MURRAY**FUTURES**
Lower Lakes & Coorong Recovery

Research to Support the Real Time Management Strategy to Avoid Acidifcation in Lakes Alexandrina and Albert.

Ecological Consequences of managing water levels to prevent acidification in Lakes Alexndrina and Albert: Technical Report

December 2011

Australian Government

Government of South Australia

WATER FOR GOOD

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Ecological consequences of managing water levels to prevent acidification in Lakes Alexandrina and Albert: Technical Report.

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December 2011

Government of South Australia
Department of Environment, Water and Natural Resources

KERRI MULLER NRM
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Executive Summary

Lakes Alexandrina and Albert, at the junction of the River Murray and the Southern Ocean in South Australia, are at risk of widespread acidification if River Murray inflows are low and lake levels drop to -1.5 and -0.5 m AHD (approximate metres below sea level), respectively. To address this, the Department of Environment and Natural Resources (DENR) commissioned an assessment of the likely ecological consequences associated with different water management options.

The first option is to Do-nothing, let the lakes drawdown and potentially acidify. Another option is to introduce seawater into Lake Alexandrina, through the barrages that separate the lakes from the Coorong, Murray Mouth and the sea, to just above the critical levels. A third option is to deliver additional River Murray flows and use freshwater to maintain lake levels. Within each of these regional options is the additional choice of pumping water from Lake Alexandrina to Lake Albert, or not, yielding a total of six management scenarios. Hydrological models for salinity, pH and water levels were run for each scenario for five years of action (e.g. Do-nothing from 2009 to 2015) and ten years of either entitlement or average recovery flows (1,850 and 4,000 to 5,000 GL/y, respectively). These model outputs were then assessed for ecological consequence.

Do-Nothing

If pumping to Lake Albert continues, evaporation of impounded water in Lake Alexandrina will lead to increases in salinity followed by widespread acidification. This will be fatal to all biota except salt-tolerant fish or plankton that may persist in deeper, neutral waters. Acidification will not occur in Lake Albert. However, increases in salinity will lead to loss of all resident biota except the most salt-tolerant (e.g. small-mouthed hardyhead).

If pumping to Lake Albert ceases, salinities in Lake Alexandrina will not increase as much as if pumping continues but never the less all freshwater plants and most freshwater animals will perish. Disconnection from the Coorong and Murray Mouth will limit or prevent colonisation by most estuarine biota that might replace declining or lost freshwater taxa. Without water, Lake Albert will acidify and dry to a few, isolated pools, resulting in complete loss of the aquatic ecosystem.

Thus, there is a trade-off between salinisation or acidification of one or both lakes when deciding on whether to pump to Lake Albert, or not, under the Do-nothing scenario.

Introduce Seawater

Introducing seawater to maintain target water levels will prevent widespread acidification in Lake Alexandrina but salinities will increase to hypersaline concentrations, whether pumping to Lake Albert continues, or not. This will result in loss of all freshwater and any colonising estuarine taxa (including fish) within the second and third year of seawater introduction. The most salt-tolerant fish and insect larvae may persist into the fifth year. Importantly, a healthy, estuarine/marine community will not establish and the result will be ecological catastrophe.

If pumping continues, Lake Albert will not acidify but salinities will increase to hypersaline concentrations and result in near complete ecological loss. If pumping ceases, there will be loss of the Lake Albert aquatic ecosystem because it will acidify and dry out as in the Do-nothing scenario.

Deliver Freshwater

Delivering just enough River Murray water to maintain target water levels will prevent acidification but it will not prevent on-going ecological decline. Salinities will be much lower than in the Do-nothing or introduce Seawater but will still rise to ten times the Ramsar target, leading to the loss of the ten most salt-sensitive indicator taxa. Pumping to Lake Albert will marginally improve the salinity regime in Lake Alexandrina, compared to when pumping ceases, because the hydrological model will demand more River Murray water to satisfy the demands of both lakes and salt will be exported to Lake Albert. Even under these lower salinity levels, the ten most salt-sensitive indicator taxa will still perish.

Pumping freshwater in from Lake Alexandrina will prevent widespread acidification in Lake Albert but it will cause a progressive increase in salinity. This will lead to the loss of all but the most salt-tolerant taxa within the first year. The remaining biota will become increasingly stressed over time. As for the two options above, the Lake Albert ecosystem will be completely lost from acidification followed by desiccation if pumping ceases.

Capacity to recover under Entitlement and Average flows

Lake Alexandrina

Under Entitlement flows, the water levels will be too low to reconnect the main lake body to the former riparian zone or to allow the removal of barriers (e.g. open barrages, remove regulators). Aquatic vegetation will be unlikely to establish around the 'new' shoreline, therefore, very little ecological recovery will occur.

Average recovery flows will fill the lakes and reconnect the former riparian zone, allowing the regulators to be removed and the barrages to be opened. Simple reed beds with low diversity and poor ecological function will establish but will not provide the pre-conditions for full recovery. This will limit recovery to just the hardiest taxa.

Salinities will decrease but not far enough to support all biota seen in the Ramsar state. Salinities in the seawater scenarios will remain higher for longer across larger lake areas than in the other scenarios, resulting in lower ecological recovery. Similarly, salinities will be significantly higher for longer and, thus, ecological recovery will be lower in Lake Albert than in Lake Alexandrina.

Overall, the greatest number of Ramsartaxa will recover in the Freshwater scenario but recovery potential will be lower in the Do-Nothing and lowest in the Seawater scenarios. Recovery will be better following the catastrophic impacts of widespread acidification in the Do-nothing pumping scenario than following the catastrophic impacts of hypersalinity in the Seawater scenarios.

The loss of the Lake Albert ecosystem when pumping ceases and it is allowed to dry out will be unrecoverable, regardless of the management option and the magnitude of recovery flows.

The ecological consequences associated with any of the management options will persist beyond the ten-year recovery period, that is, beyond 2025.

1. Introduction

1.1. Study Approach

The Department of Environment and Natural Resources (DENR) commissioned this Ecological Consequences Assessment (ECA) to determine the likely ecological outcomes from several options for managing water levels to prevent acidification of Lake Alexandrina. It is understood that Lakes Alexandrina and Albert are at risk of widespread acidification if their respective water levels drop to -1.5 and -0.5 m AHD (approximately metres below sea level) due to exposure of acid sulfate soils (ASS; DENR 2010a). Water levels could be maintained higher than these critical levels (tipping points) by introducing seawater into Lake Alexandrina through the barrages that separate the lakes from the Coorong, Murray Mouth and the sea or by providing freshwater inflows from the River Murray. The other regional management option, if River Murray inflows were insufficient for maintaining levels, would be to Do-Nothing and allow the lakes to drawdown below the acidification tipping points. Thus there are three regional water management options:

- Do-nothing;
- Introduce Seawater; or
- Deliver Freshwater.

The South Australian Government's management objective is:

To understand the hazard of acidification to Lakes Alexandrina and Albert and the ecological consequences associated with different water management options.

In order to address this management objective, ECA aimed to differentiate the water management options by:

1. Assessing the ecological consequences and probable effects of the modelled physico-chemical conditions on selected flora and fauna;
2. Determining whether acidity, salinity (derived from evapo-concentration or seawater introduction) or a combination of both was of greater ecological consequence.
3. Evaluating the capacity for the selected flora and fauna to recover from any ecological effects; and
4. Describing the ecosystem states and transitions through time, including capacity to return to the freshwater state.

Hydrological modelling was undertaken to provide a suite of predictions for the likely physico-chemical conditions in the Coorong, Murray Mouth region and Lakes Alexandrina and Albert (Wainwright and Hipsey, 2010). These hydrological modelling outputs are used here to assess the likely ecological consequences (both positive and negative) associated with each regional water management option.

The start date for the ECA was October 2009. At that time, water levels in the lakes were very low (approximately -0.8 mAHD compared to full supply level of +0.75 mAHD) and it was not known whether future River Murray inflows would be sufficient to prevent further drawdown. Flow regulators were in place at Clayton and across the Narrung Narrows in October 2009 (See Figure 1.1). The Clayton regulator ponded water in Goolwa Channel to act as a freshwater refuge should the main lake bodies become more saline, acidic or both due to sustained low River Murray inflows.

Figure 1.1: A map of the site showing the permanent barrages between the islands in the south of Lake Alexandrina and the temporary bunds in place at Clayton and across Narrung Narrows. Maps showing the ECA modelling points appear in Attachment D.

The Narrung Narrows bund (earthen embankment) effectively uncoupled water level management of Lakes Alexandrina and Albert. It also provided a regulator across which water could be pumped from Lake Alexandrina to Lake Albert (see below). It was assumed that the Pomanda Island weir near Wellington was in place to protect Adelaide's water supplies drawn from the Lower Murray from poor quality water moving upstream from Lake Alexandrina (DEH 2010). It was also assumed that that the barrages were closed except for when seawater was being introduced in the seawater scenarios.

Pumping to Lake Albert was, thus, an additional variable (other than regional water management) resulting in six management scenarios requiring assessment of ecological consequences:

Do-nothing (drawdown) ± pumping to Lake Albert. No additional water is sourced and the water level is allowed to drawdown to below the acidification tipping points if water consumption exceeds inputs (-1.5 m AHD and -0.5 m AHD in Lakes Alexandrina and Albert, respectively).

Seawater ± pumping to Lake Albert. Where seawater is sourced and supplied via the barrages to maintain water levels above the acidification tipping points; and,

Freshwater ± pumping to Lake Albert. Where freshwater is sourced and supplied via the River Murray to maintain water levels above the acidification tipping points.

The hydrological modelling assumed specific River Murray inflows over the South Australian border and local climate conditions (see Wainwright and Hipsey, 2010 for hydrological modelling details). The ECA "action" period within which time these management options of Do-nothing, Seawater or Freshwater were applied, extended from spring 2009 to the end of March 2015. After March 2015, a ten-year "recovery" period was modelled to show whether water levels and salinity were predicted to return to typical operating levels (e.g. approximately +0.6 mAHD and less than 0.7 g/L or 1000 µS cm-1 in Lake Alexandrina) by 2025.

The ECA process began with facilitated expert workshops to document current knowledge of the Lakes and Coorong ecosystem and to identify a suite of ecological receptors (e.g. species, assemblages, functional groups) suitable for assessing both positive and negative consequences to the flora and fauna of the Coorong, Murray Mouth and Lakes Alexandrina and Albert. Sixteen local scientists familiar with the biota of the Coorong and Lakes Alexandrina and Albert were collectively trained in a common set of consequence assessment methods as detailed in Muller 2010a and Muller 2010b. Using these methods, each scientist determined the likely habitats, baseline conditions, thresholds and other considerations regarding tolerance and recovery strategies for their respective receptors. Each of the evaluations was based on three primary stressors: salinity, water level and pH.

The experts identified a total of 55 receptors across six biotic groups that could collectively be used to assess the consequences to the flora and fauna of the site. The experts independently completed the full suite of assessment templates (Muller 2010 a and b) using preliminary hydrological modelling outputs and attended a series of six two-day workshops in June 2010 covering six biotic groups: plankton, vegetation, lacustrine macroinvertebrates, estuarine macroinvertebrates, fish, frogs and birds. A combined workshop was then held to prepare guidelines for integration of individual receptor consequence scores and to review conceptual State and Transition models prepared in response to the information used in the workshops (see Souter and Stead 2010).

The outputs of these workshops were used to score consequences for each of the 55 receptors within these six biotic groups associated with three primary stressors: salinity, water level and pH, using outputs from the hydrological modelling. The consequence scores were then used to determine the most likely ecological outcomes (in terms of consequences to the different resident receptors and invasion of new taxa) under the six scenarios.

The following report presents:

- methods for the ecological consequence assessment (Section 2)
- descriptions of the Ramsar and the October 2009 Baseline ecosystem states (Attachment A)
- rationale for receptor selection and groupings, notes on the baseline condition for each receptor at October 2009 and determination of probable receptor responses to stress (Section 3, Attachments B and C);
- the results of the consequence scoring and the consolidated effects of the primary stressors on the receptors during the 'action' period for each scenario (2009 to March 2015; Sections 4, 5 and 6, Attachment D);
- an exploration of the potential for ASS management techniques, other than the six regional water management scenarios (e.g. vegetation, limestone dosing), to treat or control any acidification events predicted by the hydrological models (Attachment F);
- an evaluation of the capacity for each receptor to recover from impacts experienced during the 5-year action over a subsequent 10-year "recovery period" under either entitlement (1,850 GL/y over SA Border) or average (4,000 to 5,000 GL/y) River Murray flows (Section 7);
- descriptions of the alternate ecosystem states and transitions in state predicted for each management scenario (Section 8);
- conclusions drawn on the likely ecological outcomes over the whole 15-year period from October 2009 when the action commenced to December 2025 when the recovery period ended (Section 9); and
- recommendations for further works (Section 9).

Together these components provide DENR with critical information on how the different flora and fauna may respond under each management scenarios and a scientifically sound justification for meeting the management objective of choosing the regional water management option with the least negative effects on the Ecological Character of the site.

1.2. Acid Sulfate Soils

The central premise of this ecological consequences assessment is that there is likely to be widespread acidification of Lakes Alexandrina and Albert if their water levels drop to below their acidification tipping points: -1.5 mAHD and -1.0 mAHD, respectively. This is based on the proportion of acid sulfate soils (ASS) exposed by receding water levels and thus the amount of acid generated and mobilised into the water body before the neutralising capacity of the water is overwhelmed (DENR 2010). Background information on ASS is provided here to assist the reader's understanding of the consequences for the flora and fauna and the possible options for preventing acidification of the lakes' system.

Acid sulfate soils (ASS) are defined as soils or sediments that contain (or once contained) high levels of reduced inorganic sulfur (mostly as sulfide, elemental sulfur, or both) and when exposed to oxygen, the soils or sediments undergo a chemical reaction that produces acid (EPHC & NRMMC 2011). In order for ASS to form there needs to be supplies of iron minerals, organic matter and sulfate as well as reducing conditions in the sediment which will support sulfate reducing bacteria to convert the sulfate ions to sulfides such as ferrous sulfide (Baldwin and Mitchell 2000; Fitzpatrick 2010).

In recent years ASS have been identified in many Australian inland aquatic ecosystems, including Lakes Alexandrina and Albert, and a number of associated risks posed by ASS have also been identified (EPHC & NRMMC 2011) including:

- Acidification: Generation of acid via a series of complex oxidation reactions when ASS is exposed to oxygen. If the amount of acidity produced by this oxidation process is greater than the system's ability to absorb that acidity (the acid neutralising capacity) the pH of the system falls.
- Deoxygenation: Some ecosystems containing ASS have high capacity to neutralise acid and may not acidify. However, ASS oxidation consumes oxygen and can deoxygenate the water resulting in extreme anoxia events that lead to mortality of aquatic organisms (e.g. fish kills). Deoxygenation is most likely to occur if monosulfidic materials (formerly monosulfidic black oozes), are physically disturbed and distributed throughout a water column.
- Release of metals and metalloids: Oxidation of sulfidic materials may lead to heavy metals (such as cadmium and lead) and metalloids (such as arsenic) becoming more available in the environment. Once freely available in the environment they can be directly incorporated into living tissue and potentially enter the food chain. Dissolved aluminium, the most common and harmful metal released is toxic to many aquatic plants and fish (ANZECC and ARMCANZ 2000). It can be released from clays that are broken down under acidic conditions. Metal flocculants may also form, which can be fatal or cause injury to organisms with gills.

ECA focuses on the ecological consequences associated with acidification but does not evaluate the ecological consequences of deoxygenation or release of metals and metalloids. That is not to say that the consequences of acidification are necessarily more or less ecologically damaging but is simply the scope of the current assessment. Hydrological modelling outputs are available for dissolved oxygen and a range of other water quality parameters that can be evaluated subsequent to the assessment of consequences from the three primary stressors: water level, salinity and pH.

There are different types of ASS. Materials that actually generate acid are termed sulfuric materials. Sulfuric materials have a pH of less than 4 in the field and generate sulfuric acid. Materials that have the potential to generate acid are termed hypersulfidic and hyposulfidic materials. Hypersulfidic material is sulfidic material that acidifies when aerobically incubated under standard conditions in the laboratory. Alternatively, hyposulfidic material is sulfidic material that has a field pH of 4 or more and which does not acidify by a drop of at least pH 0.5 to pH of 4 or less in the laboratory. Those ASS materials that do have a pH of less than 4 in the field are termed sulfuric. These terms are taken from NRMMC (2011).

From the extensive CSIRO soil library, Fitzpatrick *et al.* (2010) have prepared a spatial database and compiled sets of maps showing the distribution of various ASS types and parameters for the lakes and tributaries in the CLLMM region. A map can be prepared to show relative proportions of sulfidic and sulfuric materials at a given time and lake level, such as that shown in Figure 1.2 for August 2009.

Figure 1.2 shows that both sulfuric and sulfidic ASS materials are generally widespread throughout the Lakes Alexandrina and Albert. Fitzpatrick *et al.* (2010) found that across all of their lakes' samples:

- 10% contained sulfuric material (pH < 4.0),
- 39% of sites had considerable potential for further developing sulfuric materials from hypersulfidic materials if the water levels continue to drop exposing these soil materials and allowing them to oxidise.

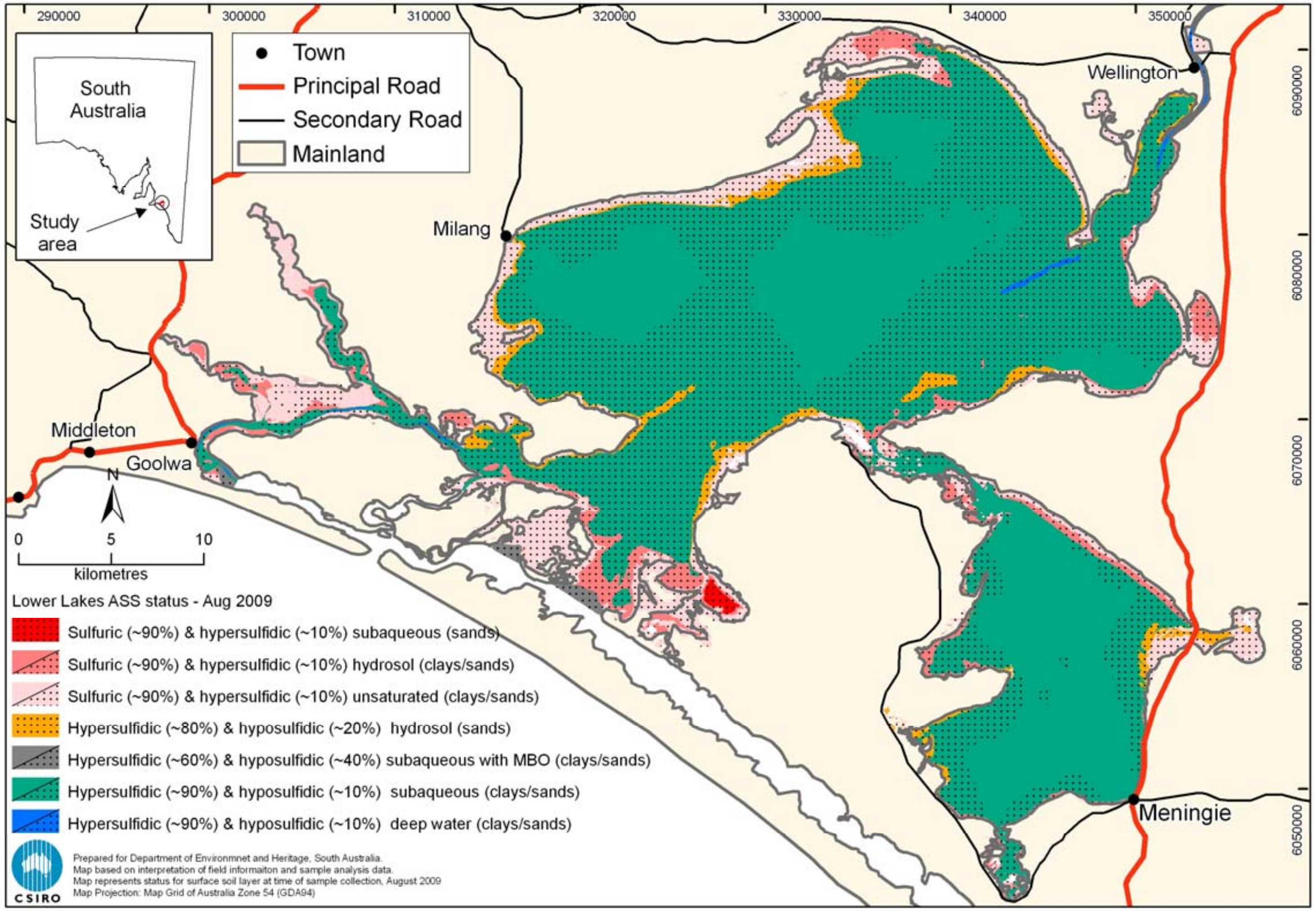


Figure 1.2: Map of different types of Acid Sulfate Soils (ASS) in the lakes at August 2009.
Source: Fitzpatrick et al. (2010).

