, the Queensland Environment Protection Agency and the Victorian Department of Sustainability and Environment.

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Result summary continued

6. Low numbers of waterbirds and breeding was observed on key wetland systems including Cooper Creek, Menindee Lakes, Lowbidgee and Macquarie Marshes extending a sequence of below average years (Figs 5 & 6). A combination of drought and long term cumulative effects of river regulation, continues to impact on wetland availability, waterbird abundance and breeding.

7. Species at or near their lowest recorded numbers in 25 years included: Grey Teal, Black Swan, Australasian shoveler, Australian Shelduck, Musk Duck, Pacific Heron, Yellow-billed Spoonbill and Royal Spoonbill (Figs 9-29).

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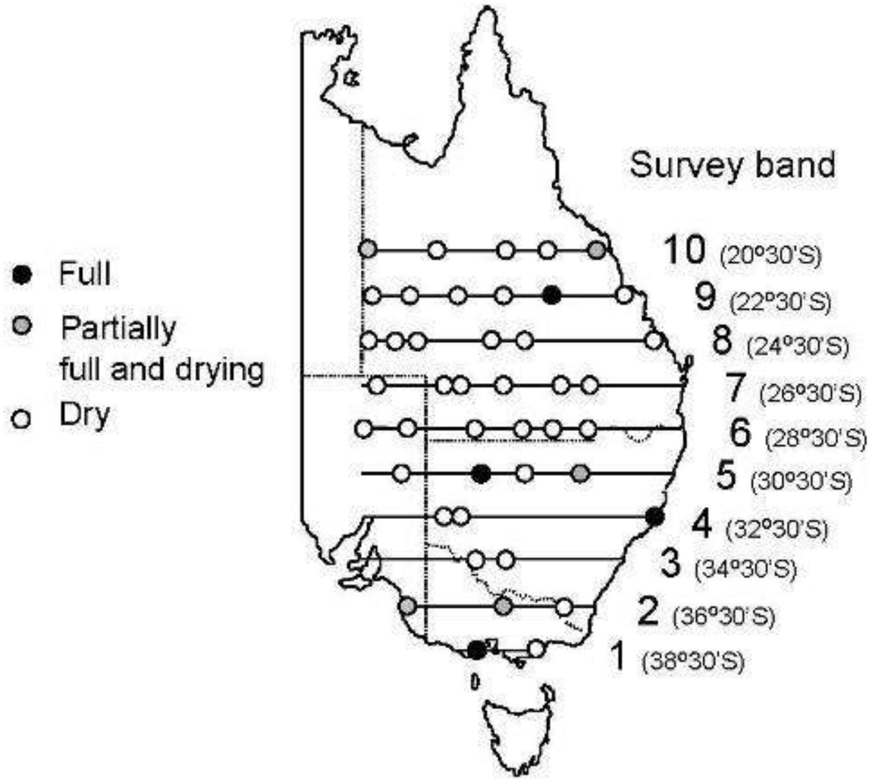
Figure 1. Wetland map 2008



Key to wetlands from W-E, by band

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9 Georgina R, Eyre Ck, Hamilton R, Diamantina R, Lake Galilee, Styx R

8 Mumbleberry-Torquinnie Lakes, Eyre Ck, Diamantina R, Thomson R, Barcoo R, various small coastal wetlands

7 Goyder Lagoon, Lake Yamma Yamma, Cooper Ck, Bulloo R, Paroo R, Warrego R

6 Lake Eyre, Lake Hope, Bulloo R, Paroo R, Warrego R, Balonne R,

5 Lake Frome, Paroo O'flow, Darling R, Macquarie Marshes

4 Menindee Lakes, Talywalka Lakes, Myall Lakes

3 Murray River Lakes, Lowbidgee Swamp

2 Coorong, Cooper + Mokoan Lakes, Cooma-Monaro

1 Curdies Inlet, Jack Smith Lake

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Figure 2. Total wetland area

