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Planning for the recovery of Lake Toolibin, Western Australia

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Abstract

Lake Toolibin, an intermittently flooded freshwater wetland in the southwest of Western Australia, is threatened by salinization due to extensive clearing within its catchment. The lake is a Wetland of International Importance under the Ramsar Convention because of the extensive stands of trees on the lake bed and its significance as a waterbird breeding site. Past research and monitoring have identified the causes of wetland vegetation and water quality decline and this information has been used to design a Recovery Plan for the lake. The plan is currently in the early stages of implementation and includes both short-term engineering measures to reduce salinity within the lake and long-term rehabilitation measures within the catchment. Community involvement in the recovery process is an integral part of the plan and ensures that recovery of the lake remains as the focus for ongoing catchment rehabilitation.

Introduction

Eighty-seven per cent of land in the agricultural area of southwest Western Australia has been cleared of native vegetation during the past 150 years. In the case of the Lake Toolibin catchment, the figure is 97%. This has caused massive changes in hydrological cycles (George et al., 1995) and in the distribution and abundance of many species of fauna and flora (Kitchener et al., 1980; Hobbs and Hopkins, 1990; Saunders and Curry, 1990).

Of the remnant patches of natural vegetation, the majority in private ownership are small, degraded by grazing and weed invasion and tend to be on poorer soils. Therefore, the reserve system probably has the major, albeit inadequate, role in conservation of the biota. The conservation value of wetland reserves, however, depends very much on the management of their catchments, both adjacent to the reserve and at a whole-of-catchment scale (George et al., 1995). Almost all wetlands have been affected by the rise in saline groundwater that has been the principal hydrological change resulting from land clearing.

Lake Toolibin is an intermittently flooded wetland with a surface area of about 240 ha, located 40 km east of Narrogin in the agricultural area of southwest Western Australia (Figure 1). The Lake Toolibin Nature Reserve provides only a narrow band of native vegetation around the lake. Surrounding land is used mostly for growing annual cereal crops and annual pastures, which are grazed by sheep. The area has a Mediterranean climate: 70% of the average annual rainfall of approximately 415 mm falls between May and September and average maximum temperature in January is 31°C.

The lake has historically supported many breeding species of waterbird (Halse, 1987), and is the last remaining wetland in the region with extensive stands of *Casuarina obesa* and associated *Melaleuca strobophylla* and *Eucalyptus rudis* (Froend et al., 1987). This was the typical vege-