- Hypersulfidic subaqueous soils with associated hyposulfidic subaqueous soils and hypersulfidic hydrosols comprise 70,829 ha (i.e. are significant covering about 80% of the 89,219 ha).
- Sulfuric unsaturated soils and sulfuric hydrosols comprise 18,226 ha (i.e. accounting for about 20% of the 89,219 ha), and
- Sulfuric subaqueous soils comprise 165 ha (i.e. accounting for about 0.2% of the 89,219 ha).

As a consequence of the widespread distribution of ASS materials, Lakes Alexandrina and Albert are at risk from both soil and water acidification. This Ecological Consequences Assessment (ECA) is focussed on quantitative assessment of ecological consequences associated with water acidification using the hydrological modelling outputs. Consequences from soil acidification are considered in the evaluation of each receptor's capacity to withstand the action period impacts and recover. The level of risk of water acidification depends on how much of the ASS is exposed and how the ASS exposure is managed. If acidification occurs it could be localised and contained to an embayment or fringing wetland area that does not interact with the main lake body. Acidification events can also be widespread and affect most or all of one or both lakes. Ecological impacts are assessed here for some receptors when pH drops below a value of 6 based upon their specific pH tolerances. Others are not adversely affected until pH drops to less than 5 (see Section 3 for pH tolerances).

The ASS materials present in the lakes can change from being sulfidic (relatively benign) to sulfuric (generating acid) and back again depending on environmental conditions (Figure 1.3). When wet, the ASS is under reducing conditions and the ASS materials will tend towards the sulfidic state. When exposed to air (dry or disturbed) and under oxidising conditions, the ASS materials will tend towards the sulfuric state. Acidified soil thus represents an environmental hazard and the potential for acidification of the water body increases as the area of sulfuric material increases. Flora and fauna can be affected by acidification directly if the pH drops to below their tolerance (Section 3) or indirectly via oxidation products such as heavy metals (not assessed here). ASS that is kept wet is likely to remain in a reducing state and thus does not represent an environmental hazard.

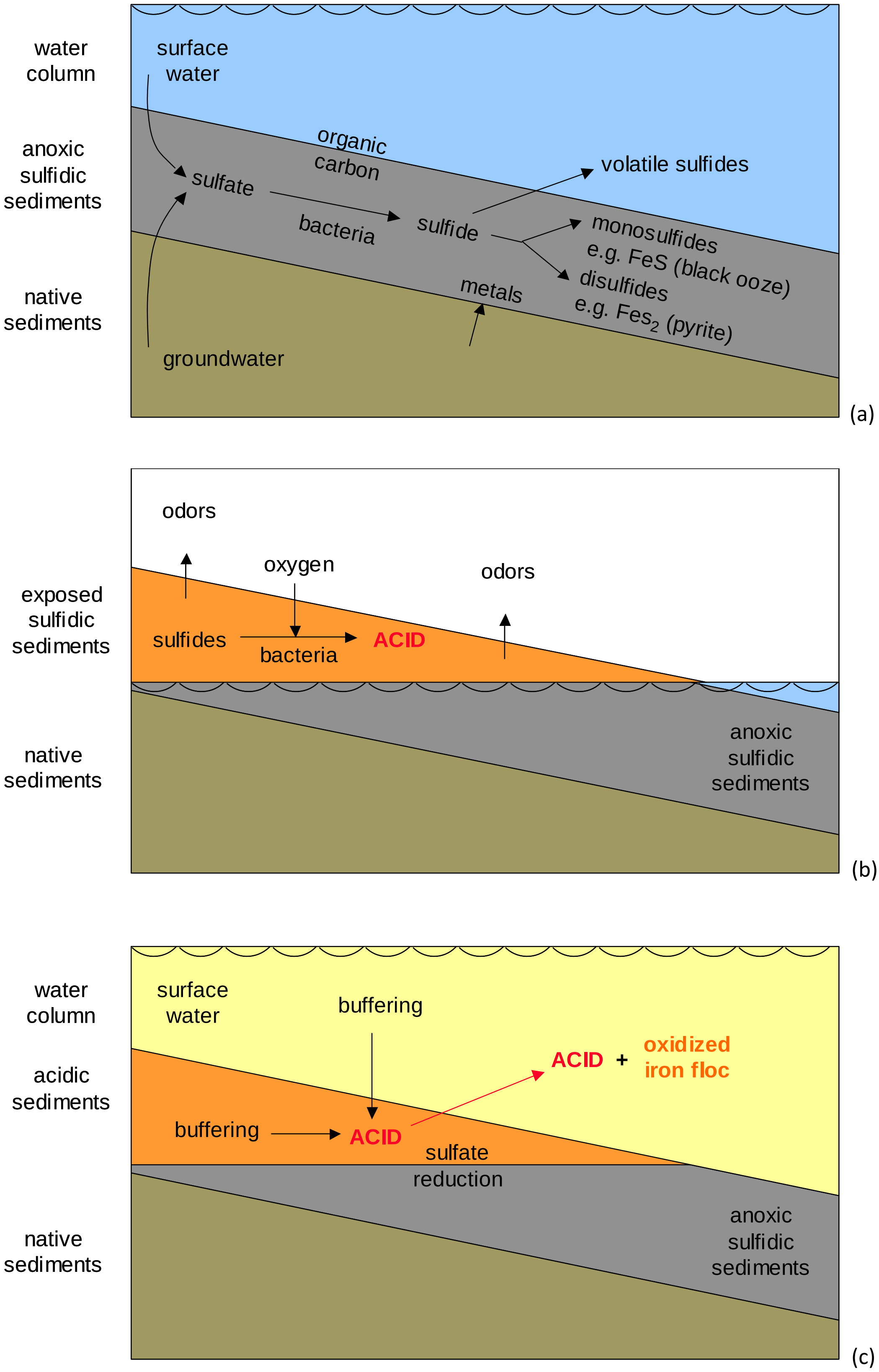


Figure 1.3: Schema of acid sulfate soils (ASS) under different water regimes. Biological formation of ASS through sulfate reduction when submerged (a), generation of sulfuric acid via sulfide oxidation when ASS exposed (b) and flushing of acids from ASS into the water the water column when exposed ASS are rewetted (c). Source: Baldwin (2009).

1.3. ASS Management scenarios being assessed.

As introduced above there are three different ASS regional water management options for the Coorong, Murray Mouth and Lakes Alexandrina and Albert wetland system: Do-nothing, introduce Seawater or deliver Freshwater. Within the site there are management options for pumping from Lake Alexandrina to Lake Albert, or not.

Action period

The assessment of ecological consequences during the 5-year action period (October 2009 to March 2015) was undertaken for receptors in Lakes Alexandrina and Albert for all scenarios for the three primary stressors: water level, salinity and pH.

Receptors in the Murray Mouth and Coorong Lagoons (North and South) were assessed for the Seawater introduction scenarios only and then only for water level and salinity. This yielded six management scenarios (three regional water management and two Lake Albert pumping options) for the action period across two or five intrasite water management units as shown in Figure 1.4. The potential for alternate ASS management options to prevent, treat or control acidification in Lakes Alexandrina and Albert were explored for the six action period scenarios.

Recovery period

The evaluation of each receptor's capacity to recover during the 10-year recovery period (April 2016 to December 2025) was undertaken for receptors in Lakes Alexandrina and Albert only. Simulations for the recovery period in the Murray Mouth and Coorong were not available and were outside of the scope of the assessment.

There were two recovery flow regimes: Entitlement flows (1850 GL/y) and Average flows (4,000 to 5,000 GL/y) over the South Australian Border. This yielded a total of 12 management scenarios for each of the two lakes across the three regional water management options, two Lake Albert pumping scenarios and two recovery flow regimes as shown in Figure 1.4.

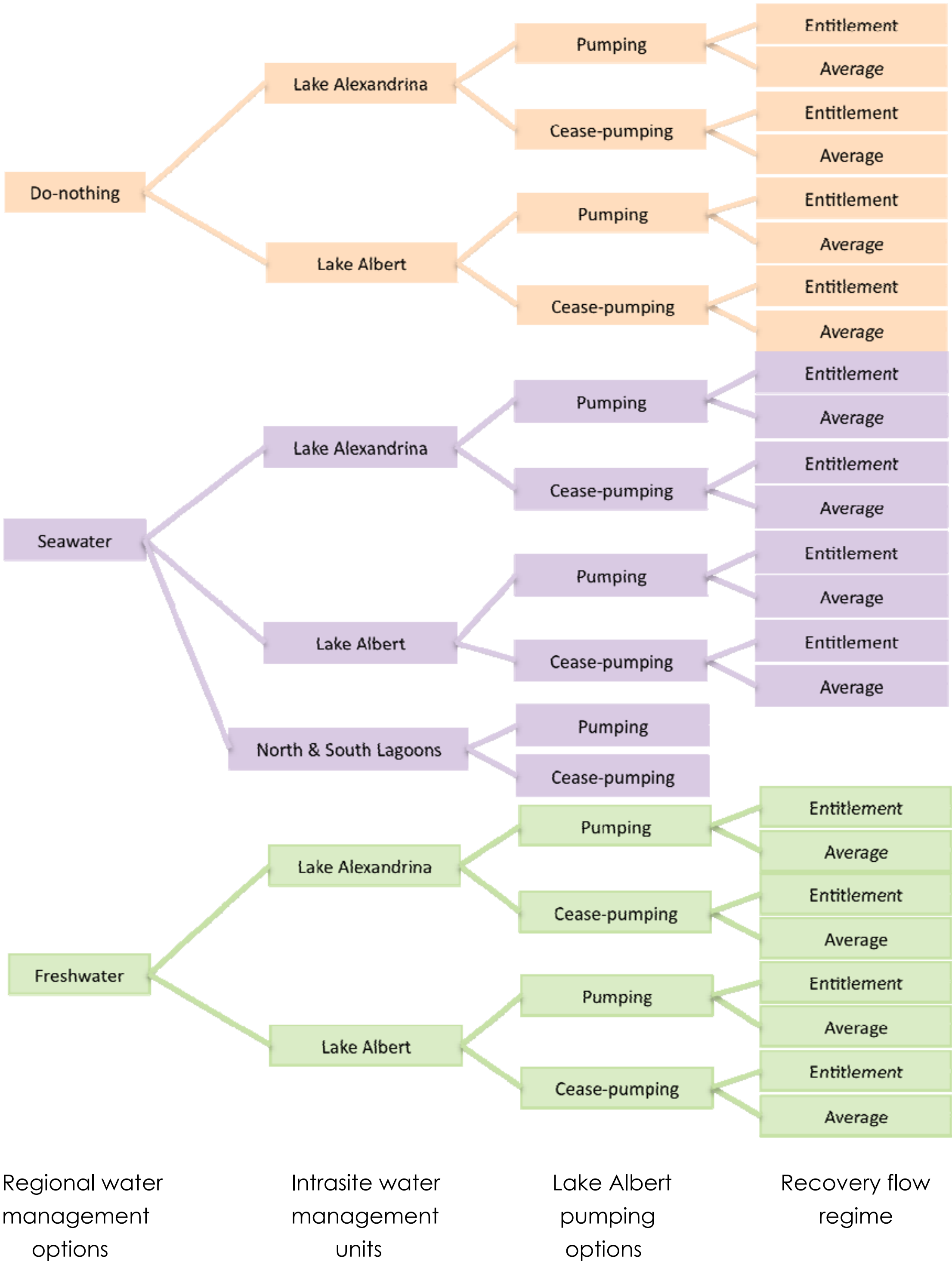


Figure 1.5: Schema of the management scenarios for the assessment of ecological consequences during the action period and capacity to recover during the recovery period. Pumping refers to Lake Alexandrina water being pumped into Lake Albert over the Narrung Narrows bund. Recovery flows are either Entitlement (1,850 GL/y) or Average (4,000 to 5,000 GL/y) flows across the South Australian border.

2. Methods and Assumptions

The overall ECA process is shown in Figure 2.1. In this assessment, only the three primary stressors: salinity, water level and pH have been assessed. Potential effects from other secondary stressors such as nutrients and heavy metals may be assessed later where relevant (i.e. where the primary stressor effects are considered insignificant and thus significance of secondary stressors requires assessment). The experts were involved in the first four parts of the assessment using preliminary hydrological modelling and semi-quantitative risk scoring (Likelihood x Consequence; Muller 2010b). The ECA scoring protocols are based upon their inputs (Attachments B and C) and the final hydrological modelling outputs (Wainwright and Hipsey 2010).

Experts were responsible for reviewing the literature (Bice 2009; Aldridge *et al.* 2010; Ecological Associates 2009; Gehrig and Nicol 2010; Napier 2010; Rolston *et al.* 2010 and Shiel 2010) and providing their advice in order to:

- select suitable receptors that would meet the objectives and aims of the assessment (Section 1.1)
- determine the baseline condition of each receptor (Attachment B),
- evaluate the level of stressor effect as primary or secondary (Attachment C),
- describe habitat specialisations (Attachment B, literature reviews),
- determine a receptor's susceptibility to each stressor (Attachment C, literature reviews), and
- provide relevant thresholds for exposure (e.g. salinity tolerance bands, Section 3).

In many cases the literature did not provide specific information on stressor thresholds so the experts either utilised published data from similar taxa or applied knowledge of presence and/or abundance of a given receptor within habitat of varying water quality at the site to estimate a threshold or tolerance value for use in the consequence scoring (Section 3). If threshold data was found in the literature it was often LC50 data (i.e. lethal dose for 50% of the test population). The experts agreed that acceptance of LC50 data posed two significant difficulties: 1) LC 50 is not a conservative approach to ecosystem management (targets should be considerably lower in order to protect species in the wild), and 2) chronic exposure (longer than 4 day exposure used in LC50 trials) may have deleterious effects and at levels that may be assumed to be 'safe'.

Overall, there was very little or no toxicity data for the species residing in the Lower Lakes and Coorong. There was also a paucity of quantitative data on distribution and abundance for most species, especially in Lake Albert.

Part 1 of the consequence assessment (Figure 2.1) the selection of relevant receptors, was conducted independently by the experts before the facilitated workshops. Relevant receptor selection was based on the presence of the receptors in the region during October 2009. Several experts expressed concern that using that criterion would lead to important receptors being omitted. Therefore, some receptors considered to be key components of Ecological Character for the site were included even if they had not been seen for several years (e.g. Yarra pygmy perch) or if it could only be reasonably assumed that they would be in the system (e.g. yabbies).

Next the experts screened the selected group of receptors for susceptibility and exposure to each of the primary stressors: salinity, water level and pH (Parts 2 and 3; Figure 1.2). The experts focussed on mortality of adult receptors because the majority of the available tolerance data was for adults and in many cases the experts felt they did not know enough about recruitment to be able to score it separately. It is acknowledged that further investigations into the effects on juveniles and recruitment are needed to inform the management decision.

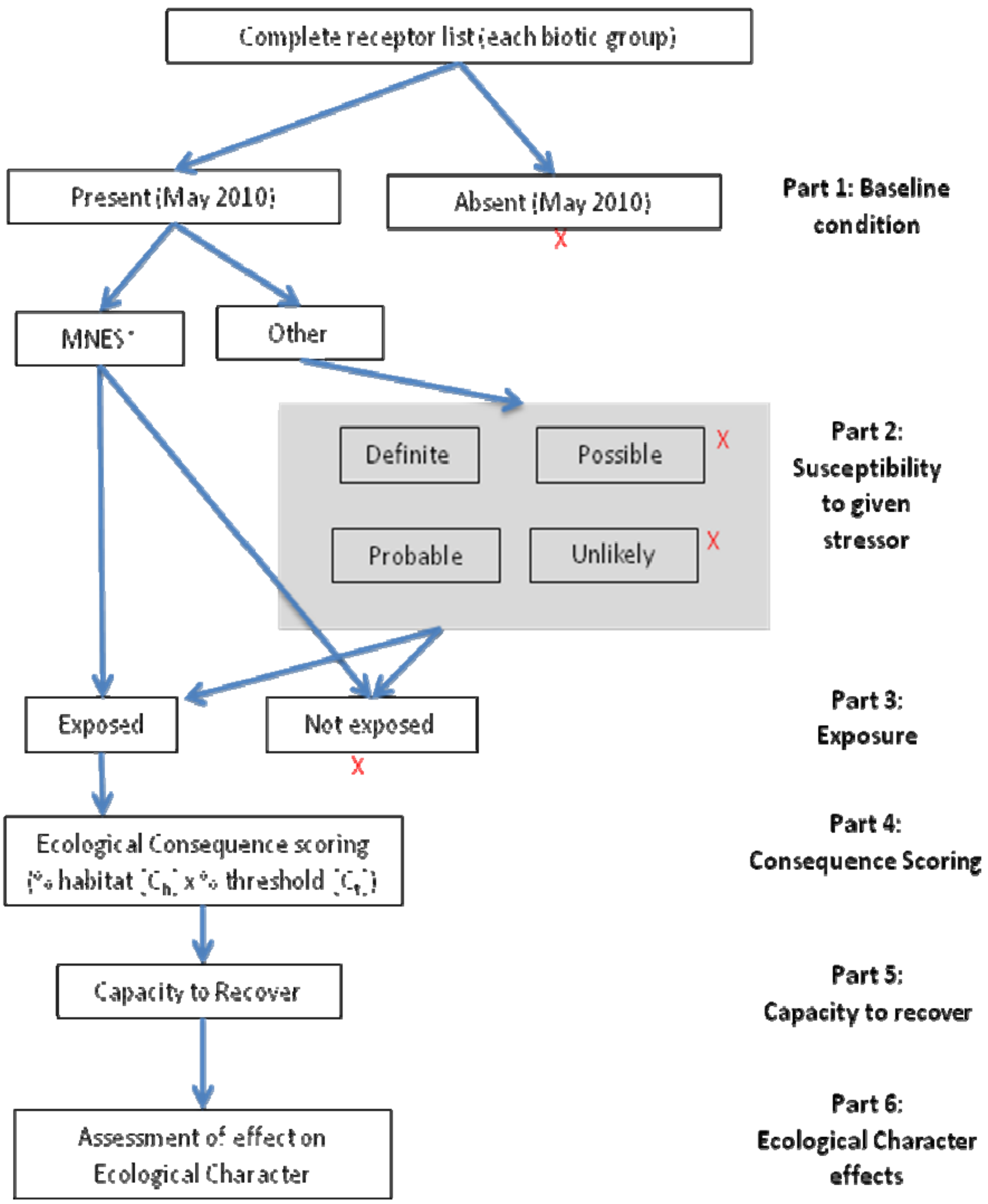


Figure 2.1: The six parts of the Ecological Consequences Assessment taken from Muller (2010b). *MNES are Matters of National Environmental Significance. Red crosses denote assessment end-point for that receptor.