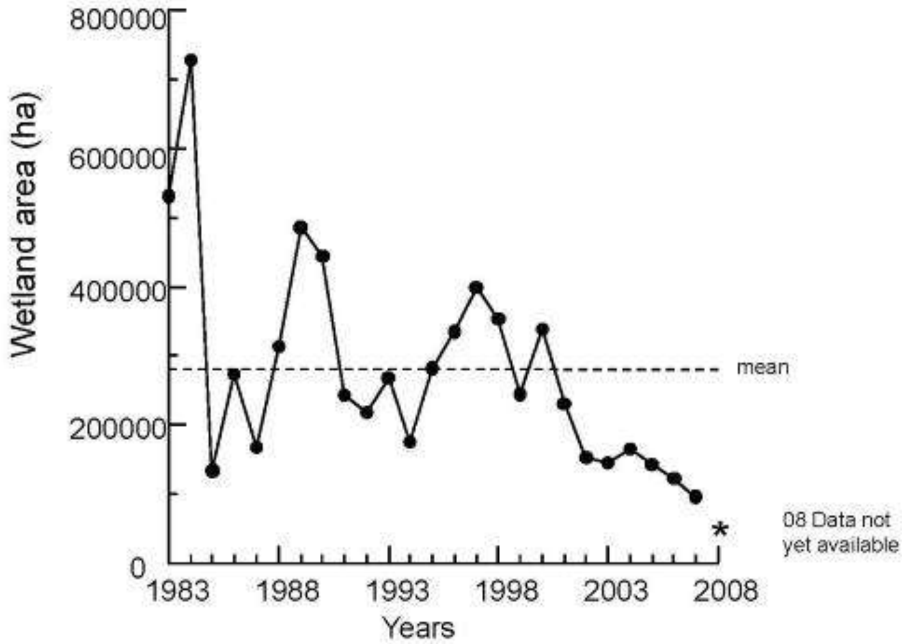

Figure 3. Total waterbirds

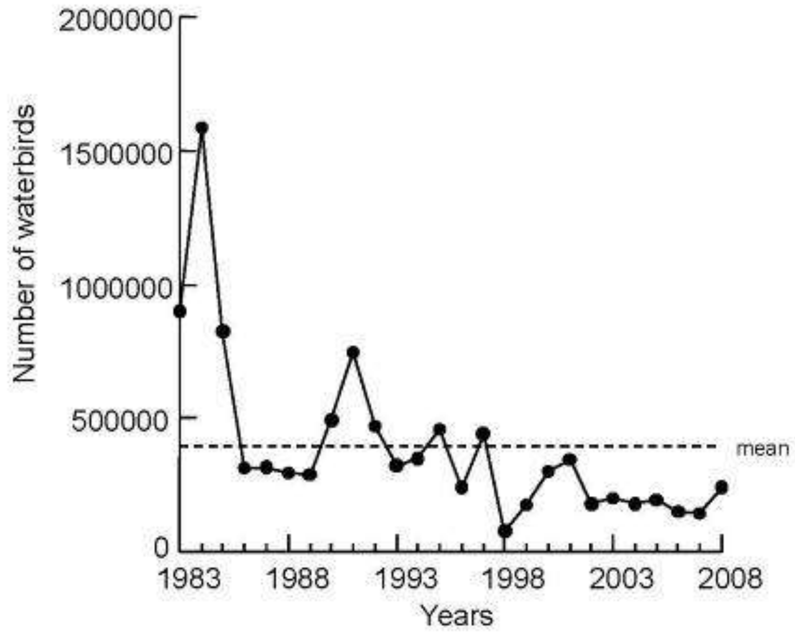

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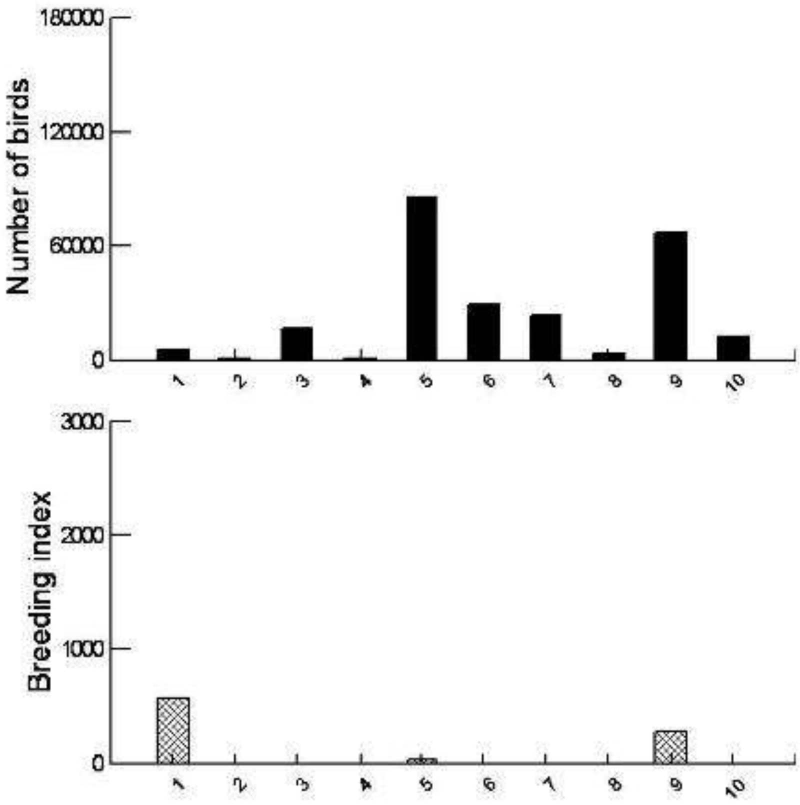
Figure 4. Band totals 2008



Scales vary on graph axes
5

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Ramsar additional infomation -
Richard Kingsford

Figure 5. Breeding index (all species)

