

**Bioassessment of freshwater lentic wetlands  
using the  
reference condition approach**

**Toni Furlonge**

**August 2016**

A thesis submitted in fulfilment of the requirements for the degree of  
Doctor of Philosophy in Applied Science

Institute for Applied Ecology  
University of Canberra

## Copyright notice

© The author (2016). Except as provided in the Copyright Act 1968, this thesis may not be reproduced in any form without the written permission of the author.

I certify that I have made all reasonable efforts to secure copyright permissions for third-party content included in this thesis and have not knowingly added copyright content to my work without the owner's permission

## Statement of contribution

The thesis entitled **Bioassessment of freshwater lentic wetlands using the reference condition approach** includes a published paper (Chapter 4) and one manuscript prepared for publication (Chapter 5), which were written under the supervision of Dr. Fiona Dyer and Prof. Jenny Davis (Institute for Applied Ecology, University of Canberra).

These people provided guidance throughout the writing and comments on manuscript drafts. I have not received other assistance than stated above.

As chair of the supervisory panel I agree with the above statement.



.....  
**Dr. Fiona Dyer**

**Date: 09 / 03 / 201**

## Acknowledgements

My first and foremost gratitude is to my supervisors Dr Fiona Dyer and Professor Jenny Davis. Thank you for your guidance, and encouragement to continue writing when I felt isolated. Thank you for being patient when you had to explain the same thing to me more than once. I thank Trefor Reynoldson and Professor Peter Davies for being available to discuss my questions, and Richard Norris in spirit for our initial research discussions. I also thank the other wetland macroinvertebrate scientists throughout the world for sharing their work and enthusiasm.

I thank Scott Schilg, Andrew Baldwin and Natural Resource Management North for supporting me during the research and in return please accept the outputs of the research. I hope wetland research and the use of the model continues.

I thank my good friend and work colleague Debbie Searle for introducing me to macroinvertebrates, rivers and wetlands. Thank you to Matt Taylor, Janet Smith, Jason Neasey, Alan Charlton, Craig Searle, John Gooderham, Di Thomas and Greg Stewart for assisting with selecting and sampling wetlands. The diverse range of protected wetlands sampled would not have been possible without assistance from Jason Neasey (World Heritage Areas; Tasmanian Parks and Wildlife Service; Liaweenee), Janet Smith (Resource Management and Conservation, DPIPWE) and Matt Taylor (Tasmanian Land Conservancy).

I thank my parents for having my girls while I went looking for waterbugs in wetlands, and Lydia, Skye, Amy and Alan for putting up with me while I wrote a PhD thesis.

To Amy, Lydia and Skye, please see this as a challenge for you to achieve more than you plan.

## **Abstract**

Almost half of the world's wetlands have disappeared as a result of anthropogenic influences, with few wetlands remaining in an undisturbed condition in temperate regions. Conservation and restoration of extant wetlands need programs that can assess wetland condition and report on change. Rapid assessment methods are increasingly seen as central for the implementation of freshwater bioassessment and monitoring programs, with protocols well established for rivers and Great Lakes. Bioassessment programs that use the reference condition approach (RCA) and predictive models to assess river health, are common in the United Kingdom, North America, Australia and Canada. In this thesis, I develop and implement the RCA to biological assessment of lentic wetlands, using macroinvertebrates as indicators. My study is based in Tasmania, Australia (a temperate climate zone) where many wetlands are regarded as having high conservation values with more than 60% located within protected areas.

From an initial dataset of approximately 20 000 mapped wetlands and waterbodies, 80 were identified to be in best available condition and suitable for sampling macroinvertebrates for the purposes of my research. Using a Geographic Information System (GIS), existing spatial data, expert local knowledge and ground-truthing, sites located in a range of landforms in protected areas were selected. Sites were categorised using a broad scale classification, refined using a hierarchical rule set, then selected based on the absence of human disturbance and the presence of four habitats considered to be optimal for macroinvertebrate communities. Of these wetlands, multivariate analysis identified six groups, based on 40% similarity. The environmental attributes of land tenure, water regime, dominant habitat and protection zone were significantly associated with the six groups of wetlands. This method of site selection provided an accurate, rapid and cost-effective selection of sites required for this study and would be suitable for other monitoring programs to use.

To consider the influence of spatial and temporal variability on the application of field sampling methods, 48 macroinvertebrate samples were collected from two Ramsar wetlands over a three year period. Samples were collected from four discrete habitats at each wetland, from the austral spring 2009 to autumn 2011. A rapid assessment method was used, employing live picking in the field and family-level identification in the laboratory. No significant differences were detected in the composition of macroinvertebrate assemblages

between habitats within wetlands, between seasons or between years. However, assemblages differed significantly between the wetlands. I concluded that a protocol based on the collection of a single (austral spring), macroinvertebrate sample (representing a composite of four within-wetland habitats) was appropriate for the rapid assessment of wetlands in this region.

