Applying Hydrological Thresholds To Wetland Management For Waterbirds, Using Bathymetric Surveys And GIS

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Keywords: *Wetlands; GIS; Waterbirds; Hydrology; Modelling.*

EXTENDED ABSTRACT

The Lake Warden wetland system (LWWS), on the south coast of Western Australia (WA), is a wetland of international importance for waterbirds. It occurs at the bottom of a heavily cleared agricultural catchment. Rising water levels associated with clearing have been identified as a threat to waterbird diversity. Different species of waterbird are typically found in specific ranges of water depths. Studies indicate overall waterbird diversity is sensitive to the area of shallow water, which is the only habitat in which wading birds and shorebirds can forage given their morphological limitations.

An analysis of historical waterbird and depth data over the past 25 years was undertaken to determine relationships between waterbird diversity and water depths in the LWWS. A 5m digital elevation model (DEM) of the wetland's bathymetry was created with ArcInfo Geographic Information System (GIS) software to relate depth gauge data to water volumes and areas of differing depth ranges, representing waterbird habitat types. The DEM was generated from a Real-Time Kinematic Differential Global Positioning System (RTK DGPS) bathymetric survey and an Airborne Laser Scanning (ALS) survey.

Individual waterbird surveys were associated with water depth records where they were within a week of each other. Simple scatter plots and regression indicate a negative relationship between waterbird diversity (measured as species richness and abundance) and depth, for the deeper lake depths recorded in recent times. Lake Warden (LW) had a notable decline in waterbird abundance at depths above 1.4m. These relationships coincide with the loss of exposed shore and shallow water habitats quantified by the DEM. LW has lost approximately 65 hectares of wading habitat (defined as depths < 25cm) and 100 hectares of exposed shore habitat since the early 1980s. The loss of these habitats, and associated decline in diversity with lake depth is not as pronounced for other lakes in the system, owing to more complex bathymetry and some surface outflow connectivity with the Southern Ocean. The limited data for the 1980s when water depths were significantly lower, indicate a positive relationship between waterbird diversity and depth.

The results were used to conceptualise an optimal annual depth range for LW fluctuates between 0.3 and 1.3m. To achieve this range LW requires the removal of approximately 8 gigalitres (GL) of water. To maintain this range a further annual removal of 1 to 2 GL per annum is required based on other lake water balance research conducted.

Further work is being undertaken with existing datasets to better understand the relationship between hydrology and wetland ecosystem thresholds such as:

- Analysing waterbird data by species and functional groups;
- Modelling the impact of lake depth upon fringing vegetation condition; and
- Interpolating lake depths, from existing depth records, where this information does not coincide with bird surveys.

This process demonstrates how biological, hydrological, terrain surveys and GIS technology can be used to determine thresholds, so measurable targets and objectives can be set for management purposes.

1. INTRODUCTION

The LWWS (Figure 1) is recognised as internationally significant for waterbirds under the Ramsar Convention. Its catchment was declared a Natural Diversity Recovery Catchment in 1997, under the WA State Salinity Strategy. Agricultural clearing in the catchment and major flood events in 1989, 1999, and 2002 have contributed to rising water levels in the LWWS (Marimuthu et al. submitted). Clarke and Lane (2003) suggest this may lead to lower usage of the wetlands by waterbirds because there will no longer be the diversity of water depths required by the 59 different species known to use the lakes (CALM 1999). There are similar concerns about waterbird habitats elsewhere in the world (David 1994, Powell 1987).

The significance of water depth as a habitat variable for waterbirds is well established in ornithological literature. Particular species typically occur in a specific range of water depths (Boettcher et al. 1995, Hayes and Fox 1991). The primary importance of water depth over other habitat variables has been explained by waterbirds being opportunistic foragers (Bolduc 2002, Skagen and Knopf 1994, Euliss et al. 1991). Many waterbirds can readily alter diets and feeding locations to the food sources available, but the accessibility of food is limited by the bird's morphological attributes.

For wading birds and shorebirds the size, shape and function of their body parts places a limit on the water depth to which they can access food (Bolduc 2002, Velasquez and Navarro 1993, Custer and Osborn 1978). Maximum abundance for individual species has been shown to occur at shallow depth ranges (Safran et al. 1997, Boettcher et al. 1995, Custer and Osborn 1978). For some species, exposed shore (beach) areas are their primary foraging zone. This includes the endangered Hooded Plover that occurs in the LWWS (Clarke and Lane 2003, Weston and Elgar 2000).