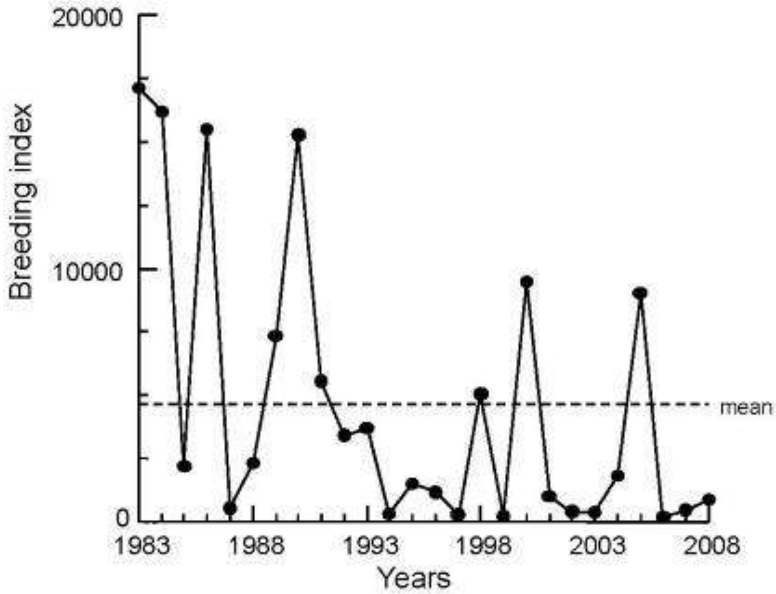
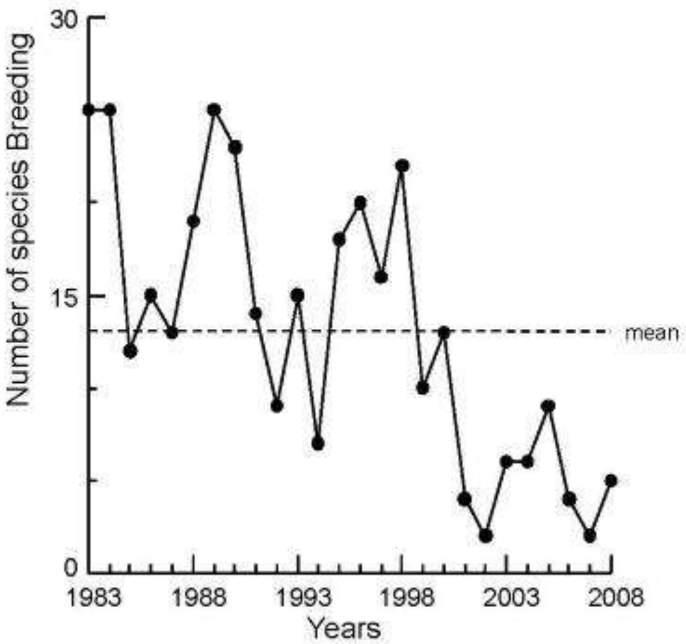


Figure 6. Number of species breeding



Scales vary on graph axes

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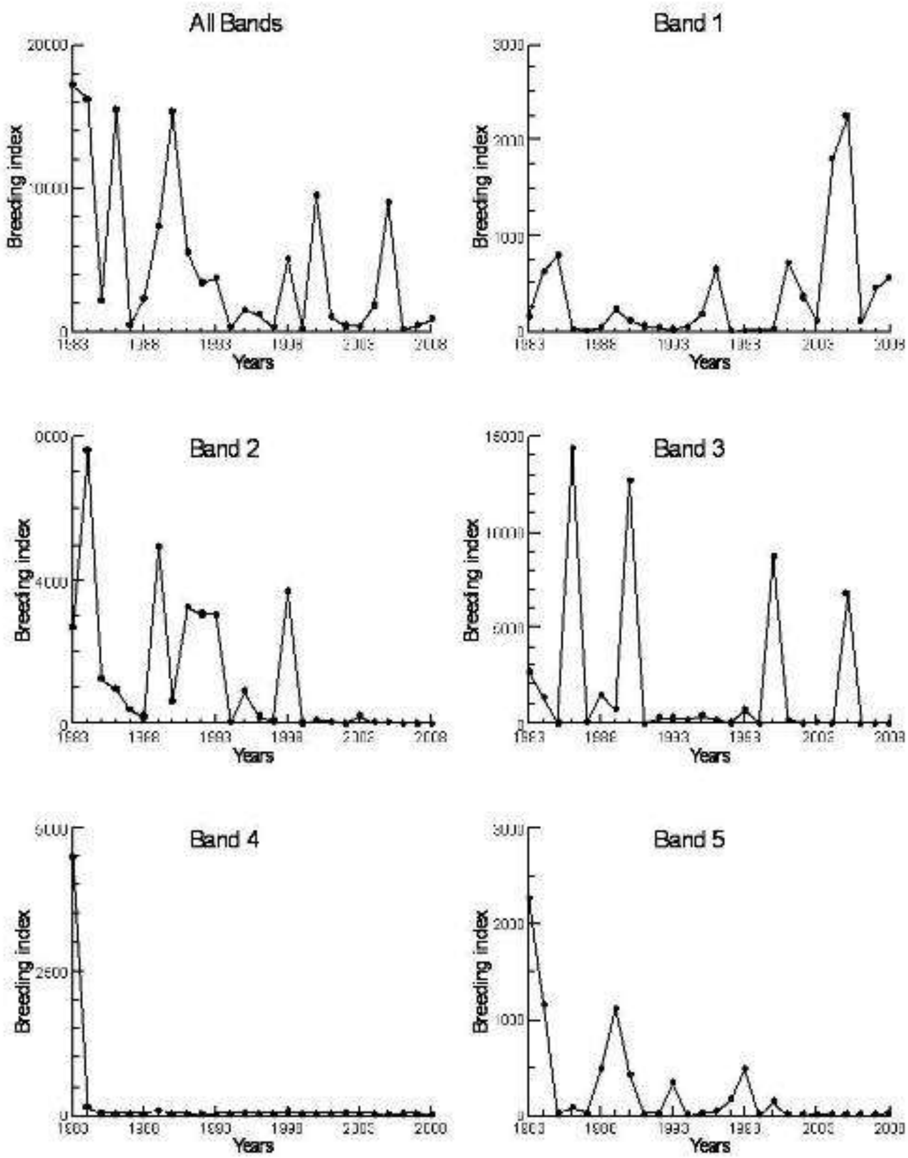
Figure 7. Breeding index (all species) 1-5