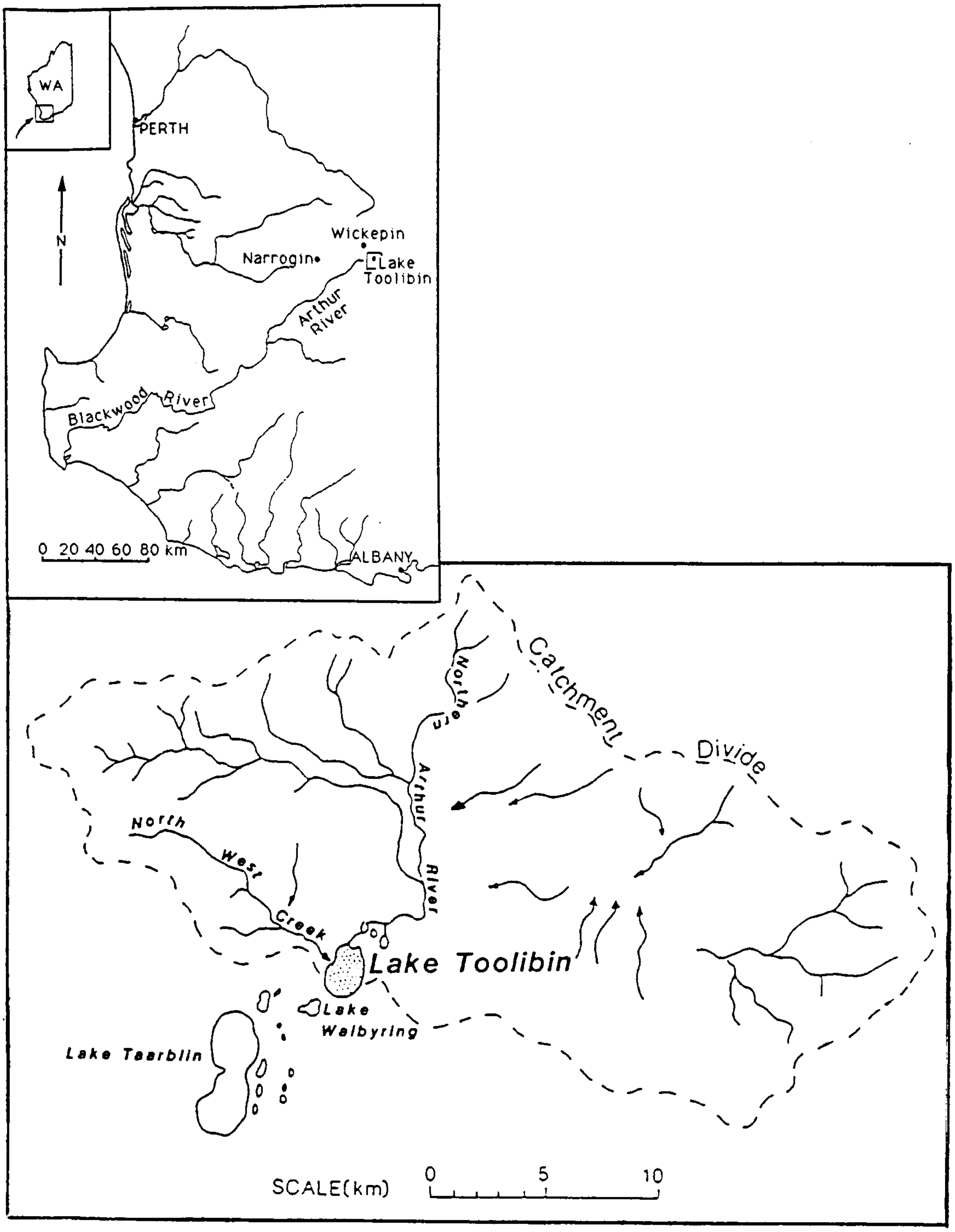

Figure 1. Location of Lake Toolibin in the southwest of Western Australia.

tation association occurring in wetlands of the agricultural area before clearing-induced rises in saline groundwater (Halse et al., 1993a). For these reasons the wetland has been listed as a Wetland of International Importance under the Ramsar Convention, which requires signatory countries to maintain the ecological character of listed sites.

In this paper, we describe how land clearing has changed the Lake Toolibin catchment and caused salinization in much of the area. A noticeable decline in the vegetation and water quality of Lake Toolibin in the 1970s lead to monitoring and the development of a Recovery Plan to maintain the conservation values of the lake by preventing it becoming saline, as neighboring wetlands have done. We summarize the biological data available for Lake Toolibin and outline the major features of the Recovery Plan. We also briefly discuss requirements for future monitoring and the relative importance of monitoring the lake versus its catchment.

An altered environment

The agricultural area of southwest Western Australia has a relatively short history of impact by Europeans compared to the agricultural landscapes in the northern hemisphere. However, within less than 100 years from settlement, the natural landscape and ecology of this region have been extensively altered. The decline of wetlands was the first sign of an altered hydrological regime as a result of land clearing in the drier wheat-growing areas. Although some wetlands were naturally saline, many were fresh and all were surrounded, and sometimes covered, by healthy vegetation. Within the last sixty years, salinization has caused many wetlands to decline from healthy, biologically diverse systems to degraded, salt-affected sumps supporting a far less diverse assemblage of flora and fauna (Halse et al., 1993a).

Land in the Lake Toolibin catchment was first used for farming in the 1890s, but this consisted mainly of sandalwood pulling and sheep grazing. Clearing did not begin until circa 1905, and it was not until after the First World War that widespread clearing commenced. By the mid-1930s about one-third of the natural vegetation in the catchment had been removed. By 1972, 90% was under crops or pasture (NARWRC 1978), and a further 7% has been cleared since then.

Following clearing, water tables rose as interception and transpiration rates were reduced and recharge increased. By the 1930s the majority of freshwater soaks that were used for watering stock were abandoned by farmers because they had become saline. Water tables generally have risen 12–15 m over the last 60 years and by 1977 about 3% of the catchment was severely salt-affected, with a further 2.6% slightly affected (Watson, 1978).

As a result of rising saline groundwater levels within the catchment, salinization is beginning to occur at Lake Toolibin. The water table is now within 1–2 m of the lake bed and has led to an increase in the soil salinity of the root zone of the *Casuarina obesa* and *Melaleuca strobophylla* community that covers most of the lake bed. This has resulted in the death of trees in some parts of the wetland (Froend et al., 1987).

During periods of drought, which may last as long as 3 years, salt accumulates in the surface sediment of the lake bed via capillary rise of shallow saline groundwater. Surface water drainage via the Northern Arthur River from salt-affected land within the catchment increases salt loads in Lake Toolibin, and the high water table has reduced ‘flushing’ of this salt down into the lower soil profile during filling events. Periods when the system partially fills but does not overflow exacerbate the problem, further increasing salt loads, with no outflow flushing (Froend et al., 1987; Froend and Storey, 1996). This is a phenomenon common to other salt-affected wetlands in wheat-growing areas of southwest Western Australia (Froend and McComb, 1991).

Monitoring and research to-date

Hydrology and water quality

Using models based on run-off characteristics of the catchment and long-term rainfall data, Stokes and Sheridan (1986) indicated that, historically, Lake Toolibin was at least 1 m deep for more than 70% of the time. During the period 1978–1996, which was comparatively dry, the lake was 1 m deep less than 40% of the time, receiving substantial inflow five times and overflowing four times. After substantial inflow, the lake usually contained water for at least two years.