Only those receptors meeting the following criteria were included in the consequence-scoring component of the assessment (Part 4):

- present or a Matter of National Environmental Significance (defined in EPBC Act 1999),
- susceptible to the stressors in the adult life history phase, and
- likely to be exposed to the primary stressors.

For most receptors the habitat requiring assessment was the whole of the water body (e.g. 100% of Lake Alexandrina, Section 3) except for:

- Murray Cod, which were assumed to use the whole of both lakes except for the shallow areas around the Narrung Narrows in Lake Albert;

- Generalist shore birds, Murray hardyhead and Yarra pygmy perch that were assumed to use only a 500 m width around the lake margins (littoral zone). Murray hardyhead and Yarra pygmy perch were confined to Lake Alexandrina;
- Marine macroinvertebrates were assumed to only be present on the lake side of the barrages, i.e. south of Point Sturt in Lake Alexandrina;
- Estuarine shorebirds that were assumed to only use 500 m around the edge of Lake Alexandrina (littoral zone) south of Point Sturt; and
- Lacustrine macroinvertebrates that were scored separately for their preferred habitat, which is 500 m around the edge of the lakes (littoral zone), and the remaining deeper water that has unknown habitat quality but may act as a refuge.

The former littoral zone in the lakes occurred at approximately +0.6 mAHD but was disconnected and desiccated in October 2009. Therefore the littoral zone was generally considered to be a band 500 m wide around the water's edge, recognising that this shifted with winds and changes in water levels and was unlikely to be providing ecosystem services typical of healthy littoral zones. In Lake Albert, it should be noted; the Narrung Narrows area was always considered part of the littoral zone. This area was assumed to comprise 5% of the baseline area of Lake Albert and 15% of the baseline littoral fringes.

The ecological consequences (e.g. receptor mortality) associated with each of the three primary stressors (salinity, pH and water level) were scored for individual receptors as habitat affected at a certain stressor level. The first Consequence score (Ch) used a five-point scale representing the percentage of the receptor's available habitat affected by a given stressor:

Score	Percentage of habitat affected
5	> 90% of habitat
4	40 to 90% of habitat
3	20 to 39 % of habitat
2	1 to 19 % of habitat
1	no habitat affected

Given the aforementioned problems with application of LC50, consequence of mortality from stressor exposure (Ct) was scored across the five-point scale as follows for salinity:

Score	Percentage of threshold
5	salinity over threshold, ≥ 100%
4	salinity between 51 and 99 % of threshold
3	salinity between 26 and 50 % of threshold
2	salinity between 6 and 25 % of threshold
1	baseline to 5% of threshold

It is acknowledged that the receptors' responses to salinity may not be linear. It may be that there is little or no apparent effect over a range of values leading up to a threshold and then rapid change at or around the threshold value. However, a linear response was assumed because it was considered conservative given that the threshold values were often based on LC50 values and the experts were not confident to assign non-linear threshold responses to the receptors.

The two consequence scores were multiplied to give an overall consequence score (Ch x Ct) between the lowest possible value of one (1 x 1) and the highest possible value of twenty-five (5 x 5). The consequence scores were evaluated at the maximum area of habitat affected at the highest percentage of their threshold during the action period, even if the receptor's threshold was not breached. If the receptor's threshold was breached but it was not the maximum habitat area affected then the habitat area over the threshold was noted and used in the interpretation of the consequence scores and development of the consolidated effects diagrams (see below). Thus the scoring protocols were applied to yield the highest consequence score during the action period or 'worse-case'. In addition if the threshold was breached, the earliest breach was recorded. Notes were made on how the changing salinity affected the receptors such as how rapidly the maximum habitat affected was reached or periods of lesser habitats affected where relevant (see Attachment D for completed consequence scoring sheets). Thus final consequence scores were comprised of a quantitative value, but required some level of interpretation to determine the likely effect on each receptor.

The same methods were used for assessing habitat-based consequences (Ch) for the pH stressor as for salinity above. Scores were applied to the maximum habitat affected but only those receptors for which the pH threshold was breached were scored therefore the threshold-based consequence score (Ct) was always five. It can be assumed that if a pH score is not shown for a given receptor in Attachment D then pH remained within suitable range for that receptor. In latter versions of ECA, it may be that a five-point scale for pH is developed but the percentage of threshold ranges would need to be developed in consideration that pH is a logarithmic scale not linear. For this version of ECA, the Ct scores for pH are effectively binary.

Water level (quantified as lake area in ha) was used as a qualitative moderator of the salinity and pH consequence scores determined for each receptor. Ecological and site-specific constraints were also determined (Section 3.9) and then applied as probability moderators to determine the effect on the receptors (Figure 2.2; Sections 4 to 6). These were based on the characteristics of the receptors (Sections 3.1 to 3.7) and the likelihood scores provided by the experts on the preliminary modelling outputs (Muller 2010b).

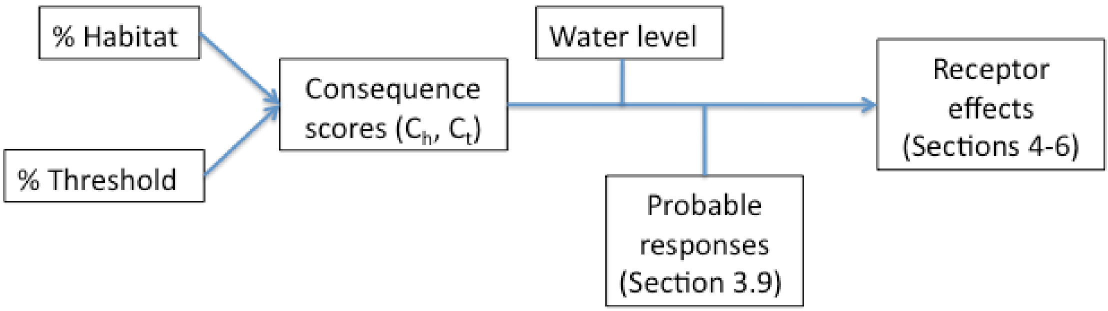


Figure 2.2: Flow chart for moderating consequence scores with water level and probable receptor responses to determine receptors effects.

The ECA five-year "action" period extended from spring 2009 to the end of March 2015 after which the ten-year "recovery" period began. The consequence scores were calculated in the same manner regardless of whether the stressor was trending towards better or worse conditions for the given receptor. In most cases, the receptors were scored for negative effects but in some cases the score may represent proliferation from baseline conditions, or positive effects for that receptor, if habitats became more suitable. This was primarily relevant for estuarine and marine species in Lake Alexandrina. It is important to note that assessment of consequences on recruitment of estuarine and marine species was outside of the scope of the assessment. Therefore the assessment of positive effects was confined to determining whether the lake habitats were suitable for adults rather than for self-supporting populations.

For the majority of receptors, the consequence scores represent adult mortality. Recruitment loss or sub-lethal injuries were not considered since these are more difficult to assess without suitable data or understanding of recruitment mechanisms and stressor interactions. For some receptors, additional effects were assessed when feasible. For example, one fish receptor (Congolli) was assessed for loss of preferred habitats for female and juvenile fish as well as adult mortality. Assessments for another fish receptor, the diadromous Short-headed lamprey, included the loss of juvenile ammocoetes, since this is the only life stage likely to be present in the freshwater lake habitats. Other receptors have scarce quantitative data on distribution and abundance, especially in Lake Albert and thus the consequence assessment was confined to known (Section 3) or assumed (see above) habitats.

The 10-year recovery period began in March 2015 and ended in March 2025. The assessment of capacity to recover began with describing and analysing the different receptor strategies and conditions required for recovery. For the vegetation, methods developed by Noble and Slatyer (1980), were followed to classify each vegetation receptor according to persistence, arrival, establishment and maturation mechanisms. The pre-conditions for faunal recovery were also analysed but in many cases, the Noble and Slatyer (1980) methods did not readily transfer to faunal populations. Instead diagrams of the recovery cascades required for each faunal receptor group were developed, as required. These inputs were used to compare the pathways for recovery for key receptors under each scenario. Finally, state-and-transition diagrams were prepared based upon the ecosystem states in Attachment A and the outcomes of the ecological consequence and capacity to recover assessments were synthesised and compared with the ecological effects associated with the different water management options.

2.1. Key for consolidated diagrams

2.1.1. Action period

Salinity has been seen as the foundation stressor for the consequence assessment. Therefore, salinity effects were scored first. Effects from pH or water level (as additional primary stressors) were then overlain to show the combined effects of salinity, pH and water level changes. These stressor-specific consequence scores were moderated by water level and probable receptor responses (Section 3.9) and consolidated into conceptual representations of ecological effects for each of the six management scenarios. The conceptual representations are referred to as ‘consolidated effects diagrams’ and they provide a way to illustrate the combined effects in Lake Alexandrina and Lake Albert for each of the proposed management scenarios.   The consolidated effects diagrams show the most likely expansion (positive effects) and contraction (negative effects) of receptors under each scenario.

These consolidated effect diagrams were prepared using the following process and depictions.

1. The receptor groups were listed down the first column.

2. The seasons and years were listed as column headings across the top of the diagram.

3. If a receptor was a component of the Ramsar-state for the site (Attachment A) and was present in October 2009, a green coloured band was used to represent the time and relative duration that salinity was within acceptable tolerances. A solid green block indicated the entire preferred habitat in the relevant lake was within the receptor’s salinity tolerances (No stress). Stipples qualitatively showed decline in suitable habitat and thus an increase in stress to the point of complete loss. Lighter stipples showed a lesser area of habitat within suitable salinities (i.e. greater stress).

No stress	**increasing □ stress**	**complete loss**

4. If a receptor was not a component of the Ramsar state for a given lake but it was predicted to colonise during the action period, orange was used to indicate that this was an invader. Coloured bands were used when salinities were within the given invading receptor’s salinity tolerances. Once again stipple was used to qualitatively show the lake area that had suitable habitat (positive effects) with lighter stipple indicating a lesser

amount of habitat and solid orange bars showing that the maximum habitat of suitable depth was also of suitable salinity (i.e. no stress).

No stress **suitable** | **50%** **un**suitable | **completely**

5. The percentage values that appear in the consolidated diagrams refer to the percentage of that receptor's habitat that is exceeding their threshold (resulting in loss of the receptor) or trending towards their threshold (affected). For example, a value of "75% loss" is interpreted as a 75% loss in suitable habitat due to the stressor; a value of "75% sub-optimal" is interpreted as 75% of their habitat having sub-optimal (not resulting in loss, but not ideal and likely to infer reduced vigour or damage) salinities. If the percentage appears at the end of the timeline then it relates to the effect at the termination of the action period (October 2009 - March 2015). If the percentage appears earlier against a given season then it represents the season where maximum habitat was lost or affected.

6. Periods of pH lower (more acidic) than the receptor's tolerance was depicted by a red cell and within it the percentage habitat affected by the low pH was annotated.

7. Along the bottom of the diagram, changes in water level are shown. These values represent water level as a percentage of the October 2009 baseline lake area. For example, 43% lake area means that water level was 43% lower than the level in October 2009. Periods when water levels were outside of the receptors' tolerance were depicted by a red cell and within it the percentage habitat affected was annotated. In the case of Congolli and Short-headed lamprey, effects of disconnection between the freshwater lakes and the saline habitats downstream of the barrages, as a result of water levels was depicted.

2.1.2. Recovery period

The consolidated effects diagrams for the recovery period were developed in a similar way. If a receptor was a component of the Ramsar-state for the site (Attachment A) and was present in October 2009, a green coloured band was used to represent the time and relative duration that salinity was within acceptable tolerances. A solid green block indicated the entire preferred habitat in the relevant lake was within the receptor's salinity tolerances. Stipples qualitatively showed decline in suitable habitat; lighter stipples showed a lesser area of habitat within suitable salinities.

100% suitable habitat | **increasing loss of habitat** | **complete loss of habitat**

If a receptor was not a component of the Ramsar state for a given lake but it was predicted to invade or increase its level of invasion during the action or recovery period, orange bands were used. Once again stipple was used to qualitatively show the amount of habitat within the receptor's salinity tolerance, with lighter stipple indicating a lesser amount of habitat and solid orange bars showing the maximum habitat of suitable depth that was also of suitable salinity.

>90% suitable | **50% suitable** | **completely unsuitable**

Periods of pH lower (more acidic) than the receptor's tolerance, were depicted by red cells and within them the percentage habitat affected by the low pH was annotated. In some instances the hydrological modelling outputs were not reliable past a given date and this is shown with a solid grey band. In the cease-pumping scenarios for Lake Albert the lake dried completely which is shown with grey and black stipple. If a cell has been left blank then that receptor was not expected to be present at that time in that lake. Diagrams are not provided for impacts in the Murray Mouth and Coorong areas, the ecological impacts for these areas are described in the text.

3. Receptor characteristics, selection rationale and baseline condition

The Coorong, Lower Lakes and Murray Mouth site provides food and/or habitat resources for an estimated 1000 species (Phillips and Muller 2006). Not all of these species could be assessed, therefore a sub-set of ecological receptors (species or assemblages) were selected by the experts during ECA Part 1. The selections were based upon occurrence at the site in October 2009 and the existing knowledge of the receptors.

In total, 55 receptors across six biotic groups were selected for the consequence assessment. The brief descriptions of the 55 receptors and their baseline conditions, presented below, are based upon information provided by the experts at workshops and via literature reviews (Bice 2009; Aldridge *et al.* 2010; Ecological Associates 2009; Gehrig and Nicol 2010; Napier 2010; Rolston *et al.* 2010 and Shiel 2010). The templates completed by the experts are included in Attachments B and C.

3.1. Plankton Receptors

In total, eighteen plankton receptors were chosen (Tables 3.1 and 3.2). Seventeen are receptor groups and thus were assessed at the community level not the species level. The exception was Parartemia nauplii. The selection of groups was based upon deriving a broad environmental response driven by flows and salinity regime, hence the classification around water sources. Plankton community dynamics change rapidly and are influenced by many environmental characteristics. Diversity of plankton communities tends to decrease as salinity increases (e.g. 176 taxa in River-sourced zooplankton group vs. 12 in NL1) or as other environmental factors become more extreme (e.g. pH < 6). Differential sampling effort over time and expertise available for identification is also a major factor in understanding of zooplankton presence and abundance in different areas. The whole of the Murray-Darling Basin can be a source of plankton entering the lakes, which becomes important when considering the sites capacity to recover from harsh conditions (Section 8).

Phytoplankton communities are influenced by predation by zooplankton and fish. Fish predation also impacts on zooplankton. Some plankton receptors (e.g. phytoplankton that bloom) are unlikely to be consumed and thus are of limited value to higher trophic levels. This effectively short-circuits the food web from primary production to decomposition with little or no secondary production. It is assumed that there are no barriers to dispersal of plankton and that water quality will determine the likely assemblages.

The consequence assessment is based on predicting if there will be shifts in plankton community composition and not on determining whether there is a change in planktonic productivity. Salinity and pH tolerance studies have been conducted separately so there are no data on possible synergistic effects. It is likely that pH less than 6 will lead to significant reduction in diversity regardless of salinity.

[1] Lx = Lake Alexandrina, Lb = Lake Albert, GC = Goolwa Channel, MM = Murray Mouth, NL = North Lagoon, SL = South Lagoon.

Table 3.1: Phytoplankton receptors showing salinity or pH ranges used to determine receptor groupings and considerations for the consequences assessment provided by the experts.

Receptor (salinity or pH range)	Experts' Considerations
River-sourced phytoplankton (0-3 g/L)	• 6 species mainly in northern parts of Lake Alexandrina (Lx) under river influence • can extend range further into Lx when flows are high depending on salinity regime • includes species that are common, rare and those that form algal blooms • enter lakes every time the river is flowing and will colonise in areas of suitable salinity in lake
Low salinity phytoplankton (3-10 g/L)	• typical Lx species (up to 10 taxa groups) • includes species that are common, rare and those that form algal blooms • overlapping tolerances with brackish phytoplankton but community mix will change as salinity increases
Brackish phytoplankton (10-15 g/L)	• typical Lake Albert (Lb) species • up to 10 taxa including species that are common, rare and/or form algal blooms • overlapping tolerances with low salinity phytoplankton but community mix will change as salinity increases
Estuarine phytoplankton (15-25 g/L)	• wide range of salinity tolerance (6 taxa groups) • historically in estuarine environments such as Murray Mouth (MM), Goolwa Channel (GC) and North Lagoon (NL) • Nodularia spumigenia may bloom at these concentrations and has been intermittently observed in GC, MM and NL • no estuarine environments downstream of barrages but maybe in Lx in October 2009
Marine phytoplankton (25-50 g/L)	• occur in MM and NL (6 taxa groups) • likely to enter lakes with seawater but do not tolerate freshwater as well as freshwater species tolerate salt • Nannochloris spp. regularly blooms in southern end of NL, washed in from South Lagoon (SL)
Hypersaline phytoplankton (50-150 g/L)	• occur in SL (4 taxa groups) • regular blooms of Gymnodinium spp. which are common in SL.
Extreme halophillic phytoplankton (>150 g/L)	• occur in salt lakes including SL
Acidophilic phytoplankton (tolerate pH <4)	• occur in acidic environments • likely to colonise low pH areas (particularly if acidic conditions are relatively stable)

Table 3.2: Zooplankton receptors showing salinity or pH ranges that determined the receptor groupings and considerations for the consequences assessment provided by the experts.

Receptor (salinity or pH range)	Experts' Considerations
River-sourced zooplankton (0-3 g/L)	• mainly occur in northern parts of Lx that are under river influence • can extend range into Lx when flows are high depending on salinity regime • 176 taxa were identified that may enter lakes every time the river is flowing and they are predicted to colonise in areas of suitable salinity
Low salinity zooplankton (3-10 g/L)	• typical Lx species • 32 taxa found in Lx
Brackish zooplankton (10-15 g/L)	• typical Lb species • 7 taxa found in Lb
Estuarine ostracods (15-25 g/L)	• occur in estuarine and saline environments such as MM, GC and NL (2 taxa in MM, unknown number in Coorong) • provide a food source for macroinvertebrates, and planktivorous fish and birds • already present on the lakeside of the barrages • highly tolerant and productive organisms • may have been an important part of food-web in October 2009 given the depauperate existing ecosystem
Estuarine zooplankton (15-25 g/L)	• occur in estuarine and saline environments such as MM, GC and NL

	• 25 taxa identified from MM and c. 12 in NL
Marine zooplankton (25-50 g/L)	• occur in MM and NL • likely to enter lakes with seawater but do not tolerate freshwater as well as freshwater species tolerate salt.
Hypersaline zooplankton (50-150 g/L)	• occur in SL
Extreme halophillic zooplankton (>150 g/L)	• occur in salt lakes including SL
Acidophillic zooplankton (tolerate pH <4)	• occur in acidic environments • likely to colonise low pH areas if acidic conditions are relatively stable
Parartemia nauplii	• juvenile phase of *Parartemia* spp. (brine shrimp) are part of zooplankton community • occur in large numbers in Coorong

3.2. Vegetation receptors

Only two vegetation receptors, Ruppia spp. and Floating plants, indicative of the Ramsar state (Attachment A) were present at the site in October 2009 and thus are the only two Ramsar receptors addressed in the consequence assessment (Table 3.3). In addition, the invasive and amphibious Spiny Rush (Juncus auctus) was assessed because it progressively invaded the exposed lakeshore from 2006 to 2010.