Scales vary on graphs
7

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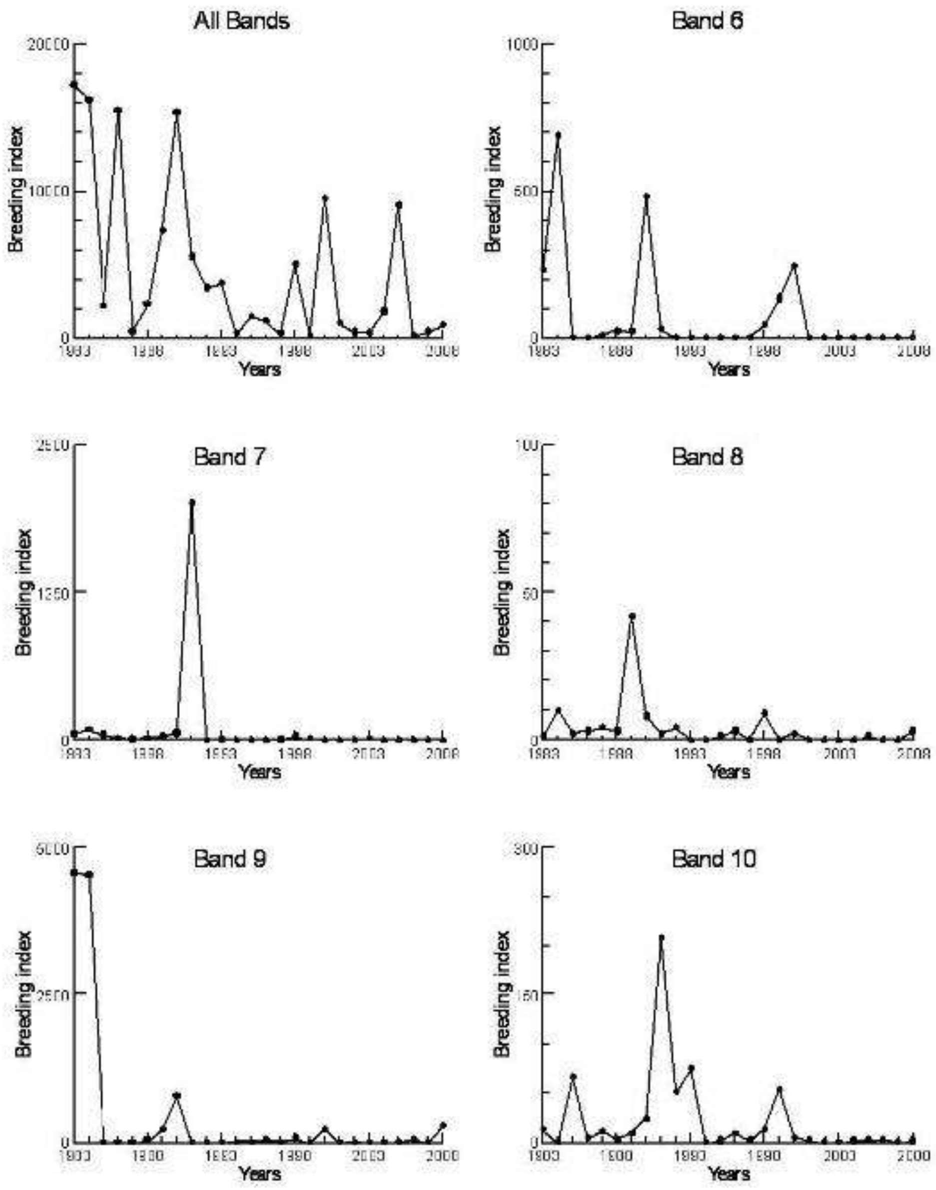
Ramsar additional infomation -
Richard Kingsford

Figure 8. Breeding index 6-10



Scales vary on graphs
8

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THE UNIVERSITY OF
NEW SOUTH WALES

Department of Environment & Climate Change NSW

Aerial Survey of Wetland Birds in Eastern Australia - October 2009 Annual Summary Report

J.L. Porter and R.T. Kingsford
School of Biological, Earth and Environmental Sciences
University of New South Wales

Results summary

1. The survey region experienced significant flooding in the Diamantina and Georgina river systems in northern Queensland in January 2009, which resulted in partial filling of Lake Eyre and northern wetlands. However, most of the flood waters in the survey bands had dried by October. In the southern and central survey region severe drought continued to affect wetlands, floodplains and rivers. Southern and central Queensland, southern and western New South Wales, most of Victoria and south eastern South Australia were drought affected at the time of surveys

2. Trend analyses indicated continued long term declines in waterbird abundance, wetland area, breeding abundance and breeding species richness. Wetland area and breeding abundance declined in 2009 compared to the previous year while total abundance and breeding species richness increased slightly.

3. The Macquarie Marshes and Lowbidgee wetlands were partially filled by environmental flows. The Paroo overflow lakes, Cuttaburra channels and Menindee Lakes were dry or almost dry. Most rivers in the Murray-Darling Basin were also low with little water on the floodplains.

4. Lakes Torquinnie and Mumbleberry in northern Queensland held water after flooding in January 2009 and together with nearby Eyre Creek wetlands supported more than 83,000 waterbirds.

5. Total waterbird abundance was below average (Fig. 3) and waterbirds were concentrated on a few wetland systems. Four wetland systems held more than 68% of total abundance: Lakes Torquinnie, Mumbleberry and Eyre Creek (33%, Band 8); Naracoorte wetlands (28%, Band 2); Burdekin River (5%, Band 10) and the Styx River (3%, Band 9) (Fig. 4).

This survey is run by the University of NSW and the NSW Department of Environment Climate Change & Water, with funding provided by the South Australian Department of Environment and Heritage, the Queensland Department of Environment and Resource Management and the Victorian Department of Sustainability and Environment.