Overflow events, which occur when the lake reaches a maximum depth of about 2.5 m, were important because they flushed some accumulated salt and nutrients out of the lake into the Northern Arthur River downstream from Lake Toolibin. During the 1980s, salt storage (concentration x lake water volume) fluctuated around 3000–4000 tonnes but since 1992 it has increased dramatically to a peak of 11,000 tonnes (Figure 2). This may indicate poorer quality surface inflow to the lake or the beginning of significant groundwater input. Salt concentrations in the lake water have ranged from 0.31 ppt in July 1983 to 20 ppt TDS in November 1994 (Figure 3)

Vegetation

The three major tree species on the bed of the lake, *C. obesa*, *M. strobophylla* and *E. rudis*, are its dominant visual feature. The populations of all three, especially *E. rudis*, have declined since 1977, when monitoring began (Figure 4). Most of the tree deaths have occurred on low-lying flat parts of the lake bed where salt encrustation was evident; trees on raised undulations called 'gilgai mounds' are usually healthier (Mattiske, 1993). The major cause of tree mortality at Lake Toolibin has been attributed to the accumulation of salt in the lake bed sediments via capillary rise of shallow groundwater and saline surface water inflows (Froend et al., 1987; Bell and Froend, 1990).

There is potential for the populations of *C. obesa* and *M. strobophylla* to recover with relatively little management intervention. Mass recruitment of *C. obesa* seedlings occurred on gilgai mounds in 1986 although all seedlings subsequently died, as a result of submersion and grazing by Western Grey Kangaroos *Macropus fuliginosus* and introduced rabbits *Oryctolagus cuniculus* (Mattiske, 1993; Froend and Storey, 1996). Seedling recruitment of both *C. obesa* and *M. strobophylla* occurred in March–April 1996 and areas of recruitment have been fenced so that the effects of grazing pressure and flooding regime can be studied.

Limited documented evidence suggests that extensive beds of sedges, probably *Juncus pallidus*, began declining in the mid-1970s and had disappeared from the lake by the early 1980s (Casson, 1988). *Juncus pallidus*, and most other sedges in southwest Western Australia, are relatively intolerant of salt (Halse et al., 1993a). In recent years the halophytes, *Halosarcia* and *Sarcocornia*, have appeared at the lake.

Aquatic invertebrates

There is limited information about the aquatic invertebrate fauna of Lake Toolibin. Doupé and Horwitz (1995) collected 36 species in September 1992 at a salinity of 2.4–3.0 ppt TDS. Average numbers of species, excluding rotifers, recorded in freshwater wetlands during previous studies in southwest Western Australia with spring or summer sampling are 35 (range 12–66) on the Swan Coastal Plain (Davis et al., 1993), 37 (range 18–56) near the coast between Augusta and Albany (Edward et al., 1994) and 37 (range 28–51) just east of Albany (Storey et al., 1993). More species have been recorded from Lake Toolibin than many wetlands that are regarded as having high conservation value, although the species at Lake Toolibin were widespread ones, most of which are known to tolerate brackish water. Salinized wetlands in the agricultural areas containing dead *C. obesa* and *Melaleuca* spp. contain few species; for example, only 5–6 species were recorded during September sampling of three lakes about 300 km north of Lake Toolibin that had salinities of 55–75 ppt TDS (Halse, 1981). If more sampling were done at Lake Toolibin, to take account of seasonal changes in the fauna and fluctuations in wetland conditions across years, the number of species recorded would increase (see Davis et al., 1993).

Fossilized ostracods from four shallow cores taken from the lake bed in 1994 were examined for differences between the present-day and historical fauna of the lake (F. Bachhuber and S. Halse unpubl. data). There was no evidence of a pronounced change in the ostracod fauna as a result of increasing salinity levels although there was

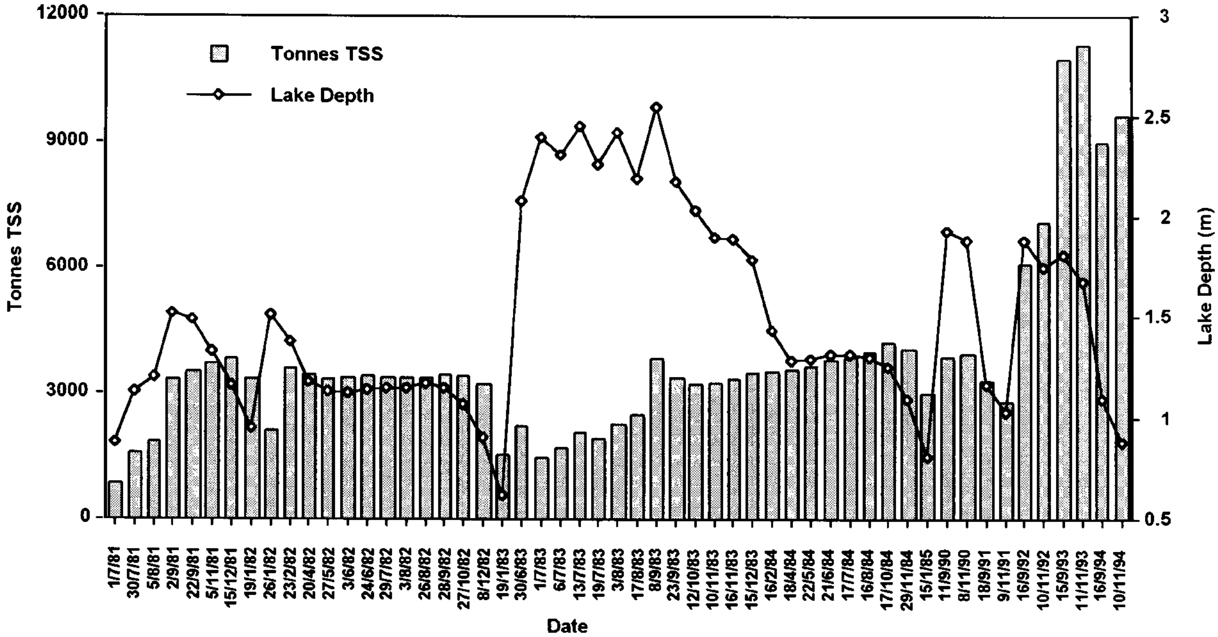

Figure 2. Lake Toolibin salt storage and water depth. Note that the x axis is not continuous. Data for salt loads were available only from 1981–1994. Data supplied by the Water and Rivers Commission and the Department of Conservation and Land Management, Western Australia.