Table 3.3: Vegetation receptors present at baseline (October 2009) and considerations for the consequences assessment provided by the experts.

Receptor	Experts' Considerations
Ruppia spp. (*Ruppia tuberosa* and *R. megacarpa*)	*R. megacarpa:* present in GC only in October 2009 *R. tuberosa* • still occurred in the Coorong in October 2009 • almost completely lost from SL • small but increasing population in central NL • also present in Lx and Lb wetlands, Loveday Bay and Narrung Wetland (lost by October 2009); • coloniser of areas with suitable salinities and water regime. • at risk from *Enteromorpha* in majority of NL if salinity comes within range due to operation of SL Salinity Reduction Scheme.
Floating plants	• only low salinity species present • two taxa (Lemna spp. and Azolla spp.) may have been present in northern Lx in October 2009 based on presence in main river channel • highly mobile being water dispersed but low salinity tolerance
Spiny rush	• native to Europe, North America and Africa; • present in Lx; • increasing in cover from 2006; • grows on exposed lakebed and seems to be able to tolerate acidic sediments.

Additional vegetation receptors used for capacity to recover assessment

These vegetation receptors are plants typical of the site in its Ramsar State (Attachment A). They play fundamental ecological roles that make them useful as indicators of recovery (Section 8; Lester *et al.* 2011). However, at the beginning of the study period their populations were either present but disconnected from the main lake body or dry and desiccated due to exposure from receding lake water levels. Therefore, they were not assessed as part of the Consequences Assessment (Part 4; Figure 2.1) but are important receptors for the Capacity to recover assessment (Part 5; Figure 2.1).

- Samphire (Halosarcia pergranulata ssp. pergrunulata, Suaeda australis, Sarcocornia quinqueflora and Parapholis incurva)
- Paperbark woodlands (Melaleuca halmatuorum)
- Lignum (Muehlenbeckia florulenta)
- Gahnia sedgelands (Gahnia filum and G. trifida)

- Water milfoil (Myriophyllum salsugineum and M. caput-medusae)
- Water ribbons (Triglochin procerum)
- Ribonweed (Vallisneria spiralis)
- Diverse reed beds: containing more reed species than just Phragmites australis and Typha domingensis (e.g. Schoenoplectus sp., Baumea sp., Eleocharis sp.)

Emergent plants may germinate around the lake edge during the action period if the lake levels stabilise around a new lake shore line to allow for correct moisture levels for establishment and then the pH may be too low for them to grow anyway. Phragmites australis and Typha domingensis seeds are easily dispersed and widespread and given they are relatively salt tolerant (found in 20, 000 EC water) it would be expected that if conditions were suitable around new lake edge that Phragmites australis and Typha domingensis would be the first plants to colonise. Such establishment of a new vegetated shoreline was not observed in the field during the recent drawdown (2006 to 2010) perhaps because of the high wind and water disturbance around the water's edge. Not all the reed beds had broken down completely in 2009 (e.g. along Mundoo Channel) but they are excluded from the consequence assessment because they were disconnected from the lake water body by several kilometres during the action period and thus any changes would not have been a result of the management actions: Do-Nothing, Seawater or Freshwater.

Marine and estuarine primary producers such as Posidonia sp., Zostera sp. and Amphibolis sp. were not used as receptors because they were considered by the experts to be poor colonisers and highly unlikely to colonise the lakes due to dispersal and establishment difficulties. Plankton of different salinity tolerances were used instead as indicators of when salinities may be within suitable bands for the establishment of marine or estuarine vegetation or macroalgae because they are good colonisers (requiring few pre-conditions) and are readily dispersed. If lake salinities remain stable and within the estuarine or marine bands for extended periods (more than three years) and pH is suitable, then assessment of capacity for invasion by marine or estuarine plants or macroalgae could be undertaken.

3.3. Lacustrine macroinvertebrates

The environmental changes to the study area and deviation from its Ramsar state (Attachment A) have had significant consequences for Lacustrine macroinvertebrates (Attachment B). Most of the taxa are strongly associated with emergent or submerged vegetation that had been lost before the assessment period began. Others are intolerant of salinities in excess of 1 g/L and given that the lakes were greater than this at the start of the study period, salinity was considered a major limiting factor.

Of the 25 taxa selected across the five lacustrine macroinvertebrate receptor groups presented below, only fourteen are assumed to have been present in the system in October 2009 (Table 3.4). Only seven of those fourteen taxa [Oligochaeta, Syllidae "ploychaeta sp.2", Nematoda, Tipulidae. Ceratopognidae, Empididae and Chironomidae], were known to still be present (SA Environmental Protection Agency 2010 surveys). It is inferred from vegetation patterns that the remaining eleven of the 25 taxa that were part of the original Ecological Character were lost in 2007 when the littoral vegetation habitat was lost (i.e. when Lake Alexandrina water levels dropped to less than +0.3 mAHD) and large areas of lake bed became exposed, bare and relatively saline (and potentially also acidic). The fauna of small wetlands adjacent to Lakes Alexandrina and Albert were not considered. It should be noted that Ferrissia was mentioned by the experts as being able to survive to pH 4.75 but does not appear to be assigned to one of the groups[2].

Table 3.4: Lacustrine macroinvertebrate receptors present at baseline (October 2009) showing salinity ranges used to determine groupings where relevant and considerations for the consequences assessment provided by the experts.

Receptor	Experts' Considerations
Velesunio ambiguus (Freshwater mussel)	• occurs in littoral zone & open water in Lx, Lb and GC • unknown whether still present at October 2009 but historically prominent • some empty shells have been observed (with *Ficopomatus enigmaticus* encrustations) but no mass death events have been reported which would be expected because of highly visible shells • can close their shells to avoid stress for a period of time (days to weeks) • known to have occurred in very large numbers in Lx prior to 1981
Fresh macroinvertebrates (salinity <3.4 g/L)	• mainly comprised of Gastropoda, Acarina, water mites, Cnidaria, Hydra sp., Ephemeroptera • highly variable receptor group that were considered at risk of loss in October 2009 • see Muller (2010b) for details of extensive taxa lists
Littoral macroinvertebrates (littoral dwellers, salinity > 20g/L)	• have been collected in lower Currency Creek behind the regulator • prefer shallow and relatively saline areas • widespread, hardy and have mobile adults • very little data for Lb • Key taxa include Mesostigmata; Oligochaeta; Nematoda; Tipulidae; Ceratopogonidae; Empididae; Chironomidae; Gastropoda; Acarina, water mites; Cnidaria, Hydra sp.; Ephemeroptera (Muller 2010b) • Some species of Ephemeroptera tolerate acid • Oligochaeta live in sediments and therefore more strongly exposed to interstitial water quality
Brackish macroinvertebrates (salinity >30g/L)	• assumed to be present in patches in October 2009 • history of occurrence in lakes • wholly aquatic with no flying stages but have multiple vectors for dispersal and thus likely to be in Lb or enter areas of suitable salinities when they occur • key taxa are Hymenosomatidae; Halicaridae; Syllidae "Polychaeta sp.2" (Muller 2010b)
Cherax destructor (Yabbies)	• assumed to be in littoral zone of Lx, Lb and GC • unknown if still present but would have been able to tolerate ambient salinities in October 2009 • existing habitat is of lower quality and productivity than that found at lake levels greater than + 0.3 mAHD when littoral vegetation was present • highly tolerant and widespread species • mobile species that can avoid stressors or retreat to burrows to escape unfavourable conditions

3.4. Estuarine macroinvertebrates

The experts identified a total of 12 estuarine macroinvertebrate receptors (Table 3.5). Sites 15-17 (Attachment E) in the Murray Mouth region are the only sites that presently have diverse and abundant estuarine macroinvertebrate communities. This represents an area only 10 km long downstream of the barrages. In 2006, Estuarine macroinvertebrates were found an area 30 km long from the Murray Mouth to Pelican Point, indicating a loss of two-thirds of estuarine habitat over the four years from 2006 to 2010. Estuarine macroinvertebrates in the Murray Mouth region have historically been a very important food source for birds and are the 'engine room' of organic matter cycling (Lester *et al.* 2011).

At October 2009, there was very low redundancy in the Estuarine macroinvertebrate communities. Capitella spp. was the dominant fauna in MM because other receptors had been lost from the system. The loss of the other Estuarine macroinvertebrate receptors

[2] During earlier work on the ECA, this group was referred to as "*Freshwater macroinvertebrates*" but the group name was changed to "*Lacustrine macroinvertebrates*" to avoid confusion because *'Freshwater macroinvertebrates'* became a specific receptor group.

had catastrophic ramifications for macroinvertebrate-based food webs because Capitella spp. were providing the main food source and there are very few other Estuarine macroinvertebrates colonising the area. Capitella spp. is also critical in maintaining soil quality and benthos activity now that many other species that would have performed those roles have been lost.

Diversity in the South Lagoon of the Coorong (SL) is extremely low. Insect larvae and Parartemia are the only macroinvertebrates still present. Parartemia was not included as an Estuarine macroinvertebrates receptor because the adults are not benthic and juveniles are part of the zooplankton community. This is not a significant gap given that the action does not significantly impact salinity in the SL. The receptors that appear below are the final list determined at the Estuarine macroinvertebrates workshop. Details can be found in Muller (2010b) although some receptors do not appear in the Baseline condition sheets because they were included or modified by consensus during the workshops.

Table 3.5: Estuarine macroinvertebrate receptors present at baseline (October 2009) and considerations for the consequences assessment provided by the experts.

Receptor	Experts' Considerations
Ficopomatus enigmaticusm (tube worms):	• older reefs occur in MM and NL with few live worms • recently colonised Lx as salinity has increased • extend from barrages to Pt. Sturt in October 2009 • well established in GC • Not yet present in Lb
Simplisetia aequicetis:	• prominent in mudflat and subtidal sediments in MM • present in NL, recently colonised GC, no longer in SL • important bioturbator and prey for waders • able to brood its young
Capitella spp./Oligochaeta:	• present in mudflats and subtidal sediments of MM, NL and GC (Lx); no longer present in SL • deposit feeders • Capitella spp. are important indicator of eutrophication and/or pollution • both groups are complexes of several morphologically indistinct species • very limited information regarding lifecycles in different salinities
Nephtys australiensis	• frequent in sediments of MM, present in NL • recently colonised GC • important benthic predator therefore susceptible to perturbations in the ecosystem • very limited information regarding lifecycles in different salinities
Boccardiella limnicola:	• present in October 2009 • not on expert forms (Attachment B)
Amphipoda	• frequent in sediments of MM, NL, GC, Lx and Lb • decreased in abundance in MM and almost absent from areas where previously high abundance prior to October 2009 • mix of several morphologically similar species • prey for birds
Paragrapsus gaimardii	• not on expert Baseline condition forms • was present prior to October 2009 but unclear as to whether still present
Arthritica helmsi	• small bivalve present in MM sediments • decreased in recent years
Large bivalves	• present in submerged mudflat sediments • recorded in sediment transfer samples at Ewe Island • have capacity to modify the sediment to create habitat for other organisms
Insect larvae	• prominent in mudflat sediments although pelagic • frequent in MM, NL, GC, Lx and Lb • adult phases can fly and deposit eggs leading to rapid responses to favourable conditions
Chironomidae	• distributed from Coorong into MM • dominant in benthos at many sites including lakes • possibly a mix of several species • wide salinity tolerances •
Large bioturbators	• not on expert Baseline condition forms • present prior to October 2009, now only individuals are found occasionally • burrowing habit affords some protection from short-term perturbations

3.5. Fish Receptors

Fourteen fish species were selected as receptors (Table 3.6). Yarra pygmy perch were potentially not present in October 2009 but were included in the consequence assessment because they are an EPBC-listed species and the experts considered them important for assessing change in Ecological Character. Short-headed lamprey ammocoetes were included because they have an unique life history that was otherwise not represented in the receptor list being anadromous with a parasitic marine adult phase, upstream spawning migration of adults to freshwaters where ammocoetes metamorphose before migrating downstream. Short-headed lamprey ammocoetes were also important to include because they are unable to move to avoid adverse conditions (e.g. rising salinity). While common galaxias and Congolli are both catadromous, their life histories are sufficiently different to warrant including both as receptors: Common galaxias are more adaptable being able to complete their life history on the upstream side of barrages during hydraulic disconnection.

Estuarine fish species were assessed in Lake Alexandrina and Lake Albert in the seawater scenarios only because under those scenarios the barrages are periodically opened and thus there is potential for their introduction and proliferation in the lakes if seawater is introduced. There were some Black Bream present in Lake Alexandrina at the beginning of the action period. Yellow-eyed mullet (Murray Mouth and Coorong) and Small-mouthed hardyhead (common in lakes, Murray Mouth and Coorong) have very high salinity tolerance and may benefit from higher salinities. Mulloway will tolerate and Black bream will prefer increased salinity up to (but not over) seawater concentrations (35 g/L).

Table 3.6: Fish receptors present at baseline (October 2009) and considerations for the consequences assessment provided by the experts.

Receptor	Experts' Considerations
Murray Cod	• apex predator • low abundance • poor recruitment • likely to be in deep areas of Lx (possibly also Lb, GC) • more details in Muller (2010b)
Golden perch	• moderate numbers in Lx and Lb • commercial fishery still operating
Australian smelt	• abundant in Lx, GC and Lb • short-lived • recruitment occurring at the site in October 2009
Bony herring	• added at interactions workshop (30/6 – 1/7/10) • important prey species for birds • assessed as for Australian smelt with regard to salinity, water level and pH responses
Murray hardyhead	• limited presence in Lx and GC • scattered distribution • associate with sheltered bays and littoral zones • unlikely to use open water
Yarra pygmy perch	• historically broadly distributed but in recent decades have been found primarily in association with fringing areas in the south/south-western parts of Lx, tributaries and islands (habitat-specific) • potentially absent from Lx in October 2009 given that last record was in Dec 2007 • conservation status warrants inclusion
Common carp	• pest species • abundant Lx, Lb and GC • spawning and recruiting at the site in October 2009
Congolli	• present in all management areas in low numbers • short-lived (probably only five years) • populations were dominated by large adult fish thought to be approx. 4 years old in October 2009 • disconnection of fresh and saline habitat areas by closed barrages obstructs recruitment and movement
Common galaxias	• broad distribution Lx and Lb • juveniles in MM • typically catadromous but adaptable life history strategies
Short-headed lamprey	• heavily impacted by disconnection • ammocoetes potentially in Lx and Lb • adults are transient visitors thus ammocoetes are the only life stage resident in the freshwater lakes

Receptor	Experts' Considerations
Yellow-eyed mullet	• estuarine species • abundant in MM but only moderate numbers in NL • greatest proportion of caught finfish at the site • not in the lakes in October 2009 but likely to enter the lakes with seawater in the seawater scenarios
Small-mouthed hardyhead	• the most abundant fish receptor in the lakes, present in all areas • a euryhaline species that is one of the most tolerant fish in the world • able to tolerate winter freshening as well as saline waters (requires < 35g/L salinity to recruit)
Black bream	• an estuarine species • primarily occurs in MM, small numbers Lx and GC • strongly impacted by disconnection • likely to enter the lakes with seawater in the seawater scenarios, • tolerant of fresh water with a preference for brackish conditions
Mulloway	• an estuarine species • moderately common in MM and less so in NL • historically found in Lx when functional connectivity was high • likely to enter the lakes with seawater in the seawater scenarios but not able to tolerate winter freshening

3.6. Frog receptors

The only frog to be included in the assessment was Southern Bell Frog (Table 3.7). This is the only frog species present in the lakes that is a Matter of National Environmental Significance (MNES). One adult frog was found at the water's edge of Channel 1 on Mundoo Island (26/11/09) in southern Lake Alexandrina, but tadpoles were not been found. Further baseline condition details can be found in Attachment B.

Table 3.7: Frog receptor present at baseline (October 2009) and considerations for the consequences assessment sourced from Mason (2011).

Receptor	Experts' Considerations
Southern bell frog	• occur in Lx but overall population abundance is considered low with respect to Riverland and South-East • Conservation status: MNES • occupy vegetated, littoral and riparian zones therefore by October 2009 they had been declining for three years since the plants were disconnected and desiccated • opportunistic predators • breed in recently inundated vegetation (Section 8.3.5)

3.7. Bird receptors

Six bird receptor groups were selected (Table 3.8). Of these the estuarine shorebirds require the greatest amount of freshwater habitat. Other bird species can go anywhere that food is available and thus are not as reliant on present conditions within the site. Terrestrial birds were not included in the ECA since they rely solely on wetlands in the Eastern Mount Lofty Ranges behind the Clayton regulator, and thus are well above the influence of water levels in the lakes. Fringe dwelling birds are also not included since they rely on fringing wetlands, which were disconnected and dry in October 2009. Despite their exclusion from the consequences assessment (Part 4; Figure 2.1) Terrestrial and Fringe dwelling birds will require assessment for Capacity to Recover (Part 6; Figure 2.1 and Section 8).

Other species not included in this assessment are those possibly found in association with reed beds in the Coorong and Salt Creek. Cryptic bird species were not included because it was determined that none would respond except around Hindmarsh Island. The bird consequence assessment was based primarily on the indirect impact to birds that may result from the loss of major prey species for each bird group. Some birds such as Pelicans will eat any kinds of fish with bony-herring likely to be their most abundant prey fish. The other major prey species for Fish-eating birds is Small-mouthed hardyhead, which are highly abundant and widespread. Coorong impacts from the proposed action were considered to be minor and thus were not assessed.

Table 3.8: Bird receptor present at baseline (October 2009) and considerations for the consequences assessment provided by the experts.

Receptor	Experts' Considerations
Generalist shorebirds	• occur in GC, MM, Lx, Lb, NL, SL • typically transequatorial migrants so presence is seasonal • some species still present in October 2009, others absent
Estuarine shorebirds	• occur in GC, Lb, NL, MM • absent from Lx • may occur on lakeside of barrages but unlikely to use main body of Lx • only Wood sandpiper recorded in Lb from this group; • primarily occur in MM region
Fish-eating birds	• found in GC, Lx, Lb, MM, NL, SL • Australian pelican and Caspian tern breeding on Coorong islands and feeding elsewhere (no food available locally)
Waterfowl	• Found in GC, Lx, Lb, MM, NL, SL • primarily ducks and swans • different suite of species in SL cf. NL & MM • were historically abundant in lakes • Black swan is strongly associated with vegetation and is most abundant in GC in October 2009 • no evidence as to whether prefer vegetation or animal feed (zooplankton and macroinvertebrates) • still found in SL and observed to be diving and feeding even though no plants so likely to be eating brine shrimp *(Parartemia* spp.)
Terrestrial birds	• were found around EMLR GC, Lx, Lb, MM,NL, SL • only present around EMLR GC (Southern Emu Wren) in October 2009 • Orange-bellied Parrot very rare
Fringe dwelling birds	• found around GC, Lx, Lb • possibly in MM, NL and SL • only occurred in GC in October 2009 • regional declines likely

3.8. Summary of baseline condition

This section shows that after years of low River Murray inflows, many receptors were in poor or degraded condition at the beginning of the action period (October 2009). Salinities in Lake Alexandrina and Albert were too high to be in the Ramsar-state (Attachment A) being in the order of 2.5 to 5 g/L in Lake Alexandrina and 4 to 9 g/L in Lake Albert (Section 4.1.1). The most salt-sensitive Ramsar receptors had been lost, or had <5% of their typical habitat within their salinity tolerances, suggesting significant salt stress. There were no estuarine conditions anywhere downstream of the barrages. The only estuarine conditions were on the lake-side of the barrages and the recent colonisation of areas in southern Lake Alexandrina and Goolwa Channel by Estuarine macroinvertebrates was indicative of the transition towards more saline conditions already underway.