Diving waterbirds are able to forage over a wider range of depths (Safran et al. 1997) than non-divers. Some may be limited by a minimum water depth that allows them to forage (Bolduc 2002). Safran et al. (1997) found a preference by some waterfowl for depths greater than 20cm. Larger diving birds, such as cormorants require a minimum depth of about 1m (Halse et al. 1993).

Many studies link highest overall waterbird diversity with areas of shallow water (Reilly 1998, Skagen and Knopf 1994, David 1994, Leach and Hines 1992, Hayes and Fox 1991). In North American studies, Ehrhardt (2001) found highest diversity with depths less than 30cm, Bolduc (2002) with depths less than 25cm and Colwell and Taft (2000) with depths less than 20cm.

The aim of this study was to:

a) Quantify the relationship between water depths and waterbird diversity in the Lake Warden wetland system.

b) Use this information to set hydrological management targets for the wetlands.

The data for the study are derived from historical waterbird and water depth surveys conducted during the last 25 years. In addition, a bathymetric and an airborne laser scanning survey were used to create a high resolution DEM of the LWWS's topography. Interrogation of this model with GIS allowed water depths to be converted to volumes, then extrapolated to spatial area, and further defined to represent differing depth ranges.

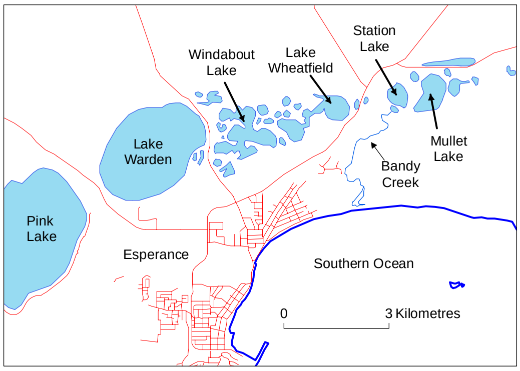

Figure 1. Location of Lake Warden Wetland System at Esperance, Western Australia

2. DATA SOURCES

2.1. Depth

Two depth gauge datasets are available within the Department of Conservation and Land Management (CALM). The South-West Wetlands Monitoring Program began in the late 1970s (Lane et al. 2004). Records were taken six times a year during the early 1980s and then reduced to one record in each of September and November. The program includes wetlands throughout the south-west, two of which fall within the LWWS (LW and Station Lake). A more recent monitoring program established under the Recovery Catchment program began in May 2002, comprising of fortnightly depth recording of all major lakes within the system. Figure 2 represents the depth records from both sources for LW over the 25 years. There is no corresponding significant trend in annual rainfall over this period.

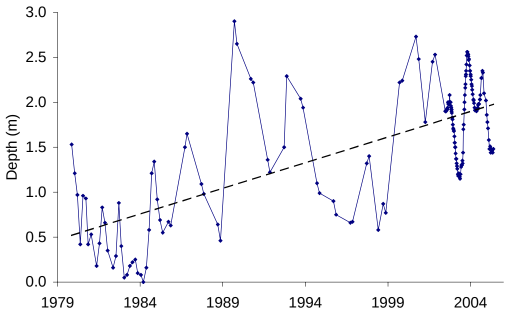

Figure 2. Lake Warden depth gauge readings over the past 25 years, with linear trend line

2.2. Bathymetric survey

A ground-based bathymetric survey of the wetland's main water bodies was undertaken. Three dimensional position data were collected using a dual frequency Real-Time Kinematic Differential Global Positioning System (RTK DGPS). Access within the LWWS with this system was difficult and required the use of a boat, walking and an amphibious vehicle. For shallower lakes, to depths of around 1.2m, a survey pole was lowered into the water with the GPS mounted on top. For deeper lakes an echo sounder, connected to a data recorder, was mounted on the side of the boat with the GPS mounted directly above.

To capture the change in slope around the lake shorelines, observations were collected in radial lines starting in the water at a depth of 60cm and running upslope to a height of 0.5 to 1.0m above the outflow. The distance between these cross sections varied from about 50m on Lake Warden to less than 20m on Lake Windabout, where more data was considered necessary to capture the shape of the lake. For the echo sounder recordings of the main bodies, the system recorded depth every 20m.