The rapid assessment protocol was used to collect macroinvertebrates from 66 protected wetlands. Two hundred and eighteen taxa were identified with an average of 33 species (or morphospecies) and 18 families recorded per wetland. The wetland assemblages were idiosyncratic, four families contributed 21% of the total recorded and only two families contributed greater than 10%. Wetlands were not significantly nested on the basis of the composition of their macroinvertebrate assemblages. No single environmental attribute had a strong relationship with macroinvertebrate richness or assemblage composition and neither species richness nor assemblage composition varied significantly between different types of protected areas. The state of the proximal zone and the type of aquatic habitat present were the most important determinants of macroinvertebrate richness and assemblage composition across all types of protected wetlands.

Using the acquired data, four RCA models were tested. The best model was developed from 46 wetlands, using macroinvertebrate data at the family level with rare families removed. The four predictor variables identified to group similar wetlands were: type of aquatic habitat present, water colour, electrical conductivity and average annual rainfall. Model performance was evaluated using both independent reference-site data and simulated biological impairment data to test both Type 1 and Type 2 errors. The model performed well with respect to Type 1 errors by correctly assigning independent reference-sites to band A and Type 2 errors by correctly detecting three levels of simulated impairment.

The adoption of the RCA to bioassessment of temperate lentic wetlands has been limited, this thesis adds to the global knowledge of the bioassessment of freshwaters using the RCA. Finding environmental attributes associated with macroinvertebrate assemblages and predictor variables to group similar wetlands, is important for the global understanding of wetland macroinvertebrates. The findings have a crucial role in improving our understanding, management and protection of: freshwater ecosystems in Tasmania; wetlands in temperate regions of the world and, macroinvertebrate communities on a global scale. Results suggest that for temperate austral wetlands, bioassessment can be undertaken using macroinvertebrates as indicators and the reference condition approach.

## Table of Contents

Certificate of Authorship of Thesis.....	iii
Abstract.....	ix
List of Figures.....	xv
List of Tables.....	xix
Chapter 1 Introduction.....	1
1. Background.....	1
2. Natural lentic wetlands.....	3
3. Global management of wetlands.....	6
4. Wetland assessment.....	7
5. Bioassessment of freshwater ecosystems using the reference condition approach.....	11
6. Knowledge gaps.....	11
7. Thesis structure and summary of chapters.....	15
8. Study context, aims and hypotheses for each chapter.....	16
9. References.....	17
Chapter 2 Selecting wetlands in best available condition for sampling macroinvertebrates...21	
Abstract.....	21
1. Introduction.....	22
1.1 Study Area.....	24
2. Methods.....	26
3. Results.....	33
4. Discussion.....	39
5. Acknowledgements.....	41
6. References.....	42
Chapter 3 Determining spatio-temporal variation in macroinvertebrate assemblages to inform bioassessment of temperate austral wetlands: a pilot study.....	45
Background.....	45
Abstract.....	46
1. Introduction.....	47
2. Methods.....	48
2.1 Study area.....	48
2.2 Water quality and environmental attributes.....	52
2.3 Macroinvertebrate sampling.....	53

2.4 Data analyses .....	55
3.Results.....	57
4.Discussion.....	65
5.Conclusion .....	67
6.Acknowledgements.....	67
7.References.....	68
Appendix A.....	71
Chapter 4 The influence of differing protected area status and environmental factors on the macroinvertebrate fauna of temperate austral wetlands.....	75
Abstract.....	76
1.Introduction.....	77
2.Materials and methods .....	83
3. Results.....	93
4. Discussion.....	103
5. Acknowledgements.....	107
6.References.....	108
Chapter 5 Applying predictive modelling using a reference condition approach for the biological assessment of temperate austral wetlands.....	113
Abstract.....	114
Keywords .....	114
1. Introduction.....	115
2. Methods.....	118
Fig. 1 .....	119
3. Results.....	127
3.1 Macroinvertebrates .....	127
3.2 Model summaries.....	128
3.3 Bands of biological condition .....	128
3.4 Model validation and testing.....	128
3.5 Model performance for detecting simulated impairment.....	128
4. Discussion.....	135
5. Conclusion .....	138
6. Acknowledgements.....	139
References.....	140