Water levels were in the order of -0.8 mAHD, approximately 1.4 m lower down the elevation gradient than the formerly vegetated littoral and riparian zones. Acid sulfate soils were exposed and acidic, however, low pH was not a significant stressor in the water column. Disconnection had been on-going since 2006 when most of the barrage gates were closed (Zampatti and Bice, 2009) affecting fish (particularly Congolli and Short-headed lamprey) and other biota requiring free passage.

The ecosystems in both Lakes Alexandrina (Lx) and Albert (Lb) had made a transition from their respective Ramsar states and were in the Disconnected Freshwater derived state when the action began (see Attachment A). The Murray Mouth, North Lagoon and South Lagoon were in a similar degraded condition.

The estimated baseline conditions for each lake receptor presented in Table 3.9 were based upon the: starting physico-chemical conditions, receptor tolerances and information in the preceding Sections 3.1 to 3.7.

Table 3.9: Summary of baseline conditions for receptors (October 2009). Invasive receptors are indicated by the delta symbol (Δ).

Receptor	Typical habitat	Baseline condition (October 2009)
Plankton		
River sourced plankton*	River-influence, Lx	• Reseeded with river flows • Lx salinities were too high except for the northern parts (10% lake area) directly under river influence • Absent from Lb
Low salinity plankton	Typical Lx taxa	• Reseeded with river flows • Co-dominant in Lx • Absent from Lb
Brackish salinity plankton (Δ for Lake Alexandrina)	Typical Lb taxa	• Reseeded with river flows • Co-dominant in Lx • Co-dominant but declining from salinity stress in Lb
Estuarine plankton	MM, NL, GC	• Highly constrained by low salinity in Lx. Only occurred just inside the barrages • Co-dominant in Lb • Very few or absent from MM, NL, GC
Marine plankton	Ocean, Marine embayments	• Marine copepods have already been recorded in NL
Hypersaline plankton	Salt lakes	• only found in SL
Vegetation		
Floating plants	Edge, open water	• Only vegetation likely to be present in Lx and Lb • All littoral and riparian vegetation disconnected and desiccated in Lx and Lb
Samphire	Floodplain Lx, Lb, GC, MM, NL, SL	• Present in Lx, Lb, GC, MM, NL and SL but disconnected
Paperbark woodlands	Floodplain	• Present in Lx, Lb, GC, MM, NL and SL but disconnected
Lignum	Floodplain	• Present in Lx, Lb and GC but disconnected
Gahnia sedgelands	Fringing wetlands	• Present in Lx, Lb and SL but disconnected
Δ Spiny rush	Floodplain	• Invading Lx, Lb and GC
Water milfoil	Littoral	• Absent Lx and Lb: disconnected and desiccated • Present GC although less diverse
Water ribbons *(T. procerum)*	Riparian, Littoral	• Absent Lx and Lb: disconnected and desiccated
Ribbonweed *(V. spiralis)*	Permanent water	• Absent Lx and Lb: disconnected and desiccated
Diverse reed beds	Riparian, Littoral	• Absent Lx and Lb: disconnected and desiccated • Present GC although less diverse
Lacustrine macroinvertebrates		
Freshwater macroinvertebrates*	Littoral vegetation Lx, Lb, GC	• Salinities too high across 60% of Lx fringing habitat • Concentrated in southern Lx • Very few or absent from Lb
Mussel *(Velesunio ambiguus)*	Littoral, open water Lx, Lb, GC	• Salinities too high for reproduction across 90% of Lx and 100% Lb fringing habitat • Adults were present in both lakes but under stress
Yabbies *(Cherax destructor)*	Littoral vegetation Lx, Lb, GC	• Assumed to be present Lx, GC and Lb but stressed by lack of riparian and littoral vegetation
Littoral macroinvertebrates	Littoral vegetation Lx, Lb, GC	• Present Lx, GC and Lb but stressed by lack of riparian and littoral vegetation • Concentrated in southern Lx and Narrung Narrows
Brackish macroinvertebrates	Littoral vegetation	• Assumed to be present in Lx and Lb. • Likely to be oncentrated in southern Lx and Narrung Narrows
Insect larvae	Littoral vegetation All areas	• Present in all areas but may be a different community composition to Ramsar-state
Δ Tube worms (Ficcopomatus enigmaticus)	< 1.5 m depth MM, NL	• Present from barrages to Pt. Sturt in southern Lx and well-established in GC • Few live worms in MM and NL • Absent from Lb
Δ Estuarine	MM, NL, SL	• Less than 5% of Lx (southern areas) suitable

Receptor	Typical habitat	Baseline condition (October 2009)
macroinvertebrates		• *Simplisetia aequisetis* present in Lx near barrages • *Boccardiella limnicola* likely to follow Tubeworms • Absent in Lb • Very few or absent from MM (Low redundancy) • Several have recently colonised GC • Still present in NL but low diversity and abundance • All absent from SL except Insect larvae
Fish		
Murray Cod	Open water	• Still present in Lx and probably Lb and GC • Low abundance and poor recruitment
Golden Perch	Open water	• Moderate numbers in Lx and Lb.
∆ Common carp	Littoral, open water	• Abundant and recruiting in Lx, Gc, Lb
∆ Redfin perch	Littoral, open water	• Abundant and recruiting in Lx, Gc, Lb
Short-headed lamprey	Diadromous	• Ammoceotes potentially in Lx and Lb
Australian smelt	Open water	• Abundant in Lx, Gc, Lb
Murray Hardyhead	Littoral, sheltered edges	• Limited presence Lx and GC
Yarra pygmy perch	Littoral	• Probably absent from Lx (last record Dec. 2007)
Congolli	Diadromous	• Salinities were too high for adult Female and juvenile congolli across 98% of Lx and 100% Lb. • Aging fish (≥ 3 years old)
Common galaxias	Diadromous	• No preferred habitat in Lx or Lb but salinities not exceeding tolerance
Small-mouthed hardyhead	Estuary, Lakes	• Present in all areas (euryhaline)
Yellow-eyed mullet	Estuary MM, NL	• Abundant in MM • Low numbers in NL • Absent from Lx, GC and Lb
Black bream	Estuary MM, Lx, GC	• Low numbers in MM, Lx and GC due to on-going disconnection
Mulloway	Estuary, Lakes MM, NL, Lx, Lb	• Moderately common in MM • Low numbers in NL
Frogs		
Southern bell frog	Littoral, streams Lx, Lb, GC	• Only present in Mundoo Channel (southern Lx)
Birds		
Generalist shorebirds	Shorelines GC, MM, Lx, Lb, NL, SL	• Transequatorial migrants so present seasonally • Some still present in Lx
Fish-eating birds	Littoral, open water GC, MM, Lx, Lb, NL, SL	• Present in GC, MM, Lx, Lb, NL, SL
Waterfowl	Littoral, open water GC, MM, Lx, Lb, NL, SL	• Present in GC, MM, Lx, Lb, NL, SL although opportunistic and community composition changes
Terrestrial birds	Fringing wetlands All areas	• Only present in GC (EMLR wetlands)
Fringe dwelling birds	Fringing wetlands All areas	• Only present in GC (EMLR wetlands)
Estuarine shorebirds	Shorelines GC, MM, Lb, NL	• Absent from Lx • Only Wood sandpiper recorded in Lb, otherwise unlikely to use Lb because landlocked

3.9. Probable receptor responses to changes in salinity, water level and pH.

The salinity, water level and pH thresholds for the different receptors (Table 3.10) provide a theoretical order in which the receptors would be lost if any of these stressors changed. For example, if salinity increased to beyond the tolerance of the Lacustrine macroinvertebrate receptor group, Brackish macroinvertebrates would be the last of that group to survive before there was a shift to the more saline tolerant Estuarine macroinvertebrate receptor group based on salinity alone. Salinity is being used as the foundational stressor, therefore, the receptors could be grouped again based upon similar salinity thresholds, as follows in order of increasing salinity tolerance:

5. River-sourced plankton and Freshwater macroinvertebrates;
6. Floating plants, Waterfowl, Yabbies, Southern bell frog, Low salinity plankton, Freshwater mussel, Short-headed lamprey and Yarra pygmy perch;
7. Murray cod, Golden perch, Common carp and Brackish plankton;
8. Littoral macroinvertebrates and Estuarine plankton;
9. Australian smelt, Bony herring, Murray Hardyhead and Brackish macroinvertebrates;
10. Congolli, Common galaxias and Mulloway;
11. Marine plankton, most Estuarine macroinvertebrates, Estuarine shorebirds, Yellow-eyed mullet and Black bream;
12. Estuarine ostracods, Small-mouthed hardyhead and Fish-eating birds;
13. Hypersaline plankton, Insect larvae and Generalist shorebirds; and,
14. Extreme halophillic plankton.

Table 3.10: Receptor ranges or thresholds associated with the three primary stressors: salinity, water level (lake area) and pH used for scoring ecological consequences.

Receptors tolerate less than the stressor value where the < symbol is used and greater than the stressor value where the > symbol is used. Thresholds are adult mortality unless stated. Where known, optimal values are shown after the range in parentheses. *phytoplankton: tolerate pH of 5; zooplankton: tolerate pH of 4.

Receptor	Salinity range or threshold (g/L)	pH range or threshold	Lake water level range or threshold
Plankton			
River-sourced plankton	0 - 3	> 5 (> 4)*	Changing areas for growth; mortality if dry
Low salinity plankton	3 - 10	> 5 (> 4)*	
Brackish plankton	5 - 15	> 4	
Estuarine plankton	15 - 25	> 4	
Estuarine ostracods	15 - 80	> 4	
Marine plankton	25 - 50	> 4	
Hypersaline plankton	50 – 150	> 4	
Extreme halophillic plankton	> 150	> 4	
Acidophillic plankton		< 3.5	
Vegetation			
Floating plants	< 6.8	> 4	Changing areas for growth; mortality if dry
Lacustrine Macroinvertebrates			
Freshwater macroinvertebrates	< 3.4	> 6.5	Optimal > +0.3 m AHD
Mussel (reproduction failure)	< 3.5	> 6.5	Optimal > +0.3 m AHD
Mussel (adult mortality)	< 10	> 6.5	Optimal > +0.3 m AHD; Can use open water
Yabbies	< 8.16	> 6.5	Optimal > +0.3 m AHD; May use open water
Littoral macroinvertebrates	< 20	> 6.5	Optimal > +0.3 m AHD
Brackish macroinvertebrates	< 30	> 6.5	Optimal > +0.3 m AHD
Estuarine macroinvertebrates			
Insect larvae	1 - 138	> 6	Optimal > +0.3 m AHD; sediments; pelagic
Tubeworms	1.5 - 60	> 6	Optimal > +0.3 m AHD; > 1.5 m depth
Oligochaeta	0 -93 (<60)	> 6	Mudflat sediments

Receptor	Salinity range or threshold (g/L)	pH range or threshold	Lake water level range or threshold
Amphipoda	1 – 125 (< 45)	> 6	Mudflat sediments
Simplisetia aequisetis	7 – 88 (< 50)	> 6	Mudflat & subtidal sediments
Capitella spp.	1 – 138 (< 60)	> 6	Mudflat sediments
Nephtys australiensis	15 – 50	> 6	Mudflat & subtidal sediments
Boccardiella limnicola	4 - 60	> 6	Follows Tubeworms
Arthritica helmsi, large bivalves	1 – 129 (< 45)	> 6	Mudflat & subtidal sediments
Fish			
Murray cod	< 13.2	> 5	Open water (> 1m deep); -1.5 m AHD
Golden perch	< 14.4	> 5	Open water; -1.5 m AHD
Common carp	< 13	> 5	Open water; -1.5 m AHD; spawn in littoral zones
Short-headed lamprey ammocoetes	< 10	> 5	Optimal > +0.1 m AHD; connectivity
Australian smelt	< 30	> 5	Littoral; Optimal > +0.3 m AHD
Bony herring	< 30	> 5	Open water; -1.5 m AHD
Murray hardyhead	< 30	> 5	Littoral; Optimal > +0.3 m AHD
Yarra pygmy perch	< 10	> 5	Littoral; Optimal > +0.3 m AHD
Congolli (preferred habitat)	< 2	> 5	Connectivity and littoral optimal >+0.3 m AHD; -1.5 mAHD
Congolli (adult mortality)	< 40	> 5	
Common galaxias (females & juveniles)	< 2	> 5	Connectivity and littoral optimal >+0.3 m AHD; can use open water; -1.5 mAHD
Common galaxias (adult mortality)	< 40	> 5	
Small-mouthed hardyhead	3 – 80 (35)	> 5	Open water; -1.5 m AHD
Yellow-eyed mullet	< 60	< 5	Open water; -1.5 m AHD
Black bream	< 60 (20-35)	< 5	Open water; -1.5 m AHD
Mulloway	< 35	< 5	Open water; -1.5 m AHD
Frogs			
Southern bell frog	< 9	unknown	Optimal > +0.1 m AHD; lake connections
Birds			
Estuarine shorebirds	No specific tolerance bands; will follow Estuarine and Marine macroinvertebrates		
Generalist shorebirds	No specific tolerance bands; will follow Insect larvae		
Fish-eating birds	No specific tolerance bands; will follow fish (Small-mouthed hardyhead typically last remaining fish as salinity increases from Coorong observations and published tolerances)		
Waterfowl	No specific tolerance bands; will follow Floating plants and zooplankton		

It needs to be noted that, critical life history stages, ecological interactions and processes may significantly alter this predicted order of response. Therefore robust assessment is not as simple as just determining ten consequence scores (Ch and Ct) in each scenario one for each of the above salinity tolerance groups). These Ch and Ct scores refer only to the receptor's physiological viability, that is, its capacity to withstand a certain magnitude of a stressor in a given area of habitat (assuming the receptor remains in that habitat). Yet the receptor's response will also be affected by their ecological viability, that is, the effects of interwoven ecological interactions and processes on receptor viability, such as the receptors':

- baseline condition, including degree of redundancy (see Sections 3.1 to 3.8),
- ability to avoid stressors,
- dispersal mechanisms,
- critical life history requirements (e.g. diadromous life cycles),
- indirect trophic effects (e.g. habitat provision, predation, competition), or
- level of dependence on specific habitat or food resources.

These determinants of physiological and ecological viability may be further moderated by constraints inferred by the physical characteristics of the site and site management (e.g. barrage operations).

Most receptors will have considerable and multiple ecological and site-specific constraints. A few receptors such as Insect larvae and Small-mouthed hardyhead will have very few constraints to moderate their physiological viability. Insect larvae as a group have very wide salinity tolerances (1- 138 g/L) and the flying adults can continuously deposit a diverse array of fresh eggs that can rapidly respond to a range of conditions. Similarly, Small-mouthed hardyhead (one of the most tolerant fish in the world) are dominant, present in all areas, adults are able to withstand high salinities (80 g/L) as well as periods of fresh water and they can recruit up to 35 g/L.

Following are examples of ecological viability and site-specific moderators used in Sections 4 to 6 to transform the receptors' physiological viability (i.e. Ch and Ct scores) into probable effects shown in the consolidated effects diagrams (Sections 4 to 6).

Stressor avoidance

Typically, highly mobile receptors such as birds and fish have a greater capacity to avoid stress than less mobile receptors (e.g. rooted plants, sessile macroinvertebrates). Birds are highly opportunistic and can fly considerable distances, if needed, to more favourable habitats to avoid stress. Fish are likely to receive physio-chemical triggers of poor water quality, such as patches of low pH around the lake fringes or salinity gradients, and most will be able to avoid exposure to the stressor provided there is functional connectivity with areas of lower stress. Barriers to movement at the site prevent (e.g. Clayton regulator) or only partially facilitate (e.g. fishways on Wellington weir) avoidance movements, increasing the likelihood of exposure. Yarra pygmy perch are a relatively immobile fish species. They also have a very poor baseline condition, strong habitat specificity and their core refuge is located in southern Lake Alexandrina in areas that are readily disconnected and isolated at low lake levels. Altogether these factors make it highly unlikely that Yarra pygmy perch could avoid exposure to stressors likely to occur in these scenarios, for example, seawater coming in through the barrages (seawater scenarios only) or acidification events associated with mono-sufidic ASS inside the barrages. Short-headed ammocoetes are the only life stage in the lakes. They are immobile and thus are unable to move to avoid stress.

Habitat specificity can also affect a receptor's capacity to avoid stress. For example, Lacustrine and Estuarine macroinvertebrates generally utilise the littoral fringes of the lakes making them susceptible to acid mobilisation from exposed ASS, wave action and desiccation. Adult Freshwater mussels are an exception. They are known to use open water habitat, seeking refuge in deeper water if conditions in the fringes are hostile. They can also close their shells to avoid certain stressors. However, their capacity to survive in deeper water over the longer term or keep their shells closed for extended periods, however, is unknown.

Dispersal

Some receptors, for example plankton, will be readily dispersed during the action period. River-sourced plankton are likely be re-seeded each winter as river flows enter Lake Alexandrina and some individuals with salinity tolerance towards the higher end in this group may survive summer salinity peaks greater than 3 g/L. Over time, all the plankton that occur in the Murray-Darling Basin could potentially be delivered to Lake Alexandrina and then Lake Albert via River Murray inflows. The capacity of the various plankton taxa to survive would then be a function of their tolerance of the physio-chemical conditions (e.g. salinity, light attenuation, nutrient availability) and ecological factors such as competition and predation. This means that plankton diversity and abundance will be highly variable and that populations of plankton lost due to adverse conditions in the lakes could be readily replaced.

Estuarine plankton and ostracods may have significant difficulties colonising Lake Albert because of low abundance and diversity on either side of barrages, barrage closure, dispersal distance, Narrung Narrows bund and pumps. Colonisation of Lake Albert by Marine plankton was considered even less likely than colonisation by Estuarine plankton and ostracods. Marine plankton not only need to enter from the Murray Mouth or Coorong they are generally less tolerant of salinities below 25 g/L which occur during some winters in Lake Albert. Similarly, Yellow-eyed mullet, Black bream and Mulloway were considered highly unlikely to colonise Lake Albert because of the large distance from the barrages to the Lake Albert entrance, barriers to movement (e.g. Narrung Narrows bund) and risk of death or injury if pumped from Lake Alexandrina to Lake Albert.