Result summary continued

7. Total breeding index (all species combined) was below average and lower than in the previous year. Breeding was concentrated (80%) in three locations – Lake Mokoan (Band 2), Gippsland in Band 1, and Stanhope in Band 2 (Figs 4-6). Breeding species richness was low, and comprised mainly of three non-game species, Black Swan, White Ibis, and Silver Gull (90%). Few active breeding sites were recorded elsewhere (Figs 7 & 8).

8. Low numbers of waterbirds and breeding were observed on key wetland systems including Lake Galilee, Cooper Creek, Menindee Lakes, Paroo overflow and Cuttaburra channels, extending a sequence of below average years (Figs 5 & 6). A combination of drought and long term cumulative effects of river regulation, continues to impact on wetland availability, waterbird abundance and breeding.

9. Species at or near their lowest recorded numbers in 27 years included: White ibis, Musk duck, Caspian Tern, Pied cormorant and Banded stilt.

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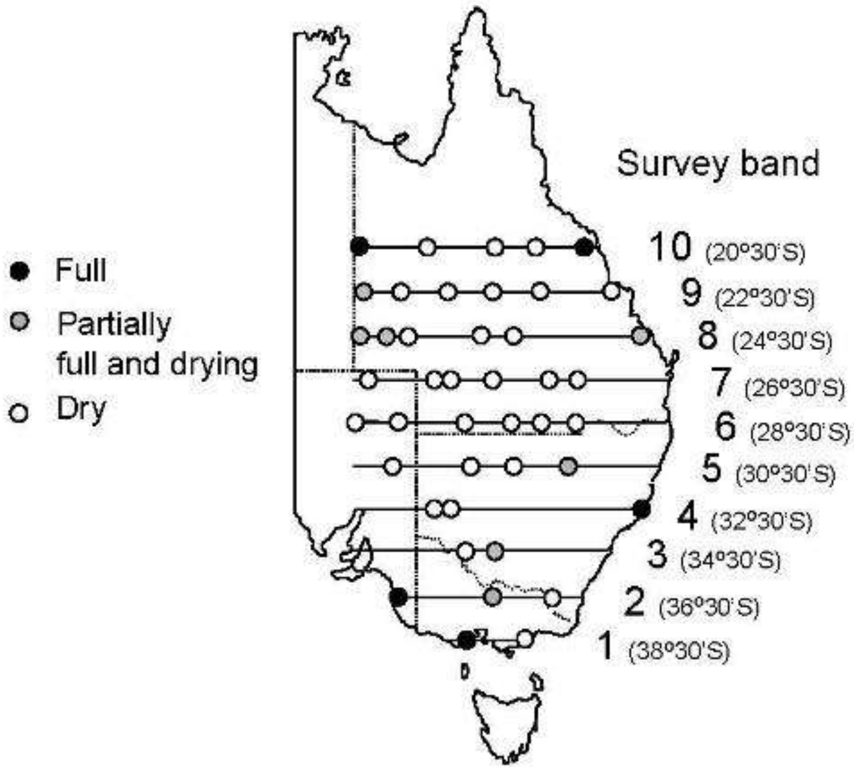
Figure 1. Wetland map 2009



Key to wetlands from W-E, by band

10 Lake Moondarra, Cloncurry River, Flinders River, Campaspe R, Burdekin R

9 Georgina R, Eyre Ck, Hamilton R, Diamantina R, Lake Galilee, Styx R

8 Mumbleberry-Torquinnie Lakes, Eyre Ck, Diamantina R, Thomson R, Barcoo R, various small coastal wetlands

7 Goyder Lagoon, Lake Yamma Yamma, Cooper Ck, Bulloo R, Paroo R, Warrego R

6 Lake Eyre, Lake Hope, Bulloo R, Paroo R, Warrego R, Balonne R,

5 Lake Frome, Paroo O'flow, Darling R, Macquarie Marshes

4 Menindee Lakes, Talywalka Lakes, Myall Lakes

3 Murray River Lakes, Lowbidgee Swamp

2 Coorong, Cooper + Mokoan Lakes, Cooma-Monaro

1 Curdies Inlet, Jack Smith Lake

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Figure 2. Total wetland area