The accuracy of the GPS recordings was maintained by not capturing data during periods of poor satellite configuration (usually for 15-20 minutes between 10am and 2pm). The accuracy of the GPS data was better than the specified 0.1m. A minimum of five percent of records were checked with additional readings, some using a different base station, and comparisons with standard survey marks. At the end of each work day, contours were plotted to visually check for any anomalies.

2.3. Airborne Laser Scanning

The bathymetric survey did not adequately reflect the existing maximum lake depths, or future projected depths. Therefore an ALS survey was undertaken to complete the upper lake level flood contours. A 5m DEM with an accuracy of +/- 0.15m at 1 standard deviation resulted. Chang et al. (2004) concluded ALS provides greater precision and accuracy than photogrammetry and radar interferometry.

2.4. Waterbirds

Waterbird surveys were obtained from three different sources.

1. Royal Australian Ornithological Union (RAOU) surveys were conducted in the 1980s (Jaensch et al. 1988).
2. The organization changed its name to Birds Australia (BA) and another major survey program began in 1996, though it did not cover as much of the LWWS.
3. CALM have conducted surveys for Lake Wheatfield since 1997 (Cale et al. 2004). This program aims to monitor biodiversity across 25 wetlands in the south-west.

Several other data sources were identified, but not considered comprehensive enough.

3. MODELLING METHODOLOGY

3.1. DEM creation

Creating a complete DEM of the wetlands required interpolating the bathymetric point data to a grid and merging this with the ALS grid. The interpolation technique used was a Triangulated Irregular Network (TIN). TINs are typically used for high-precision modelling of small areas, where the density of data points can be biased to areas of greatest variation in the surface (ESRI 2004). This supports the methodology for the 18,000 bathymetric points collected. TINs are also fast to implement and their simple assumptions provide transparency in the results. Their main disadvantage is the surface can have a jagged appearance, especially in flat areas. An Inverse Distance Weighted (IDW) interpolation was trialled, but produced a block pattern in the centre of the lakes and a wavy artefact around the lake edges.

The interpolated TIN was converted to a grid with a 5m cell size, and clipped to a polygon representing the wetlands. The grid was merged with the ALS grid using ArcInfo's mosaic command using the blend option (ESRI 2004). A small number of pixels with no data values were assigned the mean of their surrounding cells. The remaining areas lacking data were small water bodies not covered in the bathymetric survey. The final wetland DEM was used to calculate volumes and surface areas at 1cm depth intervals for each of the lakes, using 3D Analyst (ESRI 2004). This information was used to quantify theoretical waterbird habitat zones.

3.2. Relating waterbird diversity and water depth

Richness and abundance were the two measures of waterbird diversity used throughout the analysis. Richness is the number of different species in a survey, while abundance is the total number of waterbirds in a survey. Figure 3 represents species richness for surveys at Lake Wheatfield, where all three data sources, described in Section 2.4., exist. Over the same period, the CALM surveys consistently recorded more species than the BA surveys. Sampling effort partly explains the discrepancy (Cale et al. 2004) with CALM surveys using a boat to provide greater access to more lake areas than were visible in the RAOU and BA surveys, which were conducted from shore.

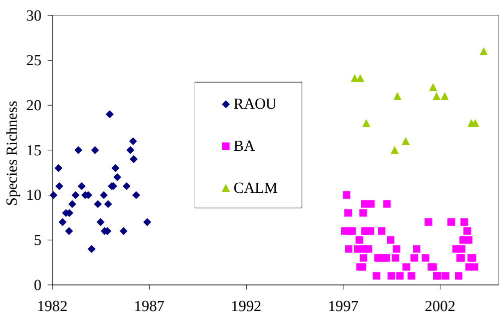

Figure 3. Waterbird species richness at Lake Wheatfield from RAOU surveys in the 1980s and the more recent BA and CALM surveys

Therefore it is difficult to directly compare survey results between these different sources. However, the sources represent two distinct periods; when water levels were lower during the 1980s and when the levels are comparatively higher during the late 1990s to present. This provides an opportunity to compare waterbird diversity and water depth relationships between the two periods. The relationships were analysed, separately for each waterbird survey source, using simple scatter plots and linear regression.

Waterbird survey results were only used where they occurred within a week of a recorded lake depth reading. Four of the lakes had sufficient number of these surveys for analysis. For Lake Warden 40 surveys were used out of the 100 available, Lake Wheatfield 27 of 100, Station Lake 13 of 29, and Mullet Lake 9 of 109.