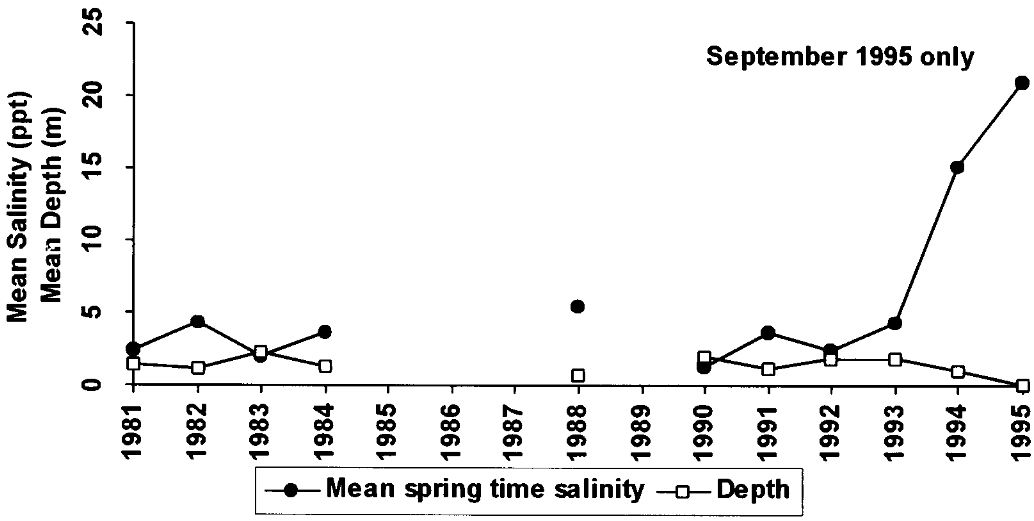

Figure 3. Mean springtime salinity in Lake Toolibin. Data supplied by the Department of Conservation and Land Management, Western Australia

very little organic sediment in the lake bed and ostracods were absent below a depth of 6 cm, suggesting that historically the lake bed has often been dry.

Waterbirds

The ornithological importance of Lake Toolibin led to more than 60 surveys of its waterbirds

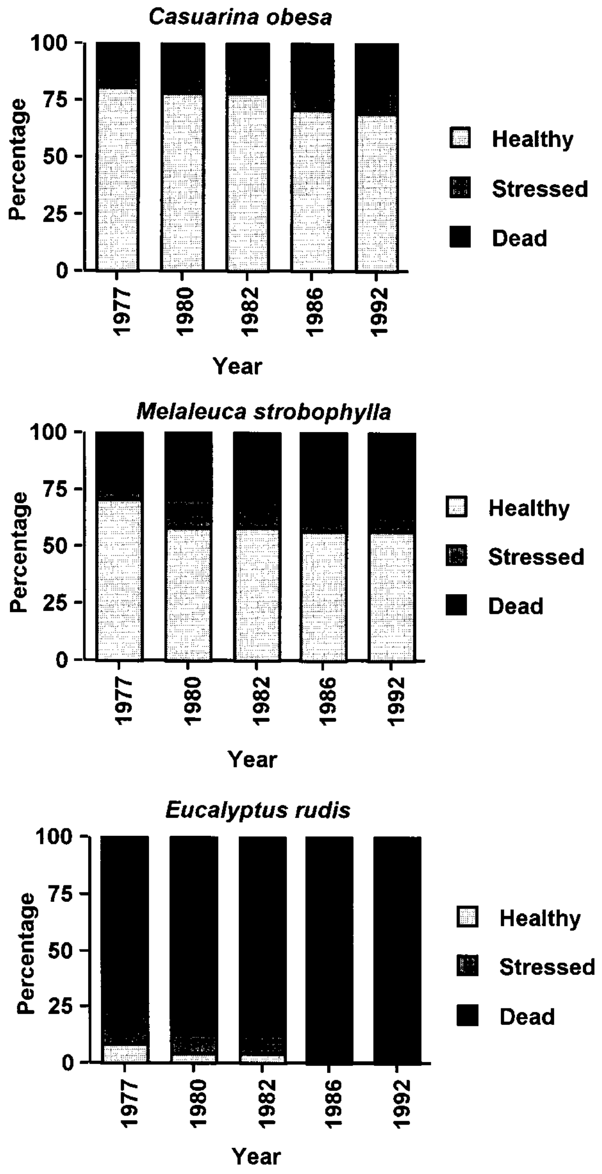

Figure 4. Percentage dead, stressed and healthy *Casuarina obesa, Melaleuca strobophylla* and *Eucalyptus rudis* in monitored vegetation plots on the bed of Lake Toolibin, 1977–1992. Data from Mattiske (1993).