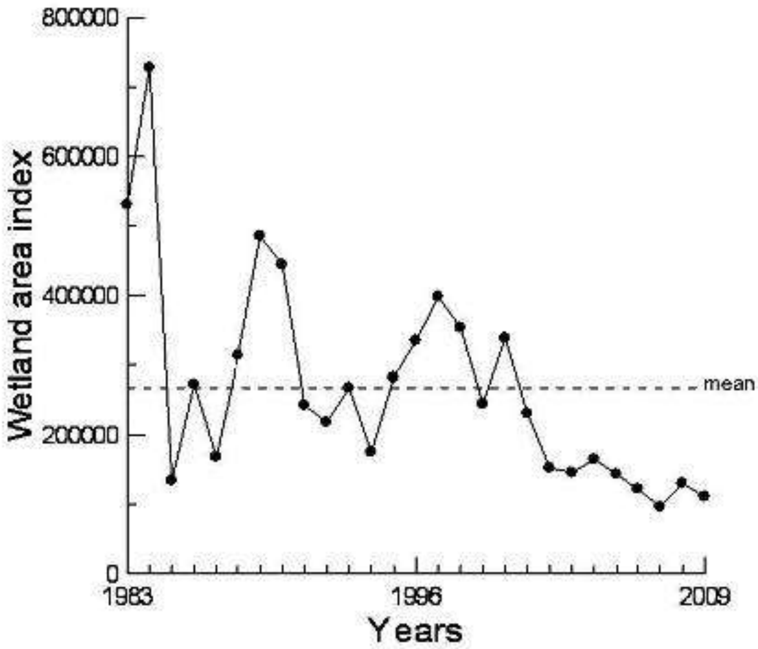
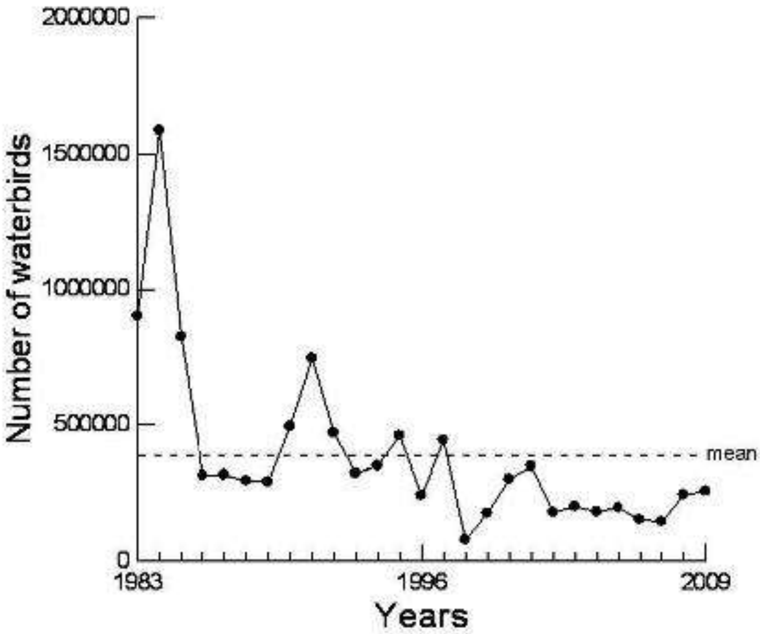


Figure 3. Total waterbirds



4

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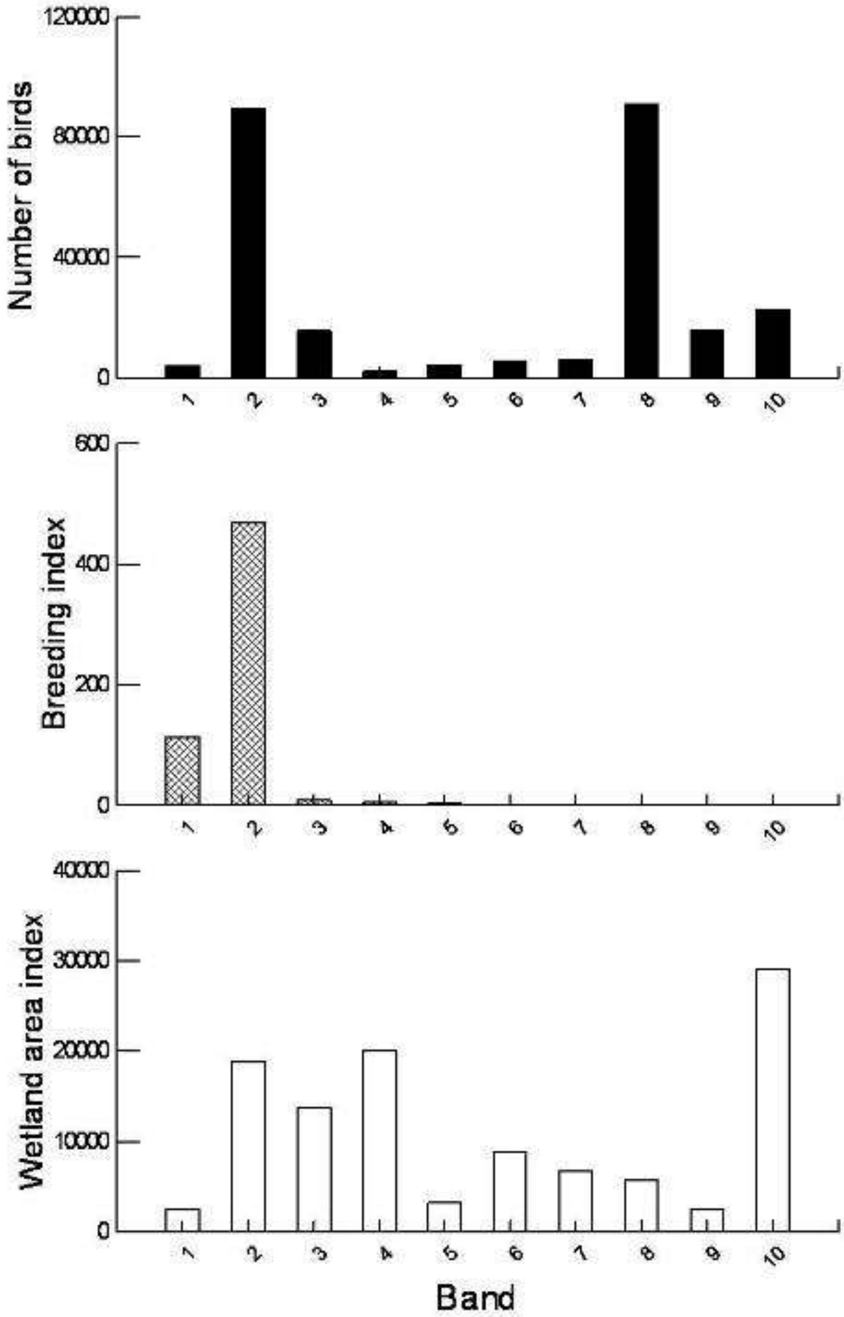
Figure 4. Band totals 2009