Appendices.....	145
Chapter 6 Discussion .....	153
6.1 Overview.....	153
6.2 Chapter 2 identified wetlands in best available condition suitable for collecting macroinvertebrates and physical attributes common between wetlands .....	154
6.3 Chapter 3 tested a rapid method for sampling macroinvertebrates, investigating spatio-temporal factors that may influence a sampling strategy.....	154
6.4 Chapter 4 sampled macroinvertebrates at 66 protected wetlands using the rapid assessment method from Chapter 3 and identified relationships between assemblages, environmental attributes and different types of land protection. ....	155
6.5 Chapter 5 developed and tested an RCA model using macroinvertebrates as indicators. ....	157
6.6 Recommendations for future research .....	159
6.7 Conclusion .....	160
6.8 References.....	162
Appendices.....	165
Appendix A- Chapter 4.....	165
Watershed and wetland attributes of the 66 Tasmanian wetlands sampled the austral spring 2012. Watershed attributes were obtained from the database held by the Tasmanian Department of Primary Industry and Fisheries in 2008 and wetland attributes were measured <i>in situ</i> in spring 2012. ....	165
Appendix B – Chapter 4 .....	169
Water quality data recorded at the 66 Tasmanian wetlands sampled for macroinvertebrates in the austral spring, 2012.....	169
Appendix C – Chapter 4 .....	173
List of macroinvertebrate taxa recorded at the 66 Tasmanian wetlands sampled in the austral spring, 2012.....	173
Appendix D – Chapter 4 .....	175
Macroinvertebrate family and species (including morpho-species) richness recorded at the 66 Tasmanian wetlands sampled in the austral spring, 2012. Means and standard errors are shown for Protected Area Type, Proximal Zone, Dominant Habitat, and Water Regime attribute categories, listed in descending order of the highest family richness .....	175

## List of Figures

### Chapter 1

Fig. 1 The terrestrial and aquatic zones of a freshwater shallow standing wetland in north eastern Tasmania. 5

Fig. 2 Map of the study area with Tasmania and Australia as inserts, showing the wetlands sampled in Chapter 4 and used to develop the RCA model in Chapter 5. World Heritage Areas are shown by solid diagonal lines and contours are shown by light grey lines. 14

### Chapter 2

Fig. 1 Location of Tasmania in relation to Australia (inset). Black diagonal lines denote World Heritage Areas and grey lines are rainfall isohyets at 100 mm intervals below 2000 mm per annum and at 20 mm intervals above 2000 mm per annum. Data were provided by courtesy of Department of Primary Industries in 2014. 25

Fig. 2 Process used to select candidate reference sites. Aerial photography provided by J D, 2011. Data were provided by courtesy of Department of Primary Industries in 2014. 29

Fig. 3 Dendrogram (Cluster, group average) showing similarities of wetlands using nine environmental attributes (water regime, land tenure, dominant habitat, protection zone, surrounding vegetation, catchment land-use, landform, rainfall, and distance to river). Slice is shown at 51% similarity. 36

Fig. 4 Ordination (MDS, 25 restarts, Kruskal fit) of wetlands selected for sampling macroinvertebrates in spring 2012, sites are colour coded with symbols by landform. All inland basin wetlands (undulating plains, low slopes and mid slopes) are shown as green circles; floodplain wetlands are shown as blue triangles; coastal basin wetlands are shown as orange squares. 37

### Chapter 3

Fig. 1 The location of Tasmania in relation to mainland Australia (top left inset). Black diagonal lines denote World Heritage Areas (WHA) and rainfall isohyets (grey lines) are shown at 100 mm intervals below 2000 mm and at 20 mm intervals above 2000 mm. The location of Little Waterhouse Lake and the Ringarooma Wetland are indicated by arrows and black circles on the right inset. Right inset shows wetlands as shaded areas and hydrology as lines. Data were provided by Department of Primary Industries in 2014. 51

Fig. 2 The mean number of macroinvertebrate families recorded at the Little Waterhouse Lake (LWL) and Ringarooma Wetland (RW) from 2009 to 2011; (a) between wetlands; (b) between habitats (fringing vegetation, emergent macrophytes, submerged macrophytes and open water); (c) between years (2009, 2010 and 2011); and (d) between seasons (austral spring and autumn). The horizontal lines inside the boxes represent the medians, the top and bottom edges of the boxes represent 25–75% quartiles, whiskers represent the range of the data and the star shows a maximum outlier. 62

Fig. 3 Ordination (nMDS) plot of spatial variability of the macroinvertebrate assemblages collected from 2009 to 2011. Little Waterhouse Lake (LWL) = solid triangles and Ringarooma Wetland (RL) = open squares. 63