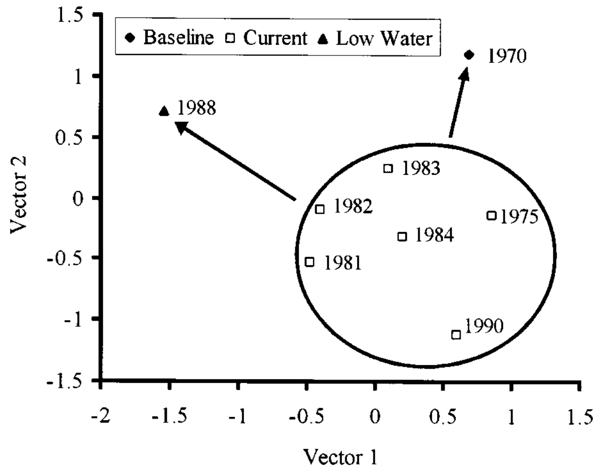

Figure 5. Ordination of surveys of waterbirds (presence/absence) on Lake Toolibin conducted in September. Year of survey and type of data (i.e., baseline, current species composition or composition recorded during incomplete filling of the wetland) are indicated. The ordination was done in 2 dimensions with a stress level of 0.159 using the Semi Strong Hybrid multidimensional scaling module in the PATN multivariate analysis package (Belbin 1993).

during the period 1965–1996 (e.g., Garstone, 1973; Jaensch et al., 1988; Halse et al., 1992). A total of 49 waterbird species was recorded, 25 of which were breeding on at least one occasion. During the period 1981–1985, 22 species bred at Lake Toolibin that made it the richest breeding habitat in southwest Western Australia. The average number of breeding species in 94 other wetlands in the southwest during the same period was 4 (range 0–20; Halse et al., 1993b). Historically, Lake Toolibin has also been the wetland supporting the largest numbers, and most breeding, of the rare Freckled Duck *Stictonetta naevosa* in Western Australia. Most of the population is centered in southeastern Australia and numbers in the southwest are usually low (Fullager, 1988) but irruptions occurred in 1960, when large numbers were seen or shot at several wetlands in the southwest (Garstone, 1973), including Lake Toolibin, and in 1982 when Jaensch et al. (1988) recorded 600 at Lake Toolibin.

Methodology, sampling intensity and lake conditions have varied greatly between waterbird surveys of Lake Toolibin. We extracted data from seven surveys of all waterbird species between late August and early October 1975–1996 and the long-term data set of R. Garstone, which was collected between 1965 and 1975 (Goodsell et al., 1978), to examine whether there were trends in waterbird use of the wetland during the breeding season (Table 1; Figure 5). While there tended to be fewer species and breeding species in later surveys, these relationships were not significant. The

Table 1. Number of waterbird species and breeding species recorded during selected waterbird surveys of Lake Toolibin between 1965 and 1993. Water depth and salinity values at time of survey are shown.

Date	Depth (m)	Salinity (ppt TDS)	No. of species	Breeding species	Source
Spring surveys					
1965–75	–	–	37	20	Goodsell et al. 1978
Oct 1975	0.76	1.00	18	6	D.R. Munro unpubl. data
Oct 1981	1.45	2.20	18	5	Jaensch et al. 1988
Sep 1982	1.16	3.80	22	4	Jaensch et al. 1988
Sep 1983	2.33	0.96	20	1	Jaensch et al. 1988
Sep 1984	1.29	3.20	21	4	Jaensch et al. 1988
Aug 1988	0.78	2.90	13	1	S.A. Halse, G.B. Pearson and R.M. Vervest unpubl. data
Sep 1990	2.01	1.13	13	4	S.A. Halse unpubl. data
Autumn surveys					
Mar 1982	1.27	2.80	15	0	Jaensch et al. 1988
Mar 1990	1.57	0.61	16	0	Blyth unpubl. data
Mar 1993	1.22	5.36	18	0	Mitchell unpubl. data

most recent ‘survey’ of all waterbirds at Lake Toolibin was provided by an outbreak of botulism in March 1993, when 450 birds of 18 species were found dead. There were comparatively few other years during the period 1981–1995 when water levels were high in autumn but comparison of the surveys in March of 1982, 1990 and 1993 do not suggest declining waterbird use (Table 1).

The lack of statistical evidence of a decline in waterbird use of Lake Toolibin does not mean the waterbird assemblage recorded in the past will continue to occur without management intervention. The Australasian Bittern *Botaurus poiciloptilus* has not been recorded since the surveys by Garstone and the Purple Swamphen *Porphyrio porphyrio*, which was common in the 1970s (Goodsell et al., 1978), has not been recorded since that time except for one individual in September 1983. Both these species utilize sedges, a habitat that has disappeared from Lake Toolibin, and they are unlikely to be recorded again unless this habitat is restored at the lake. If further habitat degradation occurs because of increasing salinities, other birds will stop using the lake. Halse et al. (1993b) showed that, on average, about half as many species and breeding species occurred at saline wetlands with dead tree vegetation as at brackish wetlands with live trees in southwest Western Australia. More detailed data on breeding success in relation to salinity suggests that fewer than half the species recorded breeding at Lake Toolibin would do so if salinities in September reached 10 ppt TDS (Halse, 1987), including the Freckled Duck and several colonial nesting species for which Lake Toolibin has historically been important (Jaensch et al., 1988). Data suggest spring time salinities may be approaching this critical level (Figure 3), although more intensive in-lake water sampling is required to confirm this observation.