Scales vary on graph axes

5

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Figure 5. Breeding index (all species)

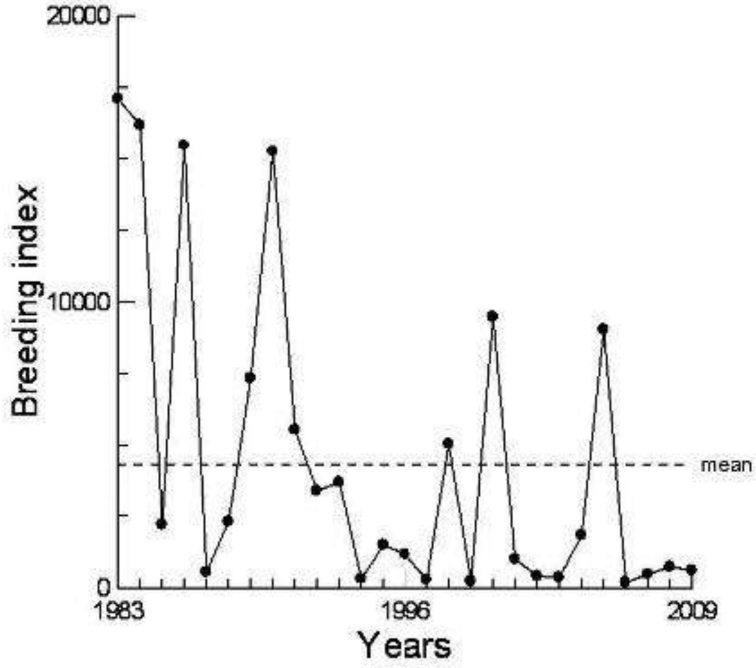
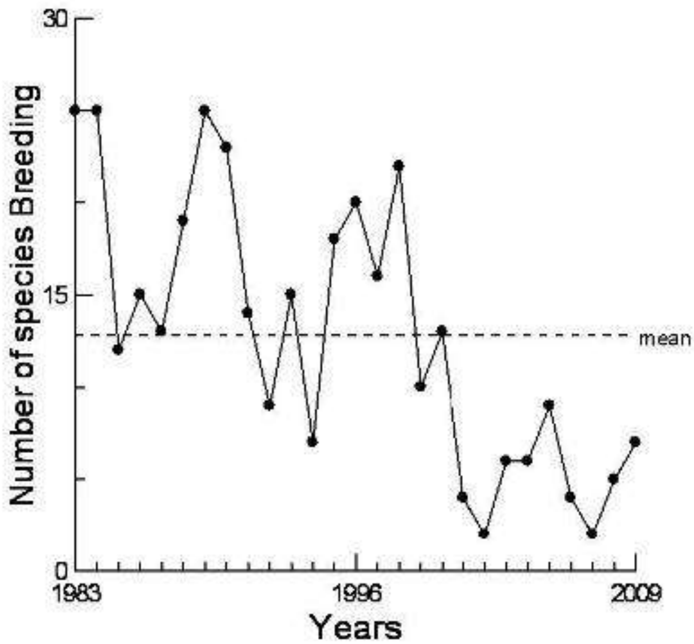