4. RESULTS AND DISCUSSION

Lake Warden is the only lake in the wetland system that has both depth data and bird surveys, for the early 1980s and since 1996. Scatter plots of waterbird richness and abundance, versus lake depth, for LW are shown in Figures 4 and 5. They indicate that the lake depth has exceeded its optimal depth range for waterbird diversity. Abundance notably collapses at depths over 1.4m.

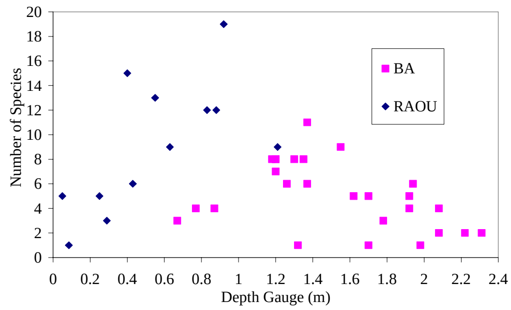

Figure 4. Waterbird species richness plotted against water gauge depth for RAOU and BA surveys at Lake Warden

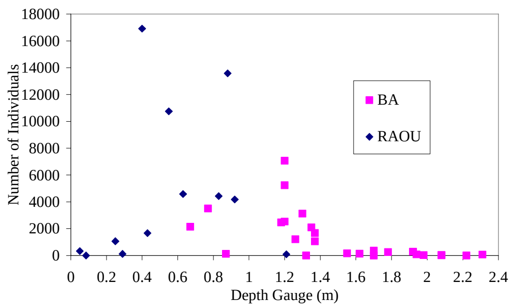

Figure 5. Waterbird abundance plotted against water gauge depth for RAOU and BA surveys at Lake Warden

Similar, though not as pronounced, declines in diversity associated with depth were evident for Lake Wheatfield and Mullet Lake. All significant linear correlations (at an 80% or higher confidence level) for the recent BA and CALM surveys, between the diversity measures and depth, are negative. For the 1980s RAOU surveys LW has a positive correlation of diversity and depth, while Station Lake has no significant correlations.

To quantify how waterbird habitats are affected by depth, the area of four conceptual habitat zones (based on the literature) were plotted against depth:

- Exposed Shore Zone (0cm deep)
- Wading Zone (< 25cm deep)
- Shallow Diving Zone (> 20cm deep)
- Deep Diving Zone (> 1m deep)

Figure 6 represents these zones for LW. The lake has a simple bowl shape, which becomes steeper towards its edge, resulting in the progressive loss of shore and wading habitat with increasing depth. This corresponds with the waterbird diversity decline indicated in the scatter diagrams. An annual depth range of approximately 0.3 to 1.3m conceptually provides maximum habitat area for both diving and non-diving waterbirds. This corresponds to a volume range of 0.8 to 6.3 GL of water. The maximum volumes reached in each of the last three years have been between 5 and 8 GL above the maximum of this range. This also represents the change in the lake's hydrology due to agricultural clearing (Marimuthu et al. submitted). The historical decline in wading habitat is represented in map form in Figure 7.

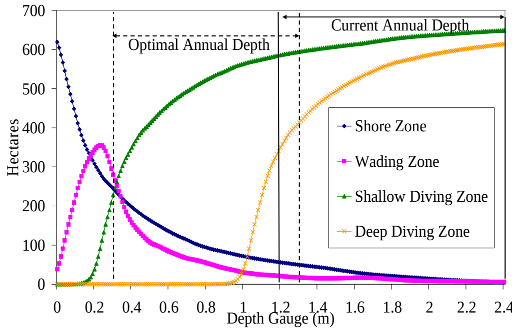

Figure 6. Area of conceptual waterbird habitat zones in relation to water depth for Lake Warden

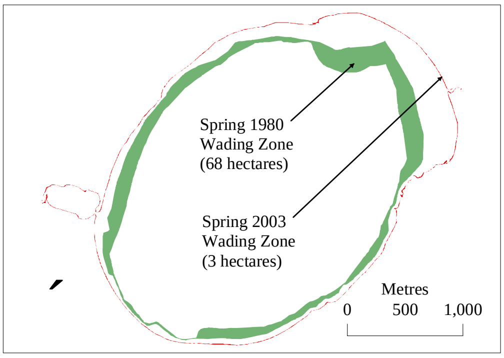

Figure 7. Comparison of the wading zone extent between spring 1980 (green) and spring 2003 (red) for Lake Warden

Lake Wheatfield is part of a more complex, interconnected central suite of lakes with a poorly defined overflow connection to the Southern Ocean. The loss of shallow habitats with depth is not as distinct as for LW, which may explain the less significant reduction in waterbird diversity with depth. The bird survey data also indicates that the central wetland system in the 1980s (pre hydraulic change) was dominated by diving waterbird species. This is indicative of the systems naturally deeper bathymetry and more extensive riparian vegetation.