Overall, the site had very low functional connectivity (see Lester *et al.* 2011). The presence of the Wellington weir was assumed to limit re-colonisation from the river to a lesser degree for receptors such as plankton and to a greater degree for receptors such as fish that require facilitated passage through barriers. It was also assumed that the pumps across the Narrung Narrows bund would cause injury or death to many receptors. This may have limited the dispersal of some receptors (e.g. fish) more than others (e.g. plankton) and may have had significant impact on populations of some receptors that were already at risk of loss (e.g. Lacustrine macroinvertebrates, Congolli). The barrages in southern Lake Alexandrina also represented a barrier to movement given that they were closed throughout the action period except for when seawater was being introduced in the seawater scenarios.

The introduction of seawater may have also introduced new receptors to Lake Alexandrina although it is less likely to be a source of receptors for Lake Albert given the increased dispersal distance and limitations such as the pumps. The capacity of different Estuarine macroinvertebrates to enter Lake Alexandrina with seawater differed. Some more mobile receptors have mechanisms for overcoming hydrological barriers while others such as Paragrapus gaimardii (crabs) were only likely to enter during periods that the barrages were open.

Critical life history requirements

Short-headed lamprey ammocoetes, Congolli and Common galaxias rely on connectivity between fresh and saline areas for migration and recruitment. The experts chose them because of their life history cycles and their high level of risk of loss at the beginning of the action period (Section 3.5).

The ammocoetes of Short-headed lampreys occur in freshwater where they metamorphose before migrating downstream to the sea at approximately 3 years of age. The barrages were effectively closed from 2006 therefore by October 2009 the ammocoetes were already three years old. This means that this receptor would become locally extinct by the end of 2010 unless functional connectivity was re-established by spring 2010. Opportunities for them to re-establish are unknown.

Congolli are catadromous requiring free passage between fresh, estuarine and marine environments. They are also short-lived, probably only living for four to five years. Due to barrage closure, large adult fish thought to be approx. 3 years old in October 2009 dominated the Congolli populations. Therefore if disconnection continued beyond spring 2010 it is highly likely that Congolli would become locally extinct. Common galaxias are also catadromous but more adaptable and are likely to be able to complete their life cycles within the lakes during hydrological connection.

Life history was also an important moderator for Estuarine macroinvertebrates. Very few adults were expected to enter Lake Alexandrina with seawater each time it was introduced. The major influx was expected to be macroinvertebrate larvae. Larvae may have very specific spatio-temporal habitat requirements and are typically less tolerant of salinity, desiccation or acidification than adults suggesting that the stressors may have a stronger effect at the population level if larvae are the only or dominant age class.

Indirect trophic effects

In some cases, the strongest effect a receptor will experience in response to changing stressor levels will be indirect. For example, Waterfowl will typically utilise inundated, vegetated habitat. Given that Floating plants were the only aquatic plants present at the baseline, effects on Waterfowl should follow effects on Floating plants. But Waterfowl may also feed on or switch to macroinvertebrates and zooplankton if conditions are not suitable for Floating plants. Their food preferences are poorly understood. Similarly, effects on Fish-eating birds will follow effects on fish and effects on Generalist shorebirds will follow effects on Insect larvae. It is highly likely that sub-lethal effects occur prior to breaching of a receptor's threshold that may affect growth and possibly value as a food source for higher trophic levels.

Souter and Stead (2010) describe the food webs in Lakes Alexandrina and Albert and the Coorong. The food web associations are extremely complex if all the receptor groups plus additional biota representative of the Ramsar-state are included. In the connected Freshwater state the food web becomes much simpler indicating that trophic interactions are likely to change as the stressor levels change. The lakes were in a Disconnected Freshwater state (Attachment A) based on receptor presence and stressor levels, thus the food web would have been even more simplified primarily by the exclusion of estuarine species from the lakes.

Competition, herbivory and predation are also types of indirect trophic effects that may moderate physiological viability, particularly when conditions change. Where known these have been used as moderators. In some instances, different indirect trophic effects may have both negative and positive effects on the receptor populations. For example, herbivory of Waterfowl on Floating plants may significantly reduce the populations of Floating plants because there is no other aquatic plants. On the other hand, the lack of other competing aquatic plants may enhance the populations of Floating plants.

Habitat specificity

Habitat specificity, itself, is another factor that can alter the effects (positive or negative) on a given receptor. For example, Southern bell frogs need inundated littoral and riparian vegetation to successfully breed.

For the invasive Tubeworms, their colonisation within areas of suitable salinities is limited by their need for solid structures upon which to grow and sufficient water depth (prefer >1.5 m depth). When these are unavailable, the spread of larvae may be limited to less than the area theoretically suitable, particularly given that water levels in many scenarios drop relative to the baseline lake area over summer when larval growth is greatest. Boccardiella limnicola can occupy empty Tubeworm casings and thus their colonisation can be both limited and enhanced by the Tubeworm's ecological needs. Few other Estuarine macroinvertebrates have been observed to colonise the lake-side of the barrages presumably because of their very low baseline abundance and diversity. Estuarine shorebirds were considered unlikely to utilise Lake Albert even though salinities may increase to within the estuarine band because it was landlocked and thus represented the wrong habitat for these birds.

Habitat specificity also affects the ability of some receptors to avoid stress. Murray hardyhead and Yarra pygmy perch utilise wetlands, littoral zones and sheltered areas. Relatively small decreases in water level that would not significantly affect open water species can lead to loss of most, if not all, of their habitat. This habitat specificity makes them more susceptible to some stressors (e.g. water column acidification) than fish that can use open water habitats.

Murray cod, Golden perch, Australian smelt, Bony herring, Common carp, Small-mouthed hardyhead and Common galaxias can all use open water habitats. However, Murray cod require water of at least 1.5 m depth. So as water levels drop, less of the lake area is deep enough to be suitable for them, which in turn may increase the strength of the various stressors. The other open-water fish receptors require water of at least 0.2 m depth, except for Golden perch that needs water deeper than 0.5 m.

Redundancy

The very low redundancy in the Estuarine macroinvertebrate communities in the Murray Mouth and southern Lake Alexandrina is likely to affect the ecological viability of other receptors as well, particularly their predators or other receivers of their ecosystem services. Capitella spp. were considered the dominant fauna in the Murray Mouth in October 2009 because there had been such extensive loss of the other receptors in this group. Thus they were a critical food resource for higher trophic levels. They were also considered critical for maintaining soil quality and benthic activity during the action period because many other species that would have performed those roles had been lost prior to October 2009. Therefore if Capitella spp. were to be lost in any scenario, it is highly likely that there would be a catastrophic loss in food resource for higher trophic levels and significant changes to key ecosystem processes.

4. Do-nothing scenario in Lakes Alexandrina and Albert: primary stressor trends and receptor effects

In the Do-nothing scenario, no additional water was sourced either from the sea or from the River Murray. Lake water levels were allowed to drop to below the acidification tipping point if evaporative and other losses exceeded inflows. The trends in the primary stressors: salinity, water levels (lake area) and pH are presented below followed by the receptor responses. The consequence scoring used to derive the ecological effects described below appears in Attachment D grouped by scenario and lake. Attachment D contains: a list of effects at the receptor scale, the raw consequence scores, the earliest dates for breach of threshold (if it occurs), percentage habitat affected and comments about how scores were affected when different percentage threshold ranges were applied.

It should be noted that the following assessment of the effect of cease-pumping on the ecology of Lake Alexandrina is hampered by the lack of reliable salinity modelling data for the pumping scenario post January 2012, which is only 15 months into the five-year action period. In most cases, however, the relative difference in pH and water level effects between the pumping and cease-pumping scenarios will be so great that the effect of salinity will be inconsequential when comparing the scenarios across all three primary stressors.

4.1. Lake Alexandrina under the Do-nothing scenario

4.1.1. Primary stressor trends when pumping to Lake Albert

Salinity

The modelling outputs show salinity to be greater than 3 g/L across 90.9% of Lake Alexandrina at the starting date (October 2009). The remaining 9.1% in the most northern parts of Lake Alexandrina under River Murray influence will have salinity greater than 2.5 g/L but less than the 10 g/L threshold. The first time salinity will exceed 10 g/L will be in the south of Lake Alexandrina in February 2011. Over that summer the south and western sections of Lake Alexandrina (up to 9.8% of the whole lake) will have salinities greater than 10 g/L, first reaching this threshold on 13/04/2011. The threshold of 15 g/L will be exceeded for the first time a year later in the western parts of Lake Alexandrina and immediately upstream of Tauwitchere barrage (7.6% of Lake Alexandrina on 15/02/2012; peak of 8.3% of Lake Alexandrina on 22/02/2012). A seasonal cycle of salinity exceedance was predicted, showing that salinities will be higher in summer than in winter.

A strong east to west salinity gradient will establish during summer 2009/10. Mixing across the main lake body in winter 2010 will destabilise the gradient so that only the area south of Pt. Sturt will have a noticeably higher salinity when compared to the rest of the lake. The pattern will repeat in 2011 and 2012 but the winter mixing will not be as strong so that an east-west gradient will persist through winter 2012. In summer 2011/12 there will be a very strong gradient from west to east but drawdown in the western and southern sections will reduce the size of the areas of high salinity (Figure 4.1). Lake Alexandrina will freshen in winter 2012, reducing the salinity gradient. In August 2012 salinity was modelled as <3 g/L in the northern half of the lake and < 5 g/L in the rest of the lake excepting the area just upstream of Tauwitchere barrage, which will have a salinity of < 7g/L. Salinity will increase once again over summer 2012/13 with the western end of Lake Alexandrina exceeding 5 g/L (16.4% of Lake Alexandrina on 30/01/2013) with a maximum of > 20 g/L in a very small patch (0.7%) on 13/02/2013.

It appears that the model resets to very low salinities in late June 2012 with predictions of less than 5 g/L except in areas south of Point Sturt, which will be < 6 g/L and < 7 g/L in a small area upstream of Tauwitchere Barrage. Whilst this may be explained by seasonal inflows of freshwater the salinity was not predicted to increase to its previous summer levels (2011/2012) thereafter. This is unexplained and does not conform to previous and expected seasonal patterns of a cyclical but steady increase in salinity. As a result there is low confidence in modelled outputs for salinity after summer 2011/2012 for this scenario and only the ecological consequences to January 2012 have been assessed.

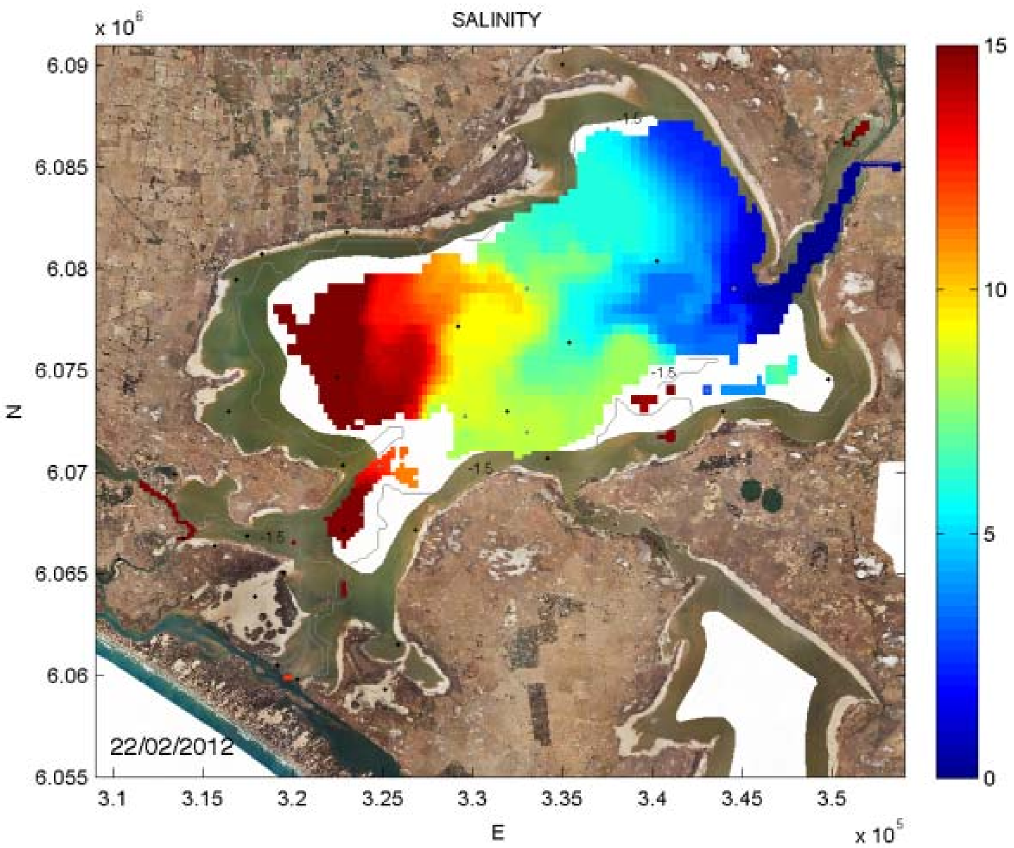


Figure 4.1: Lake Alexandrina Salinity in the Do-nothing-pumping scenario at February 2012.
Scale is in g/L.

Water level

The starting water level of approximately -0.8 m AHD is taken as the 100% reference point against which changes in lake area are described. Water levels will begin to fall in December 2010. The areas above Tauwitchere barrages will dry out and by the end of March 2011 lake area will have decreased by 28% (72% of the October 2009 baseline). Some winter recovery will be evident but lake area in winter 2011 will only return to 76% of the baseline, an increase of only 4%. Cumulative reductions in water level will occur each summer so that by February 2013 only 25% of the baseline lake area will remain (i.e. 75 % loss of area compared to October 2009 baseline). Water levels will then oscillate around the lowest water level in summer/autumn (lake area 25 to 39% of baseline) with some winter/spring refilling (lake area 66 to 71% of baseline) during the rest of the action period.

pH

Small patches of pH less than 5 will occur around the north and western fringes of Lake Alexandrina from January to May 2010 for a week or two at a time. These areas will dry in January 2011. The remaining water in the lake will stay above pH 7 until February 2012 when small patches along the eastern shores will begin to show week-long periods of acidification. In May-June 2012, most of the north of Lake Alexandrina and the western tip will be acidified to pH less than 4. In total, approximately 20% of the lake will be acidified during these months. In July 2012, the acidification events will clear and pH will be circum-neutral once again. Later in the year, from August to November 2012, sporadic periods of low pH will occur in the eastern corner of the lake and near Milang. The acidification event will again go into hiatus from midway through November until January 2013 when acidified patches will re-occur in the eastern corner of Lake Alexandrina and near Milang.

Highly dynamic and major acidification events will begin in autumn 2013. In May 2013, acidification will occur around the entire lake margin except for east of Point Sturt. During winter and spring 2013 all sections of the lake will experience pH less than 6 at some time. During this time period all but the deepest, central areas (approximately 25%) of Lake Alexandrina will experience pH less than 4. Figure 4.2 shows a snapshot of an acidification event in June 2013 in which pH is less than 4 (blue) across approximately 70% of the lake. Other than a small area on the western most fringes of Lake Alexandrina, (less than 1% of the lake), all the water will acidify in January 2014. The modelling outputs used contained no other acidification events from spring 2013 onwards even though water levels will decline markedly during late summer 2014 and 2015.

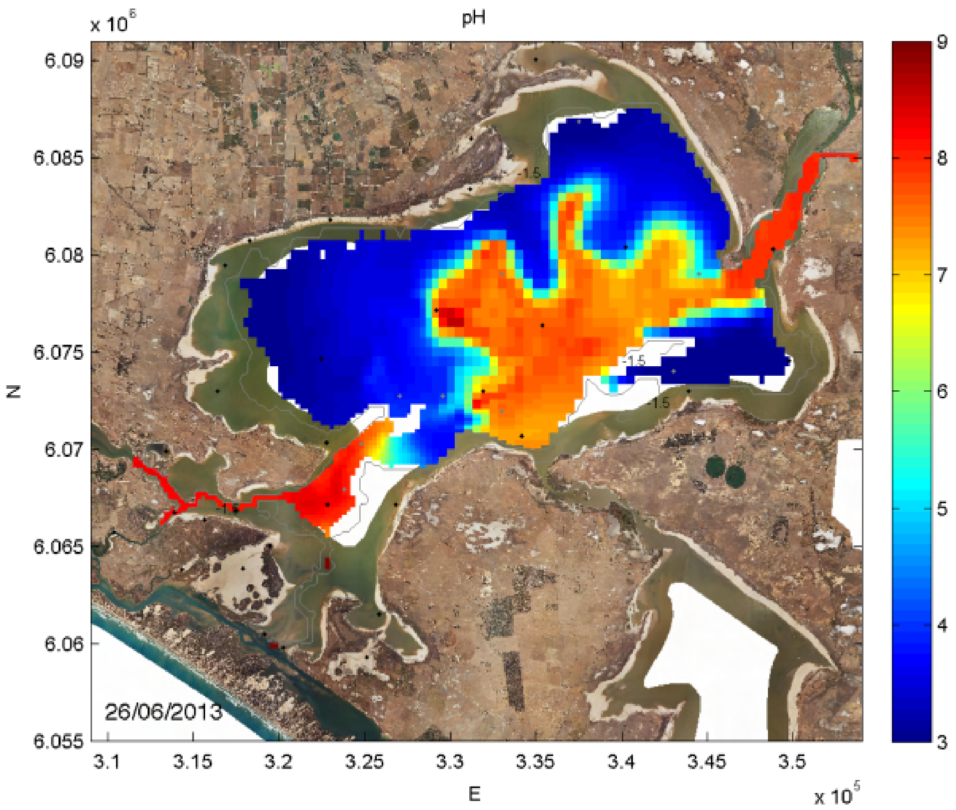


Figure 4.2: Lake Alexandrina Do-nothing pumping acidification event in June 2013. Note mid to dark blue is pH < 4 and orange to red is pH > 7.

4.1.2. Primary stressor trends when pumping to Lake Albert ceases

Salinity

In December 2009, salinity will start to increase to greater than 5 g/L in the southern and western parts of Lake Alexandrina. Each year winter inflows will freshen the lake water around the River Murray confluence to approximately 2 g/L to between 4 and 12 g/L in the main lake body. There will be slight increases in winter salinities from year to year. Salinity levels in the lake will increase over the warmer months but the north-south salinity gradient will persist into summer. Absolute summer/autumn salinities will increase year to year so that the annual salinity peaks will be: 10.4 g/L in April 2011; 18.3 g/L in April 2012; 24.2 g/L in March 2013; 27 g/L in March 2014; 27.6 g/L in March 2015 (Figure 4.3). Salinities in Lake Alexandrina will not exceed 30 g/L at any time or area within the action period when pumping to Lake Albert ceases.

Comparisons of salinities in Lake Alexandrina between the pumping and cease-pumping scenarios can only be drawn until January 2012 when the hydrological modelling in the pumping scenario becomes unreliable. In general, salinities in Lake Alexandrina will be more saline for the period October 2009 to January 2012 in the cease-pumping scenario than if pumping to Lake Albert continues. For example in the central parts of the lake, the peak at January 2012 will be in the order of 10 g/L in the pumping scenario as compared to 13-15 g/L in the cease-pumping scenario. By the end of the action period salinities in the cease-pumping scenario will be up to 27.6 g/L south of Pt. Sturt but this is beyond the period of reliable modelling for the pumping scenario so comparisons cannot be drawn.