Fig. 4 The dbRDA plot of macroinvertebrate assemblages at Little Waterhouse Lake (LWL; solid triangle) and Ringarooma Wetland (RL; solid circle) from 2009 to 2011. Vectors indicate the influence of water quality attributes: pH, electrical conductivity (EC), Total Phosphorus concentration (Total P), Total Nitrogen concentration (Total N) and turbidity on explaining the variation in assemblages (richness and abundance). 64

#### Chapter 4

Fig. 1 Map of Tasmania showing the location of 66 wetlands sampled for macroinvertebrates and environmental attributes in the austral spring, 2012. Wetlands are labelled with a unique number which is linked to wetland attributes in Appendices A, B and C. Black diagonal lines denote World Heritage Areas (WHA). Rainfall isohyets (grey lines) are shown at 100 mm intervals below 2000 mm and at 20 mm intervals above 2000 mm. The location of Tasmania in relation to mainland Australia is shown on the upper map. 83

Fig. 2 Decision tree illustrating the hierarchical rule set developed for selecting freshwater wetlands for inclusion in this study. 84

Fig. 3 (a) Differences in the number of macroinvertebrate taxa recorded from the 66 Tasmanian wetlands sampled in the austral spring, 2012 with different types of protected area status (x-axis); and (b) Differences in the number of families of macroinvertebrates recorded at wetlands with different types of protected area status (x-axis). The horizontal lines inside the boxes represent the medians, the top and bottom edges of the boxes represent 25–75% quantiles, and whiskers represent the range of the data. 96

Fig. 4 Differences in the number of macroinvertebrate taxa recorded from the 66 Tasmanian wetlands sampled in the austral spring, 2012, with differing proximal zones (x-axis). The horizontal lines inside the boxes represent the medians, the top and bottom edges of the boxes represent 25–75% quantiles, and whiskers represent the range of the data. 97

Fig. 5 Differences in the number of species of macroinvertebrates recorded from the 66 Tasmanian wetlands sampled in the austral spring, 2012 dominated by macrophytes or sediments. The latter includes combinations of clay, silt, sand, gravel, pebble, cobble or boulder. The horizontal lines inside the boxes represent the medians, the top and bottom edges of the boxes represent 25–75% quantiles, and whiskers represent the range of the data. 98

Fig. 6 Multi-dimensional Scaling (MDS) ordination of macroinvertebrate assemblages (presence-absence transformation) from 66 Tasmanian wetlands sampled in the austral spring, 2012. Wetlands are coded by symbols for: a) Protected Area Types: open triangles = National Park; closed squares = Tasmanian Land Conservancy, closed circles = Directory Important Wetlands Australia (includes Ramsar); closed triangles = Private Land Covenant, X = Public Reserve; star = World Heritage Area and + = Forestry Reserve; and b) Dominant Habitat: X = sediments -dominated; and open circle = macrophyte-dominated. 100

Fig. 7 Three dimensional ordination (MDS) of 66 protected wetlands and 6 non-protected wetlands showing macroinvertebrate taxa at family level. 102

## Chapter 5

Fig. 1 Wetlands in best available condition and in accessible areas, sampled in spring 2012, representing landforms in central and north eastern Tasmania. Black diagonal lines denote World Heritage Areas (WHA). Rainfall isohyets (grey lines) are shown at 100 mm intervals below 2000 mm and at 20 mm intervals above 2000 mm. The location of Tasmania in relation to mainland Australia is shown in the inset. Data were provided by courtesy of Department of Primary Industries in 2014. 118

Fig. 2 Distribution of observed / expected (O/E) taxa values for the validation sites and sites with 3 degrees of simulated impairment for the 'Family-Rare-Removed' Tasmanian wetland model. The horizontal dotted lines represent bands of biological condition (central 80% of sites in each of the bands). Band A is equivalent to reference condition, B mild impaired condition and C moderate/severe impaired condition. 132

Fig. 3 Ordination of macroinvertebrate presence-absence data for training sites and training sites removed from model development (atypical sites), validation sites and test sites used to develop and test the 'Family-Rare Removed' model for Tasmanian wetlands. 133

Fig. 4 Observed / Expected taxa values for 14 test-sites distributed to band A and band B in the 'Family-Rare Removed' model for the Tasmanian wetlands. The horizontal dotted lines represent bands of biological condition (central 80% of sites in each of the bands). Band A is equivalent to reference condition, band B mildly impaired condition. 134

## List of Tables

### Chapter 1

Table 1 Main groups of indicators used in wetland rapid assessment methods reviewed by Fennessy *et al.* (2004). 9