Development of a recovery plan

Following public concern over the threat to the wetland posed by rising salinity, the Northern Arthur River Wetlands Rehabilitation Committee (NARWRC) was established in March 1977 under the authority of the State Minister of Fisheries and Wildlife. The committee contained expertise on waterbird and wetland ecology, plant ecology, geomorphology, ground and surface water, and land management practices in relation to catchment clearing and salinization, and its main tasks were to recommend measures to preserve Lake Toolibin as a freshwater lake.

The NARWRC completed its studies in 1986. Recommendations that were implemented as part of early management included:

1) Installation of groundwater pumps along the western shoreline in an attempt to lower the water table away from the root zone of the emergent vegetation;
2) Purchase of a 200-m wide band of previously cleared farmland along the western shoreline to be replanted to act as a buffer and natural drawdown zone.

By the beginning of 1992, many initiatives that could benefit landholders as well as the ecological values of Lake Toolibin were underway. Nevertheless, there were issues over which different interest groups had different points of view and there was no clear process to implement the actions necessary to save the lake. Therefore, in 1992, the Australian Nature Conservation Agency (ANCA) funded the preparation of a Recovery Plan for the lake that would provide the needed coordinating mechanism (Blyth et al., 1996). Prior to preparation of the Recovery Plan, a technical workshop was held in September 1992 to attempt to develop a common understanding among research and technical practitioners regarding management actions necessary to protect and enhance the lake and surrounding reserves. Proceedings from this workshop played an important role in formulating the Recovery Plan (Blyth et al., 1996). The Recovery Plan was launched in October 1994 and is current until September 2003.

The objective of the Recovery Plan is to "ensure the long-term maintenance of Lake Toolibin and its surrounding nature reserves as a healthy and resilient freshwater ecosystem, suitable for continued waterbird usage at current high levels". To assist in determining if and when recovery is achieved, a range of biological and physical criteria were formulated:

Physical criteria
1. The minimum depth to the water table beneath Lake Toolibin and Toolibin Flats in spring, when the lake is dry, should be 1.5 m.
2. The maximum salinity of lake water when the lake is full should be 1.0 ppt TDS.
3. The maximum salinity of inflow to the lake, measured at the Water and Rivers Commission gauging station 609 010 on the Northern Arthur River, should be 1.0 ppt TDS during the winter months when the lake is full.
4. The lake bed dries periodically by evaporation, on average once every three years.
5. The levels of nutrients within Lake Toolibin should not cause excessive growth of algae or other aquatic plants, or cause deleterious reductions in dissolved oxygen concentrations in the water. Total phosphorus levels in the water should not exceed 0.0001 ppt unless long-term monitoring indicates that this criterion may be modified.

Biological criteria:
1. No further deterioration is observed in the health of the vegetation of the lake or the reserves.
2. Successful tree and shrub regeneration in the lake and reserves is established in all vegetation associations.
3. Based upon available data, the lake supports sufficient species richness and numbers of invertebrates to assure waterbird food resources.
4. The number and species of waterbird visitation (41 species) and breeding success (24 species) that currently occur are maintained or increased.

The Recovery Plan involves an integrated strategy of short-term and ongoing measures at a local and catchment scale. The principal elements of the plan are:

1. Establishment of a Recovery Team and a Technical Advisory Group to ensure efficient and adaptive implementation of the Recovery Plan.
2. Water table drawdown by staged groundwater pumping to ensure the drawdown of the saline water table beneath the lake and reserves in the short term.
3. Surface water drainage of the Toolibin Flats to reduce saline inflows to the lake and reduce waterlogging.
4. Lake outlet control to improve flushing efficiency.
5. Enhancement of vegetation in the lake and its adjoining reserves through grazing control, planting, and fire management, to improve

regeneration and maintain waterfowl habitats.

6. Revegetation in the catchment to establish and maintain a more favorable hydrological equilibrium for the Lake Toolibin catchment in the long term. This will be achieved though land management planning, the promotion of fodder crops, the revegetation of salt affected land and the targeted but broadscale revegetation of groundwater recharge and discharge areas.
7. Agronomic manipulation to maximize evapotranspiration.
8. The development of a computer-based decision support system to enable the Lake Toolibin Recovery Team to consider all available information during the implementation and ongoing management of the Recovery plan.
9. Monitoring and reporting to provide input to the Decision Support System, to determine the effectiveness of the recovery actions and to facilitate ongoing adaptive management.

The Recovery Team and Technical Advisory Group both have been formed and play a crucial role in the management of the site. The committees have a common chair: the Manager of the Wheatbelt Region of the Department of Conservation and Land Management, who controls the operations of the department in the area. This link between the committees and control of the works program of the agency responsible for management of Lake Toolibin is crucial and ensures that recommended actions occur.