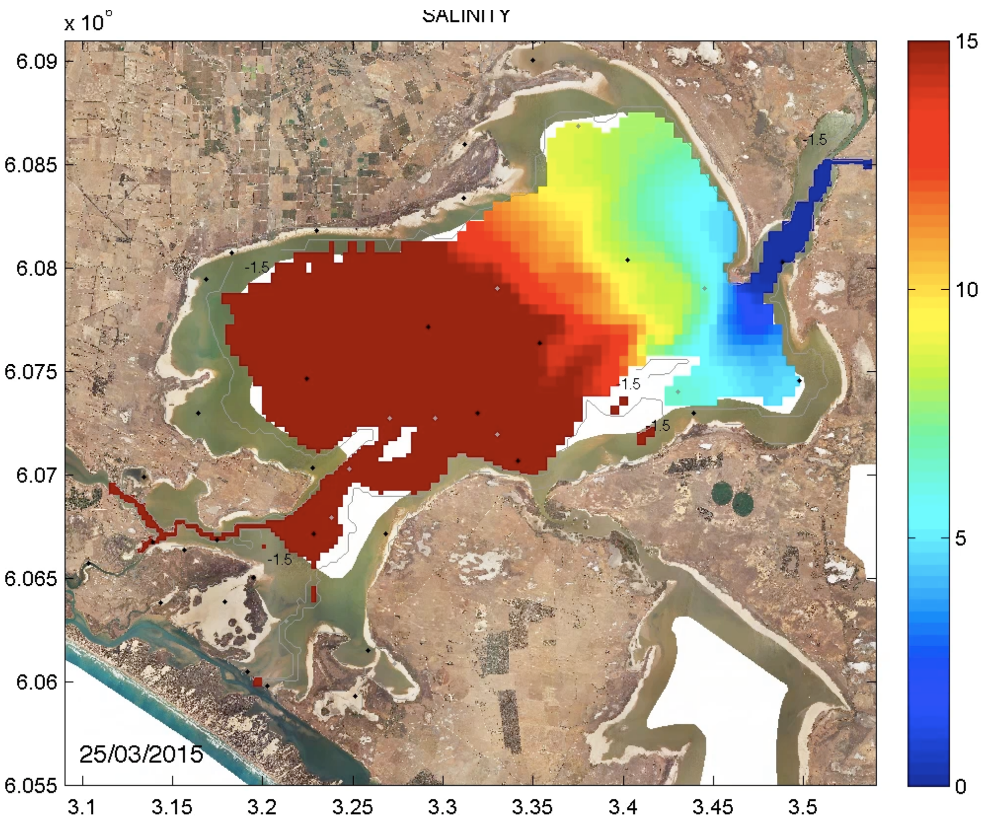


Figure 4.3: Lake Alexandrina salinity in the Do-nothing cease-pumping scenario at March 2015. Scale is in g/L and was set at 15 g/L maximum even though salinities in the saltier areas will be greater than 27 g/L.

Water levels

Water levels in Lake Alexandrina will be significantly higher in the cease-pumping scenario compared to the pumping scenario after October 2010 when pumping ceases. In the cease-pumping scenario, water levels in winter will typically be around 76% of the baseline lake area, which is similar to those predicted for the pumping scenario (71 to 76% of baseline lake area). Summer drawdown will occur each year but only to: 71% by March 2012; 67% by March 2013; 65% by March 2014 and 68% by March 2015. By contrast, summer water levels in Lake Alexandrina when pumping to Lake Albert continues will drop to: 43%, 25%, 39% and 25% lake area for the above periods, respectively. This indicates a significantly reduced lake area available for growth, foraging and survival in Lake Alexandrina if pumping to Lake Albert continues.

pH

In the cease-pumping scenario, acidification events of pH less than 4 will occur around the fringes of Lake Alexandrina each autumn and winter mostly in northern Lake Alexandrina either side of the river confluence when pumping to Lake Albert ceases. In any one of these acidification events approximately 1 to 5 % of the littoral zone will have a pH < 4 for periods of two weeks or less. From November 2010, the lake will get smaller (99 to 76% of baseline) and the fringes will shift inwards by several kilometres. This means that the fringing areas that acidified prior to November 2010 will become dry and new fringing areas, down-gradient, will be progressively affected. The main areas of low pH from May 2011 onwards will be in the north-eastern corner of Lake Alexandrina.

In the pumping scenario, periods of low pH will occur later (i.e. not until autumn 2012) but acidification below pH of 4 will affect 90% of the lake fringes and 50% of the main lake body (see Figure 4.4), which will be highly significant in ecological terms. The low pH events in the cease-pumping scenario will have very minor ecological effect compared to the pumping scenario where there will be highly adverse, longer-term and widespread acidification events.

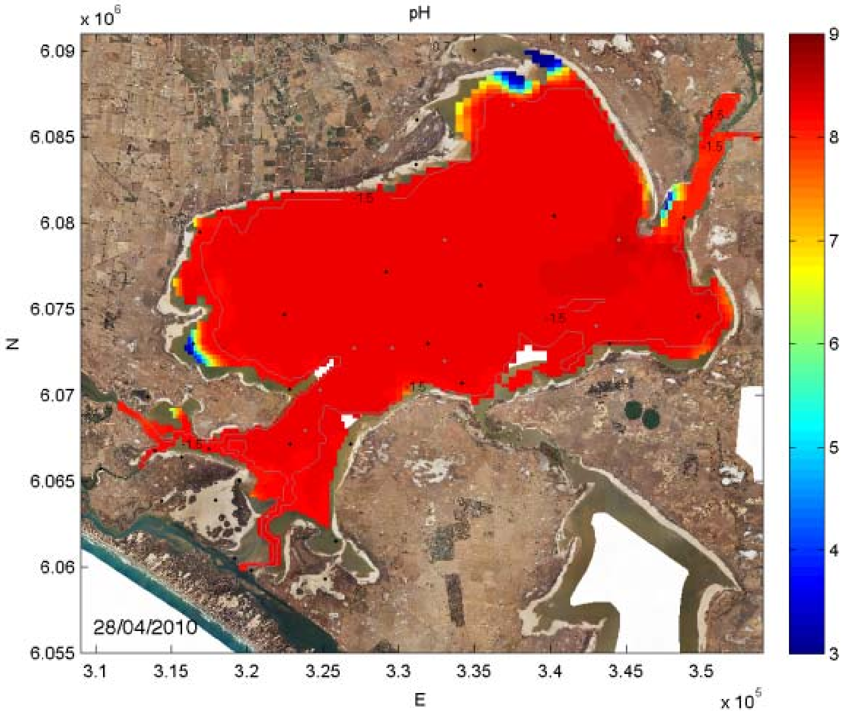


Figure 4.4: Lake Alexandrina pH in the Do-nothing cease-pumping scenario at March 2015. Note red is pH > 7 and small patches of low pH are shown in blue and teal.

4.1.3. Ecological receptor responses in Lake Alexandrina

Pumping to Lake Albert

Salinity will increase over time in the Do-nothing pumping (DN_P) scenario in Lake Alexandrina to the extent that many of the freshwater receptors present in October 2009 and expected to be in the Ramsar-state for Lake Alexandrina (Attachment A) will be lost or strongly affected by high salinities during the first two and a half years of the action period (Figure 4.5; Attachment D). The plankton community will likely undergo a major shift from plankton typical of Lake Alexandrina (mixture of River-sourced and Low salinity plankton) towards more salt-tolerant taxa typically found in Lake Albert (Brackish plankton) with perhaps some Acidophillic plankton. Salinities will also become increasingly unsuitable for Floating plants, Freshwater macroinvertebrates, Mussels, Yabbies, Southern bell frog and all the fish receptors except for the highly salt tolerant Small-mouthed hardyhead and Black bream. The declining water level in Lake Alexandrina will be likely to simultaneously increase the competition and predation pressures and exacerbate the pressures resulting from salinity.

Salinities will, however, be suitable for further establishment of tubeworms (Ficopomatus enigmaticus) and their proliferation will be limited only by other factors such as availability of hard substrates, pH and adequate water depth (> 1.5 m depth). The low lake levels will also mean that disconnection of the lakes from the system downstream of the barrages will continue, leading to the loss of Congolli and Short-headed lamprey as well as limiting the capacity for dispersal of Estuarine and Marine plankton (not likely to colonise).

Regardless of the salinity tolerances of the different receptors, mortality of 75 to 100% of all receptors in Lake Alexandrina from low pH will occur in autumn 2012 or between autumn and spring in 2013 (Figure 4.5; Attachment D). Only those fish and plankton able to tolerate the increasing salinity, avoid the low pH by utilising deep water that will have a circum-neutral pH and can persist in a disconnected state could survive. However, any biota harbouring in the deep water will be extremely stressed and will rapidly exhaust their critical resources (e.g. prey or nutrients).

The birds may have periods of high food abundance (especially Fish-eating birds during fish kills) but ultimately all birds will leave the site before or during 2013. The more generalist birds will be likely to stay longer than those with specific prey needs. Waterfowl that interact more directly with the water body than other birds are likely to be more strongly affected by ASS oxidation products (e.g. acid and heavy metals). Responses of birds and physiological effects to these types of environmental changes remain a knowledge gap.

Cease-pumping to Lake Albert

By contrast if pumping to Lake Albert ceases, water levels will remain higher and thus the acidification events will be much reduced to only 5% of Lake Alexandrina (compared to 75% in the pumping scenario). Other water level dependent processes such as competition and predation will also be comparatively lower than in the pumping scenario.

As such, salinity will be the dominant driver of receptor survivorship and many of the freshwater receptors typical of Lake Alexandrina in its Ramsar-state will still be subject to strong adverse effects from high salinities when pumping to Lake Albert ceases (Figure 4.6: Attachment D). River-sourced plankton will be lost to the combined effects of high salinity and low pH regardless of whether pumping ceases or not. Similarly, the shift from typical Lake Alexandrina plankton to more salt-tolerant taxa typical of Lake Albert (Low salinity to Brackish plankton) from increasing salinity will occur in both scenarios.

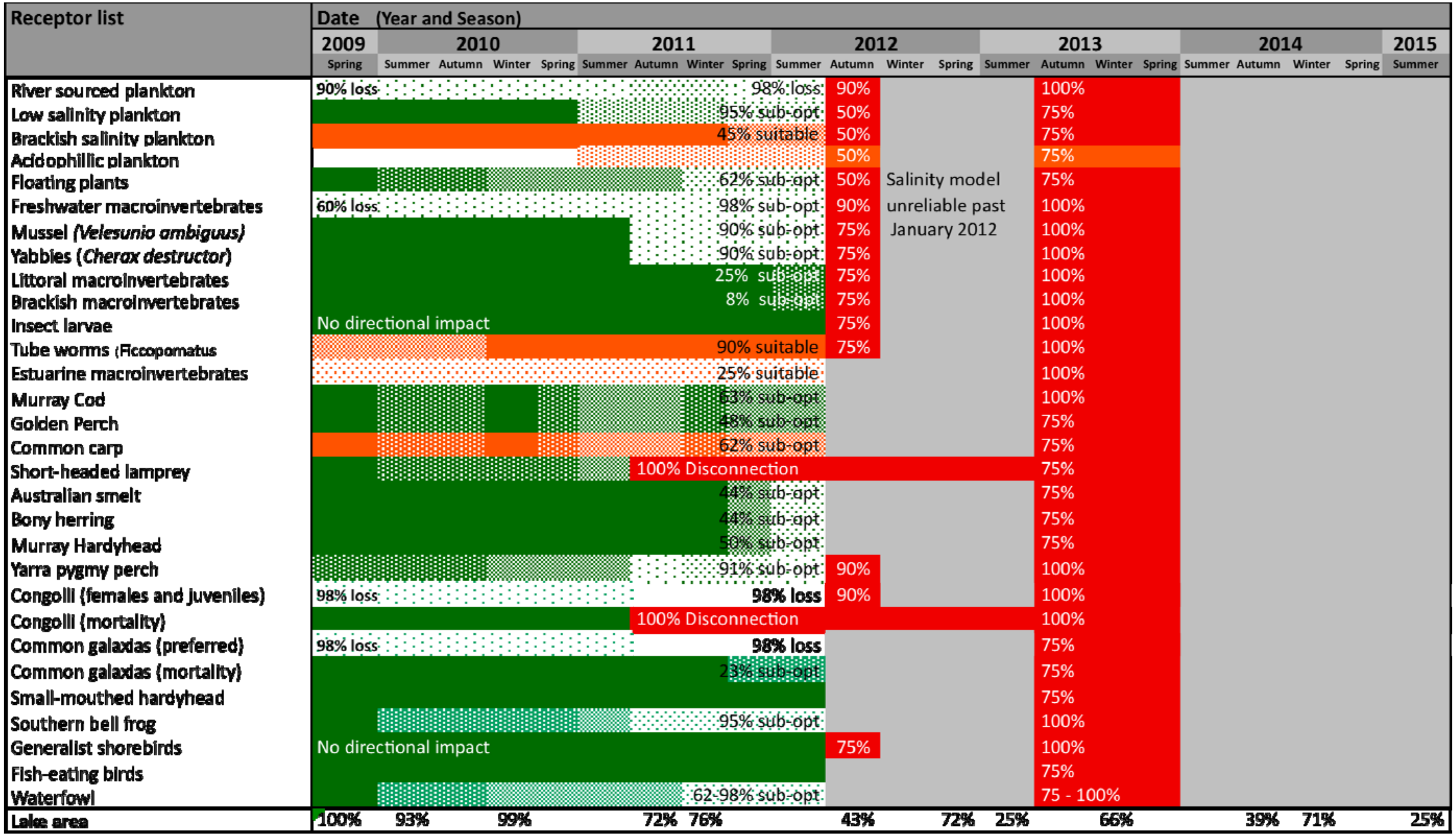


Figure 4.5: Consolidated effects of salinity, pH and water levels on receptors under Do-Nothing Pumping (DN_P) in Lake Alexandrina.

Figure 4.6: Consolidated effects of salinity, pH and water levels on receptors under Do-Nothing Cease Pumping (DDN_CP) in Lake Alexandrina.

Floating plants, Yarra pygmy perch, Water fowl, Southern bell frog and Freshwater macroinvertebrates will be less affected by low pH than if pumping continues but will still be lost across 97 - 100% of their habitat in the cease-pumping scenario from high salinity. Therefore, the overall effect between the two scenarios will be similar (noting that salinity effects beyond January 2012 in the pumping scenario cannot be ascertained). The other less salt tolerant Lacustrine macroinvertebrates, Murray cod, Golden perch and Common carp will lose between 55 and 77% of their respective habitats suggesting that their populations will be under moderate to severe salt stress.

Estuarine and Marine plankton may colonise up to 50% of Lake Alexandrina and will not be limited by low pH. Invasive Tubeworms could proliferate across up to 90% of Lake Alexandrina under the cease-pumping scenario, provided that they find hard substrates in deep enough water (> 1.5 m depth), given the lack of control by low pH compared to the widespread acidification in Lake Alexandrina when pumping to Lake Albert continues.

The on-going lack of connection through the barrages will be fatal for Congolli and Short-headed lampreys and will increase stress for many other receptors especially Common galaxias and Estuarine organisms in the Murray Mouth and North Lagoon areas.

4.2. Lake Albert under the Do-nothing scenario

4.2.1. Primary stressor trends when pumping

Salinity

Starting salinity concentrations in Lake Albert were modelled as 3.9 to 7.8 g/L at the beginning of the action period (October 2009). Salinity across the main body of the lake will be effectively homogeneous, with 97.5% of the lake having salinity > 7 g/L and only 0.4% of the lake > 7.6 g/L. Narrung Narrows will be noticeably fresher. The model outputs show that over the summer (2009/10) a strong north-south salinity gradient will began to establish with maximum salinity in the southern parts reaching 28 g/L in March 2010 (site 36). The northern parts of the main lake will be less than 20 g/L; grading to the lowest salinity in the Narrung Narrows, where salinity will peak at 11 g/L in January 2010. Gradual freshening of the Narrung Narrows and northern part of the lake will begin in January 2010 and continue through winter. As a result salinity across the lake will drop to less than 10 g/L and become more homogenous. This seasonal pattern of high summer/autumn salinities and lower winter/spring salinities will repeat annually but with cumulative salinity values each year. Summer salinity will be greater than 60 g/L in January 2014 across 16% of Lake Albert (Figure 4.7) having been preceded by a winter 2013 minimum of 35-40 g/L.

In late January 2014 salinity will suddenly and inexplicably drop by an order of magnitude, which does not conform to previous seasonal patterns. As a result there is low confidence in modelled outputs for salinity in Lake Albert after January 2014. There is also some doubt as to the feasibility of pumping water from Lake Alexandrina to Lake Albert in this scenario given that the water in Lake Alexandrina is several kilometres from the pumps at Narrung Narrows that supply Lake Albert with water.

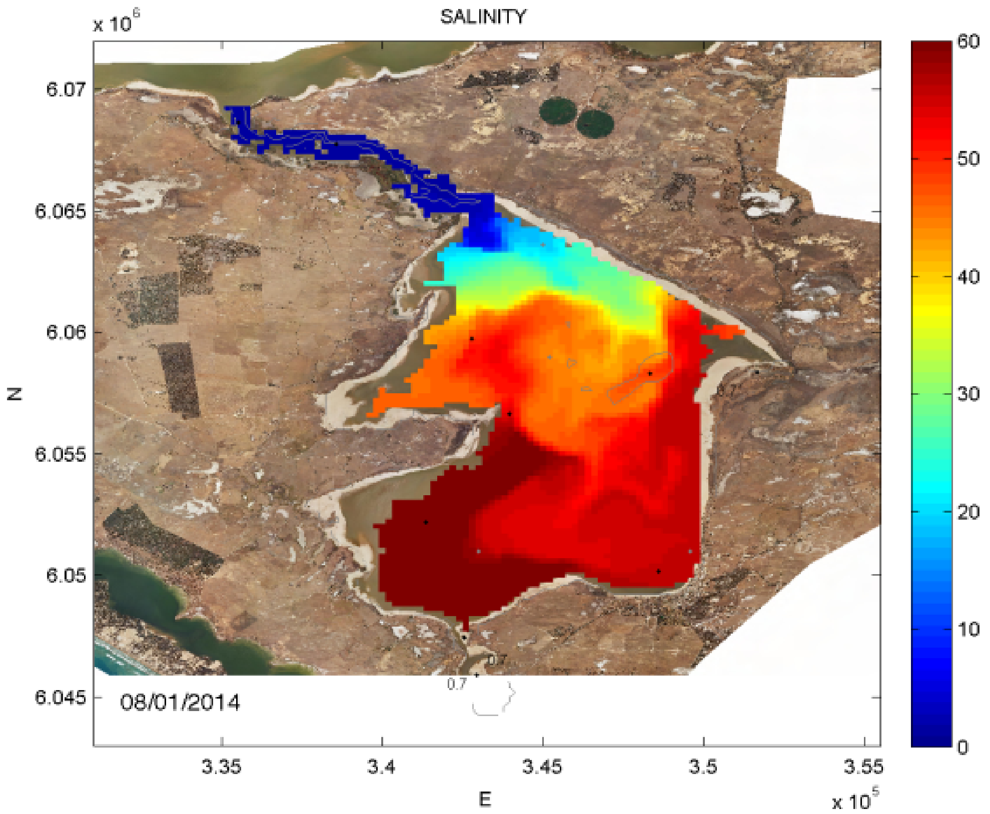


Figure 4.7: Lake Albert Salinity in the Do-nothing pumping scenario at January 2014. Scale is in g/L.