Table 2 Australian freshwater wetland assessment methods with management and planning objectives (DEHP accessed 06/12/2015). 10

### Chapter 2

Table 1 Hierarchical arrangement of environmental variables used to assist in categorising wetlands and determine extent and scale of mapped wetlands. Listed in order of large scale to small scale (1:500 000 to 1:25 000 respectively), grouped by resolution (ecosystem through to local respectively). All environmental variables were accessed as spatial data from the Tasmanian Government (DPIPWE 2008). Aerial photography was provided by one of the authors (J D, unpublished). 27

Table 2 Description of the four habitats identified in temperate Tasmanian wetlands. 32

Table 3 The number of Tasmanian wetlands, representing seven landforms and two water regimes and determined to be in best available condition. 34

Table 4 ANOSIM results for the seven environmental attributes that were associated with six groups of wetlands identified by cluster analysis. Attributes are listed in order of most significant to least significant. Landform and land tenure attributes are from the Tasmanian State Government (DPIPWE 2008), and other attributes were determined through expert local knowledge. 38

### Chapter 3

Table 1 Physical attributes of Little Waterhouse Lake and the Ringarooma wetland. Data were provided by courtesy of Department of Primary Industries in 2014. 50

Table 2 Environmental attributes recorded at Little Waterhouse Lake and Ringarooma wetland from 2009 to 2011. Data were provided by courtesy of Department of Primary Industries in 2014. 53

Table 3 Description of the four discrete habitats at Little Waterhouse Lake and Ringarooma Wetland and the number of macroinvertebrate samples collected from each habitat. 55

Table 4 Summary of water quality attributes (mean +/- standard error) recorded at Little Waterhouse Lake and Ringarooma Wetland from spring 2009 to spring 2011. 57

Table 5 Results of ANOSIM pairwise tests (using Bray Curtis dissimilarities) for macroinvertebrate communities in four habitats, at two sites in northern Tasmania (Little Waterhouse Lake and Ringarooma Wetland) in two seasons (autumn and spring) and three

years (2009-2011). Results are given as Global R with 1= greatest dissimilarity and 0 = least dissimilarity. 58

Table 6 Results of similarity percentages (SIMPER) analysis (Sorensen's similarity index, 999 permutations, single layout with *site* as factor). Twenty macroinvertebrate families were considered to discriminate between the assemblages in Little Waterhouse Lake (LWL) and Ringarooma Wetland, (RW) by contributing consistently to dissimilarity between wetlands (Average Dissimilarity/SD  $\geq 1$ ). The average abundance of each family in each wetland (LWL, RW), their contribution to between-wetland dissimilarity (Average Dissimilarity) and the consistency of these contributions to dissimilarity (Dissimilarity/SD) are shown. Families are listed in descending order according to their individual contribution to between wetland dissimilarity. 59

#### Chapter 4

Table 1 Definitions and descriptions of Protected Area Types (PAT) for Tasmanian wetlands sampled in the austral spring, 2012. 80

Table 2 Wetland attributes recorded and watershed attributes collated for each wetland. The categories for Protected Area Type, Proximal Zone, Water Regime and Dominant Habitat variables are defined in Tables 1 and 3. The GIS database is held by the Conservation of Freshwater Ecosystems Values program within the Tasmanian State Government (DPIPWE 2008). 86

Table 3 Description of Water Regime, Dominant Habitat and Proximal Zone categories defined for wetlands sampled in the austral spring 2012 in central and north eastern Tasmania. 88

Table 4 Number of study wetlands in categories of Protected Areas, Water Regime, Dominant Habitats and Proximal Zones. 93

Table 5 Macroinvertebrate taxa occurring in > 50% of wetlands, listed in order of dominance. 94

#### Chapter 5

Table 1 The 12 environmental variables unrelated to human induced stressors, used in Discriminant Function Analysis to define the variation among the training-sites. Catchment variables and variable measures were provided courtesy of Tasmanian Government (Department of Primary Industries Parks Water Environment Tasmania 2008) using Environmental Systems Research Institute Geographic Information Systems ArcMap10 (GIS). Wetland variables were recorded on site in spring 2012. 124

Table 2 Simulated impairment criteria (richness only) used to create 3 levels of artificial impairment in the validation dataset. 125

Table 3 Summary details for the AUSRIVAS-style predictive models for the Family-Rare-Removed, Family, Species-Rare-Removed and Species models tested for Tasmanian wetlands. O/E = observed/expected taxa. 130

Table 4 Predictor variable summary statistics and the number of macroinvertebrate taxa per group for each group of training-sites the Tasmanian wetland 'Family-Rare-Removed' model.

131