Short-term and long-term remedial measures

Management actions to save the wetland may be separated into short and long-term solutions. The short-term solutions predominantly are engineering ones that will buy time to save the lake but require ongoing maintenance and are not sustainable in the long term. They mostly involve surface water diversion and groundwater pumping. The long-term actions are intended to be sustainable, and predominantly involve broadscale replanting of key parts of the catchment in an attempt to lower water tables and reverse land salinization.

Of the short-term actions, lowering the water table under the lake, which is now within 1–2 m of the lake bed and within the root zone of the emergent vegetation, was given the highest priority. The Recovery Plan (Bowman et al., 1994) recommended urgent groundwater abstraction, and a pumping scheme has commenced, with saline groundwater being discharged to Lake Taarblin, a wetland that is already severely impacted by salinization. A feasibility study of salt harvesting (evaporation basins) to prevent uncontrolled loss of salt to downstream catchments is proposed.

Revegetation of cleared land adjoining the western side of the lake was identified as an immediate way of assisting to lower the water table beneath the lake and was implemented in association with the pumping. Other vegetation projects identified for immediate action included planting areas of major recharge (i.e., deep sands), revegetating discharge areas, especially along drainage lines, and protecting remnant vegetation and wetland buffers to maintain evapotranspiration and wetland water quality (Wallace, 1997).

Also of high priority was improving surface drainage of the Toolibin Flats, the broad valley bottoms of the catchment, in association with revegetating the area. The very low gradients and rising groundwater in this area have resulted in widespread ponding and waterlogging. This, in turn has resulted in increased flushing of salt from the catchment. In 1994/95, two new drains were constructed in an attempt to reduce waterlogging. An ongoing monitoring program that records rainfall, depth, velocity, salinity, total nitrogen, total phosphorus and suspended sediment loads in each drain will assess the effectiveness of this work.

Control of saline inflows to the lake was also a priority, particularly the ‘first flush’ low volume, highly saline flows experienced at the start of winter. In summer of 1994/95, a 5.5 km diversion channel was constructed around the western boundary of the wetland. The channel takes water from the Northern Arthur River upstream of Lake Toolibin and diverts it around the lake, to rejoin the river downstream of the outflow from Lake Walbyring (Figure 1), thereby protecting both Lakes Toolibin and Walbyring. A separator/barrage was constructed at the upstream end of the channel, the gates of which may be opened to allow saline flows down the diversion channel, or closed to direct fresher flows into Lake Toolibin.

Analysis of streamflow and salinity data indicated that flows less than 3.0 m^3 sec^{-1} should be diverted around the lake.

The long-term solution for protecting the wetland is revegetating the catchment, which will reduce groundwater recharge and lower the saline water table. Surface salinities will decline as salt is flushed into the lower soil profile by rainfall events. As saline groundwater recedes from the root zone, the stress on lake bed vegetation will be reduced. Revegetation also will reduce catchment runoff, which will reduce the likelihood of excessive inundation of wetland vegetation and will lower salt and nutrient loads by reducing flushing of surface-salt and nutrients into water courses and wetlands. To promote revegetation, government agencies have attempted to develop economically viable crops that will be of direct economic gain to landowners, as well as protecting the catchment. These include perennial species that produce fodder for stock, timber for fence posts, wood for craft work, tannins, and eucalyptus oil for industrial grade solvents and the pharmaceutical and cosmetics markets.

Community involvement and funding considerations

Management agencies have always recognized the need for an integrated catchment approach to saving the wetland and have worked closely with local landholders and Landcare groups within the catchment. Wallace (1997) noted that constant liaison and positive interaction between catchment groups and individuals is essential to develop congruent goals and philosophies. Major issues are summarized from Wallace (1997) below:

1. Catchment boundaries are not congruent with social boundaries defined by farming communities within the catchment;
2. Landholders higher in the catchment are not affected by Landcare problems and are more difficult to involve than those lower in the catchment, who are directly affected by salinity and waterlogging;
3. Because farmers in the area are comparatively secure in terms of agricultural productivity, due to predictable rainfall, the farming community has more readily accepted Landcare restoration projects than they might in other less secure areas;
4. There has often been conflict between farm productivity and nature conservation in terms of the likely outcomes of management actions. In some instances, further research, better engineering design and commitments to undertake additional work (i.e., revegetation) have resolved conflicts;
5. Turnover of staff within the management agency make it difficult to maintain a long term relationship of mutual trust and understanding with the community;
6. The management agency has limited resources to attend to all conservation issues within its Region, Lake Toolibin being one of many. Time for communication and information exchange is not always adequate;
7. Interlocking membership of the Catchment Group and the Recovery Team has been important in planning and liaison and in maintaining information flow.

Throughout the recovery process, the local community has played a significant role in helping protect the wetland. In 1985, local landholders formed the Wickepin Land Conservation District Committee (WLCDC) to address the loss of agricultural productivity caused by salinization. The WLCDC, with support from the Department of Agriculture, Greening Australia, Alcoa, Wickepin Shire Council, local schools, a Commonwealth Employment Scheme project, and local farmers rehabilitated 569 ha of salt-affected land on eight farms on the Toolibin Flats; 60,000 trees were planted to help drawdown the water table and 34 km of fencing were erected for their protection.