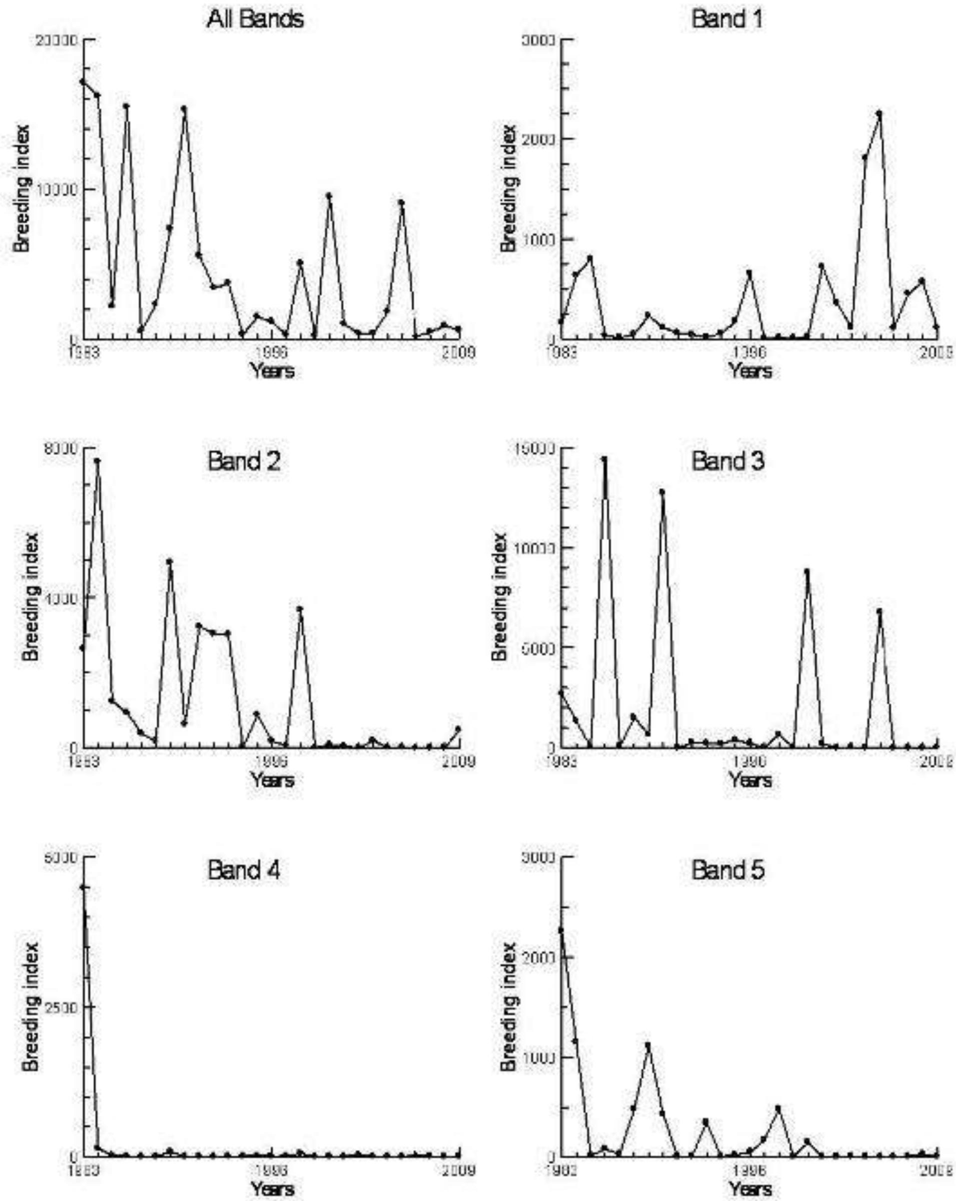
Figure 6. Number of species breeding



Scales vary on graph axes

6

Figure 7. Breeding index (all species) 1-5



Scales vary on graphs
7

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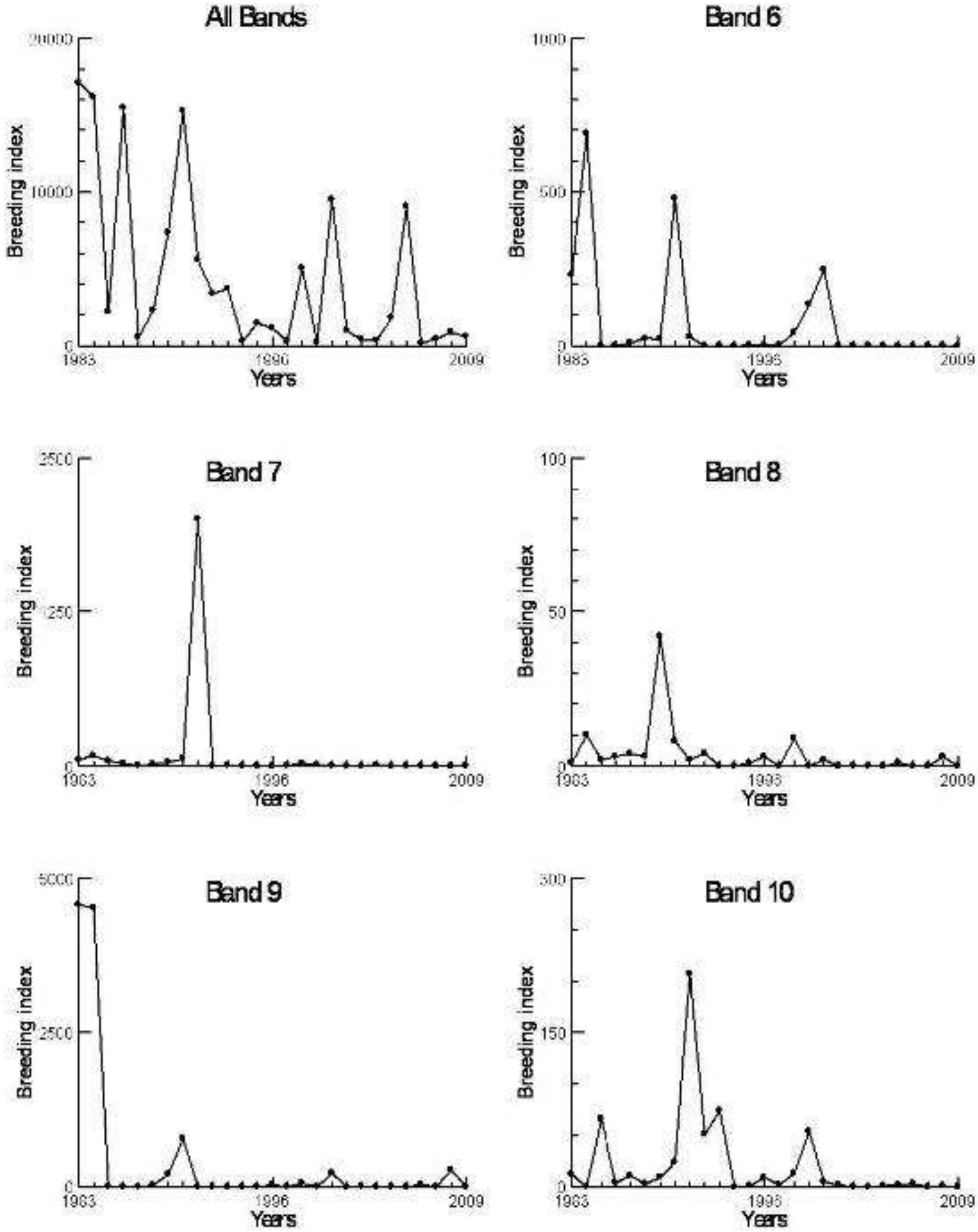
Figure 8. Breeding index 6-10



Scales vary on graphs
8

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