Station Lake is a shallow lake located within the Bandy Creek flow path and regularly overflows to the ocean. This limits the maximum water depth and loss of shallow water habitats.

This study has not incorporated other factors that may affect waterbird diversity, such as a 'natural' annual variation in both waterbird diversity and depth for the wetland system. Diversity typically peaks in summer and depth in spring for these wetlands. Seasonal variation in depth can be important for the breeding of some waterbird species (Briggs et al. 1997). Waterbirds are highly mobile and may use different types of wetlands at different stages in their lives (Kingsford et al. 2003). It is therefore important to consider regional as much as local factors in conservation efforts. In times of high water levels, some waterbirds may move to shallow water bodies that form elsewhere.

However, the strong connection between decline in waterbird diversity and habitat loss, both in the results and existing literature, provides support to management initiatives to reduce water levels in the LWWS. High water levels can also impact on values other than waterbirds. They can degrade wetland fringing vegetation through prolonged inundation and heighten the risk of flooding.

Although birds (or any one taxon) are unlikely to reflect the overall biota-wide status of wetlands, there are a number of advantages in waterbird monitoring (Mac Nally et al. 2004). Birds are a species-rich taxon and are relatively easy to find and identify. Lay persons often find them engaging, so they provide a good focus for monitoring and conservation efforts. The mobility of birds and their high trophic level means they are potential integrators of ecological conditions over vast areas.

Further analysis will be undertaken by dividing waterbirds into functional groups based on feeding habits (like Taft et al. 2002 and Roshier et al. 2001) and individual species of significance will be analysed. This will enable better quantification of habitat zones specific to the waterbirds using the LWWS. The conceptual zones presented here were derived from mainly North American literature. Riparian vegetation condition is also an important habitat requirement for waterbirds. Remotely-sensed vegetation condition data will be related to the depth/bathymetric data to quantify the impact of water levels on this important component of the LWWS. Similarly, other available datasets on water salinity, pH and invertebrates will be investigated.

A major limitation of using the historic bird survey and Esperance lakes depth data is that they were conducted independently of one another. This has resulted in several bird surveys not being able to be assessed against depth data. It is important when collecting biological data to also collect threat based data, be it water depth or quality. Hydrological modelling to interpolate historic lake depths may provide more extensive access to those bird surveys without existing depth data.

Hydrological control is an obvious tool in the management of wetlands. Reduction in runoff and groundwater recharge in the catchment will play a role in returning the LWWS to their previous lower water levels. However, due to the time lag involved, more immediate engineering solutions such as drainage and pumping of surface water may be required. The timing and rate of any drawdown in water levels will need to be considered in terms of its effects on water quality and organisms. The predicted continuation in long-term rainfall decline for the Esperance area is another factor to consider.

5. CONCLUSIONS

Despite the various caveats, the results support the scientific literature and the principle of waterbird foraging being limited by water depth. To recover waterbird diversity, optimal depth ranges need to be addressed, resulting in the need to immediately dewater at least 5 to 8 GL from LW and smaller volumes from the other lakes in the system. To maintain this range a further annual removal of 1 to 2 GL per annum is required based on lake water balance research conducted by Marimuthu et al. (submitted). The quantities of water requiring management become measurable targets for implementing engineering and land use change options.

This process demonstrates how biological, hydrological, terrain surveys and GIS technology can be used to determine thresholds, so measurable objectives can be set for management purposes. There is scope to apply this type of analysis to other wetlands in south western Australia where various combinations of waterbird, depth and bathymetry data exist.

6. ACKNOWLEDGEMENTS

This work was funded under the WA State Salinity Strategy within CALM's Natural Diversity Recovery Catchment Program. The authors thank Stuart Halse, Yvonne Winchcombe, Jim Lane, Alan Clarke and Nicky Cowcher.

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