Subsequent revegetation work was continued by the Lake Toolibin Catchment Group (TLCG), which was formed by local landowners from within the catchment. Additional land conservation groups, representing subcatchments within the main catchment, have since evolved: the West Toolibin and Scrivener Soak Catchment Groups were formed in 1994 and 1995, respectively. Following the success of these subcatchment groups, Wallace (1997) noted that the catchment scale was too broad for effective action because the TLCG was too large and the sense of mutual cooperation too diffuse; the subcatchment groups have proven more effective for implementing management actions.

Despite the enormous amount of time donated by catchment groups, land rehabilitation is expensive. Blyth et al. (1996) estimate that up to $4.5 m over ten years will be required to achieve the objectives of the Recovery Plan.

Future monitoring and research

The Lake Toolibin Recovery Plan is the first large-scale attempt to restore a salt-affected wetland in Western Australia and, as stated above, will be expensive to implement. Monitoring is vital both to audit whether the plan achieves its objectives and to document the consequences of various management actions to assist with designing other recovery plans.

A comprehensive monitoring program for the wetland and its catchment has been designed by Froend and Storey (1996). The program identifies management actions and wetland values that require monitoring, and provides a description of the design for each monitoring program with details on parameters to measure, frequency of measurement, locations where monitoring should be undertaken, levels of replication, types of instruments to use, and criteria on which to assess success. The report also indicates levels of funding required and prioritizes elements for implementation based on perceived urgency and necessity.

Shortcomings in the design and implementation of past monitoring in the catchment have been discussed by Froend and Storey (1996). Frequently there were no, or inadequate, data available on key processes in the catchment and the lake, which made it very difficult to plan appropriate management actions and to assess their effectiveness. Similarly, there were insufficient data on wetland values (*sensu* Ramsar criteria) or parameters affecting wetland values to assess the current ecological status of the lake properly. This was despite earlier reports specifically recommending monitoring. In many instances the reasons for lack of monitoring were inadequate funding but, when monitoring did occur, the lack of a consistent, standardized approach meant results had limited usefulness.

To ensure the recovery process is relevant to the requirements of the wetland ecosystem, standardized and consistent monitoring methodology is a necessity. Three levels of monitoring are required. First, the condition of the catchment must be monitored. This involves measuring groundwater levels, the volume and salinity of surface run-off, the extent of revegetation, and the success of revegetation in altering catchment hydrology. The recovery of Lake Toolibin will not be achieved by measures within the Lake Toolibin Nature Reserve alone and it is important to monitor management efforts on farmland in more remote parts of the catchment.

Second, various aspects of the hydrology of Lake Toolibin and management actions at the lake should be monitored, including inundation regime and water depth, salinity of lake water and depth to groundwater under the lake bed.

The purpose of the management action at Lake Toolibin is to maintain or restore its biological values and the third level of monitoring should be directed at the biological values of the lake. The vegetation association on the bed of the lake drives the ecology of the lake and its maintenance is one of the primary aims of the Recovery Plan. The health of the vegetation must continue to be monitored, building upon the already extensive vegetation database. If research shows that the natural recruitment of tree species is a rare episodic event, seedlings can be replanted in degraded areas once salinities of lake bed sediments are reduced by groundwater pumping.

Lake Toolibin is historically the best wetland for waterbird breeding in southwest Western Australia, as well as supporting high numbers of species. Another primary aim of the Recovery Plan is maintenance of existing levels of waterbird use. The difficulty in assembling appropriate datasets to assess whether waterbird use has declined over the past 30 years, despite the large number of surveys, illustrates the importance of regular waterbird monitoring with standardized methodology. Both the number of species present and their breeding activity should be monitored and it is suggested that, at least for the species data, multivariate analysis is the most appropriate method of finding long-term trends. Surveys can be plotted in an ordination and baseline and current conditions defined as parts of the ordination space. This is illustrated for Lake Toolibin in Figure 5. True baseline conditions for waterbird assemblages in the lake are represented by Garstone's 1970 survey point, current conditions are reflected by surveys enclosed within the balloon and data representing reduced waterbird usage are represented by the 1988 survey point. From the position of subsequent surveys, when all data are re-ordinated and plotted it should be possible to determine whether the type of waterbird community at the lake is changing. If future survey points move away from the balloon representing current conditions and towards the position occupied by Garstone's surveys, then the lake is being successfully managed for waterbirds (Figure 5). Alternatively, if future surveys move away from the balloon towards the 1988 survey, it suggests that community composition is being adversely affected by salinization, vegetation decline or other changes in the lake's ecology that make the lake less suitable for many waterbird species.

Aquatic invertebrates provide food for waterbirds, have significant conservation value in themselves and can be used as indicators of the ecological health of wetlands (Davis et al., 1993). Therefore, aquatic invertebrates at Lake Toolibin should be monitored regularly with standardized methodology. The multivariate approach described for waterbirds could be used to follow the invertebrate community of the lake through time. The occurrence of new species (or absence of previously recorded ones) can also be used to infer whether lake conditions are improving or deteriorating by reference to their known ecological tolerances (see De Deckker, 1983).

For the Recovery Plan to be effective and to save Lake Toolibin, the data generated by monitoring and modeling must be collated into a useful form for management decision-making. We emphasize the value of a computer-based decision support system for collation and analysis of all available information during the implementation and ongoing management of the Recovery Plan.

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