Water levels

The water level in Lake Albert will be maintained near the management level (c. -0.5 mAHD) as a result of pumping from Lake Alexandrina. In summer 2009/10 there will be a drop in water level to 67% of the baseline lake area (October 2009). This will recover to 87% of baseline in May 2012 and then vary between 91 and 98% of baseline for the rest of the action period.

pH

All inundated areas of Lake Albert will have a pH > 6.5 throughout the action period, which is above the threshold for all ecological receptors. This is due to on-going pumping of water in from Lake Alexandrina maintaining water levels above the acidification trigger level.

4.2.2. Primary stressor trends when pumping ceases

Salinity

If pumping to Lake Albert ceases in October 2010, salinities will rise rapidly and reach a greater concentration than under a pumping scenario. Starting concentrations in the cease-pumping scenario will be 4.5 to 8 g/L with the lower concentrations in the Narrung Narrows. These are generally very similar to the starting conditions for the pumping scenario (3.9 to 7.8 g/L).

In summer 2009/10 salinities will increase to similar levels in both scenarios and in winter 2010 freshening will occur, also in both. However, when pumping ceases in October 2010, salinity will rapidly rise to greater than 40 g/L by December 2010 and will peak at 180 g/L in February 2011 in the southern parts of the lake. By April 2011, the lake will be disconnected from the Narrung Narrows and salinities in the remaining disconnected water body will be approximately 180 g/L.

In winter 2011 the salinity will drop back to 96 g/L before returning to approximately 180 g/L by November 2011 (Figure 4.8). Salinities will remain high until the lake completely dries in April 2012. By contrast, salinities in the pumping scenario will reach a summer maximum of 66.2 g/L in only 0.3% of Lake Albert in January 2014. Therefore ceasing to pump to Lake Albert will lead to a three-fold increase in maximum salinity during the action period.

Water levels

When pumping to Lake Albert ceases in October 2010, the water level will drop very quickly so that by April 2011 only 27% of the baseline lake area will remain. After a brief winter recovery to 44% of the baseline in June 2011, water levels will decline to 10% lake area by December 2011 and 0.2% by March 2012, by which time the lake will be essentially dry. This shows that pumping water from Lake Alexandrina is critical for persistence of any surface water in Lake Albert under the Do-nothing scenario.

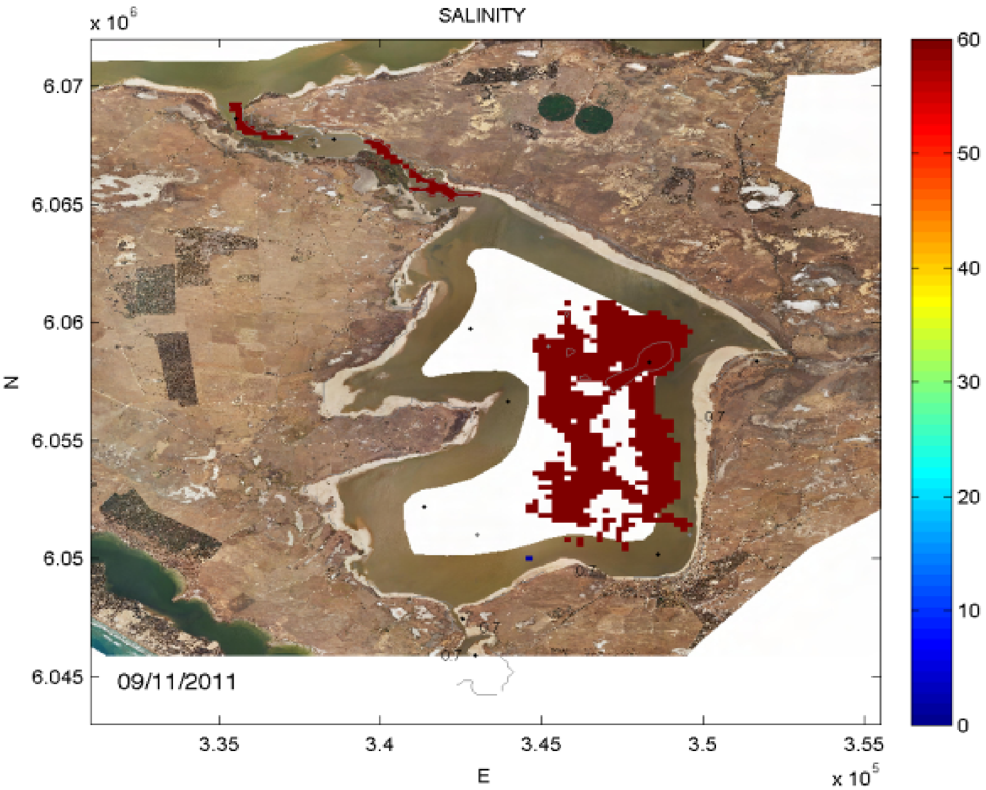


Figure 4.8: Lake Albert salinity in the Cease pumping scenario at November 2011.
Note the contracted water level and the scale in g/L only extends to 60 g/L even though salinities will be up to 180 g/L. pH at this time will be < 4. Water levels will drop further beyond November 2011 and the lake will dry completely.

pH

In the pumping scenario, there will be no significant acidification events in Lake Albert (pH > 6.5 at all times). In strong contrast, when pumping to Lake Albert ceases in October 2010, pH will rapidly drop and the water will become unsuitable for all biotic groups (except acidophiles) by spring 2011. The first low pH events (< 4) will occur in summer 2011 across 15% of the open water habitat and 20% of the lake fringes. In autumn 2011 the whole lake will have pH < 6.5 and by spring it will be < 4. In late November 2011, the water level will be 15.3% of the baseline lake area and thus there will still be 3,056 ha of water body remaining that will now be highly acidic (pH less than 4 in 94.5%).

4.2.3. Ecological receptor responses in Lake Albert

Pumping

Water level (Lake area) will be maintained at the management target throughout the action period and no acidification events will occur when pumping to Lake Albert continues. Therefore, salinity was considered the primary driver of ecological community composition in the Do-nothing pumping scenario. Most of the receptors typical of the Lake Albert ecosystem (e.g. Brackish plankton, Floating plants, Lacustrine macroinvertebrates, Water fowl and less salt-tolerant fish) will be progressively lost to increasing salinity from spring 2009 to winter 2013 (Figure 4.9). Estuarine osctracods and Marine plankton will be unlikely to migrate to Lake Albert although salinities in Lake Albert will be suitable for their colonisation from summer 2010/11 onwards. If they do find a migration mechanism, new salt-tolerant plankton may proliferate but will probably be subjected to very high levels of predation by higher trophic levels given the almost complete lack of other plankton. Therefore, it is likely that the plankton community will undergo a shift from those typical of Lake Albert in the Ramsar-state to more salt tolerant lacustrine receptors (e.g. Brackish and Estuarine plankton) and then markedly decline in diversity and abundance from winter 2013.

Narrung Narrows will act as a less saline refuge during this period until salinities there also increase beyond the salinity tolerances of these less salt tolerant receptors. Notably Murray cod in Lake Albert will perish very early on (by the end of summer 2009/10) because they are not expected to utilise the shallow waters of Narrung Narrows. This severe reduction in the fish community suggests that Small-mouthed hardyheads will be the dominant fish species with few other fish surviving (e.g. Common galaxias and Congolli) in the main lake body after winter 2013. It is unlikely that Fish-eating birds will be affected by these losses in the fish community because of the persistence of Small-mouthed hardyheads, congregation of fish in shallow areas and high likelihood of fish kills as the less tolerant fish die out. The extremely broad salinity tolerance range of Insect larvae would suggest that they may also persist and with them the Generalist shorebirds. However, it is likely that the remaining fish will rapidly exhaust their food supplies under this scenario, which will exacerbate the underlying sub-lethal salinity stress. Predation pressures on fish and Insect larvae will also increase and if the foraging success of birds thus declines, the Fish-eating birds and Generalist shorebirds will leave towards the end of the action period.

Cease-pumping

If pumping to Lake Albert ceases, complete ecological collapse will occur from the combined effects of high salinity, low pH and lake drying. Salinity will be too high for most Lake Albert receptors by summer 2010/11 and for all by winter 2011 (Figure 4.10).

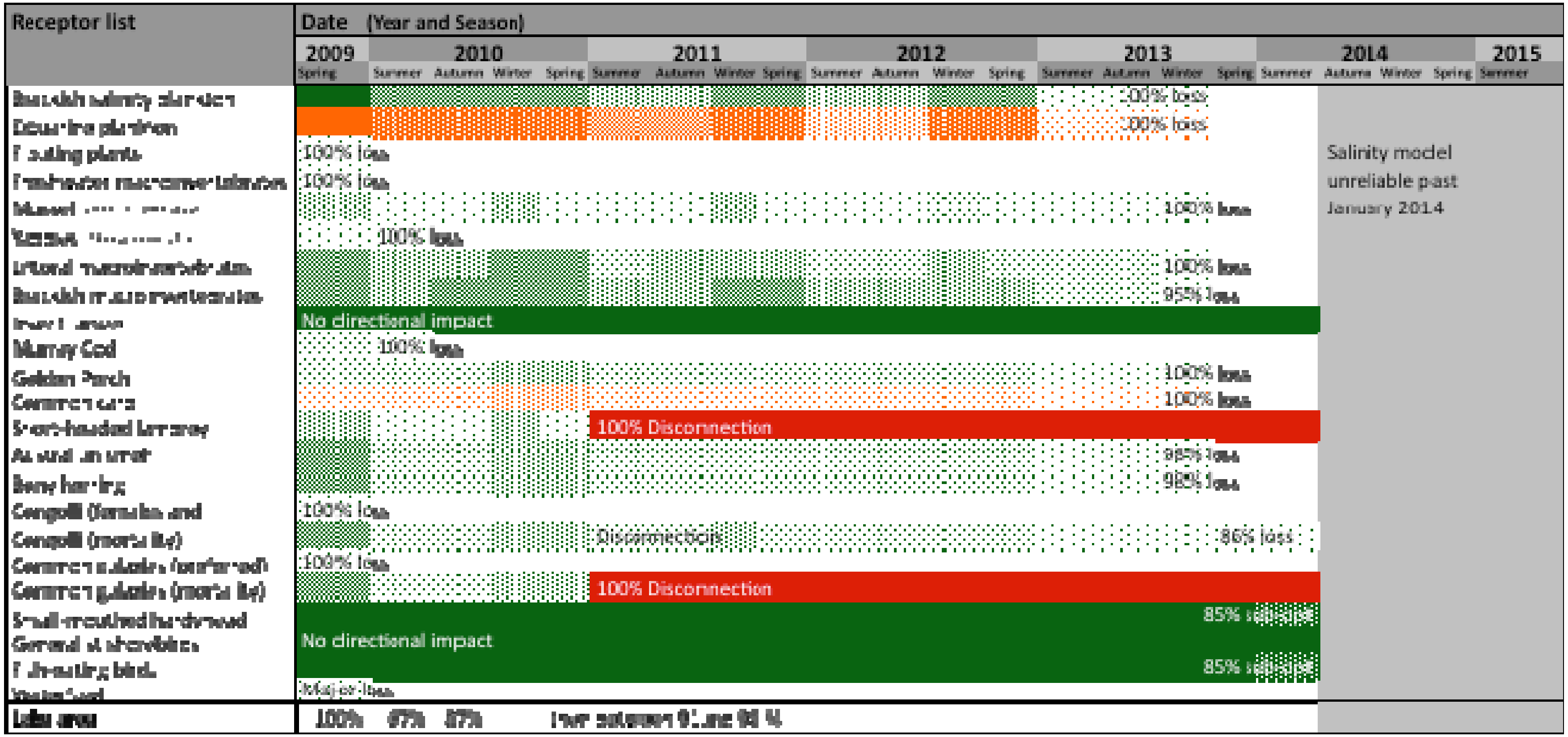


Figure 4.9: Consolidated ecological effects of salinity and water level for Do-Nothing Pumping (DN_P) in Lake Albert.

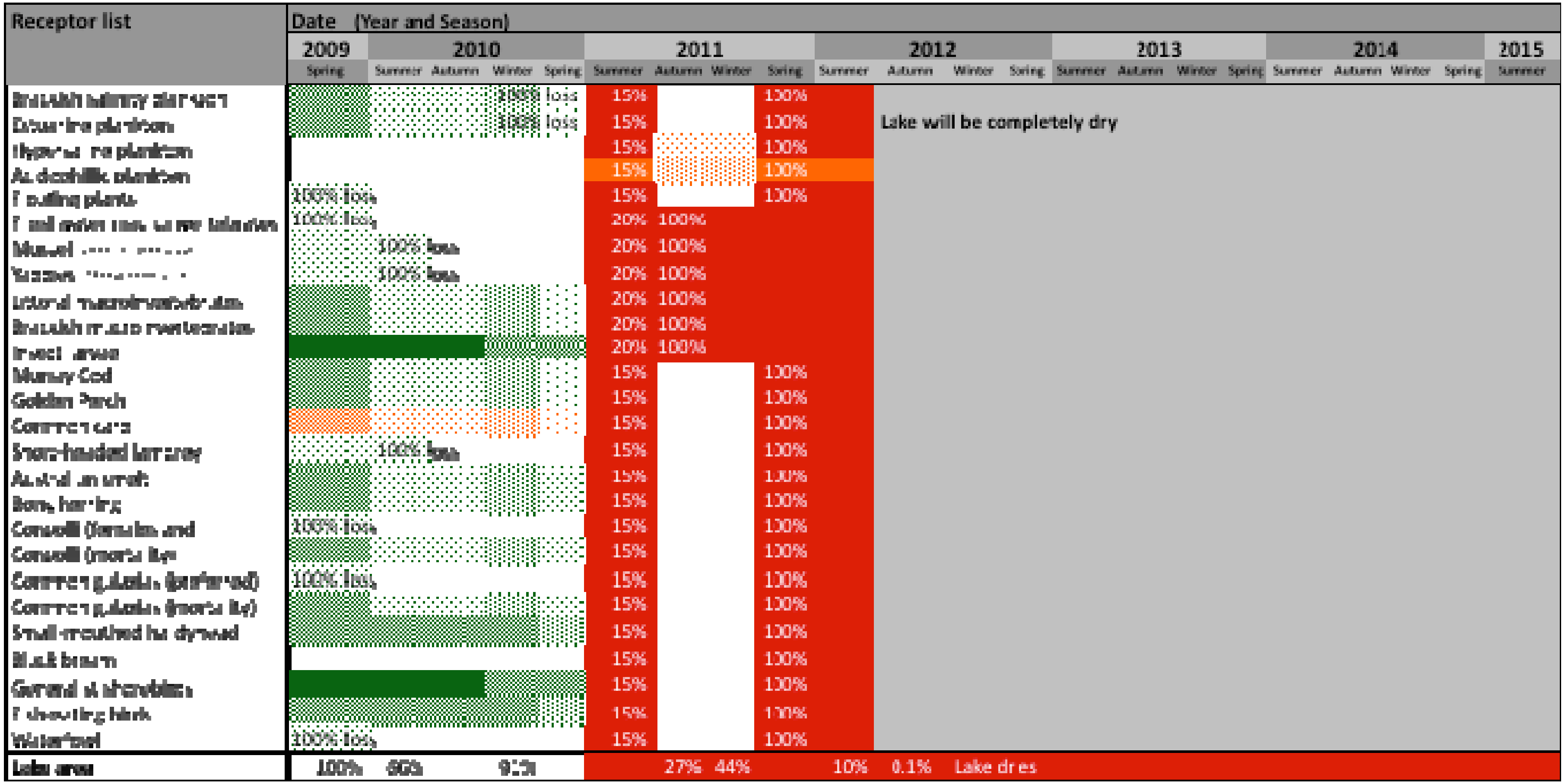


Figure 4.10: Consolidated ecological effects of salinity and pH for Do-Nothing Cease Pumping (DN_CP) in Lake Albert

The first acidification event will occur in summer 2010/11 covering 15% of the whole lake and 25% of the littoral zone by which time only 27% of the lake water body will remain. Acidification will spread to become widespread from autumn 2011 before the lake dries completely over summer 2011/12 and all aquatic habitat is lost.

4.3. Conclusions for the Do-nothing scenario

Under the Do-nothing pumping scenario, Lake Alexandrina will have an extremely simplified ecosystem comprised of saline tolerant plankton and fish surviving in the deep water and very little else. Those fish and plankton that may survive will be highly stressed and likely to exhaust critical resources (e.g. nutrients, light or food) and ultimately perish.

Some receptors in Lake Alexandrina will benefit from ceasing to pump to Lake Albert. The ecosystem in Lake Alexandrina will be more complex if pumping ceases than if pumping continues because widespread acidification will not occur. However, salinity will still be a major stressor and the less salt-tolerant receptors will still perish from high salinity. The overall ecological composition will be strongly skewed towards the more salt-tolerant receptors, including estuarine invaders (e.g. tubeworms).

The high salinities predicted for Lake Albert in the pumping scenario will result in progressive losses of most Lake Albert receptors and a major simplification of the ecosystem to one dominated by a few highly salt-tolerant fish, Insect larvae and the birds that feed upon them (analogous to the "Dead sea downunder" description of the South Lagoon of the Coorong; Lester and Fairweather 2009).

If pumping to Lake Albert ceases, the lake will become highly saline and then acidic before drying out. All biota and aquatic habitat will be lost.

5. Seawater scenario in Lakes Alexandrina and Albert, Murray Mouth and Coorong: primary stressor trends and receptor effects.

In the Seawater scenario, water will be sourced from the sea via the barrages in the south of Lake Alexandrina. The trends in the primary stressors: salinity, water levels (lake area) and pH are presented below followed by the receptor responses to those stressor trends. Copies of the consequence scoring sheets appear in Attachment D grouped under scenario and lake as for the Do-Nothing scenario.

5.1. Lake Alexandrina under the Seawater scenario

5.1.1. Primary stressor trends when pumping

Salinity

The modelling outputs show salinity to be greater than 3 g/L across 100% of Lake Alexandrina at the starting date (October 2009). When seawater is first introduced in October 2010, salinity rises very rapidly to > 30 g/L in the southern channel connecting the main lake body with the Coorong at the Tauwitchere Barrages. By 10th November 2010 the lake water south of Point Sturt will be > 20 g/L with the most southern areas near Tauwitchere Barrages > 30 g/L. The saline water can be traced entering the channel connecting the lake to Tauwitchere Barrages and then filling the area south of Point Sturt quite homogeneously before swirling around to the western areas of Lake Alexandrina.

A salinity gradient will then form across the main lake body from west to east, with higher salinity in the west and south of Pt. Sturt. This gradient will persist over summer 2010/11 although the relative salinities increase so that salinities will be between 26 and 30 g/L in the west of the lake and 20 g/L in the east. South of Point Sturt, salinities will range from 30-35 g/L at the end of summer 2010/11. Areas around the north-east end of the lake, near the River Murray confluence, will have considerably lower salinities (5 – 10 g/L) and will be relatively fresh.

The main body of the lake will be 20-25 g/L with a general gradient from west to east (higher in the west) in winter 2011. Site 64 (south of Point Sturt) will be the exception with salinities around 25 g/L. The north-eastern area of the lake under River Murray influence will be relatively fresh in winter 2011 (15-20 g/L) and winter 2012 (around 20 g/L). The main lake body will remain at salinities of 30 to 40 g/L. There will only be very localised freshening around the confluence with River Murray and the fresh water will not penetrate far into the lake. The saltiest areas of the lake will be south of Point Sturt and in the western corner of Lake Alexandrina where salinities will be 40 to 43 g/L in winter 2012. In winter 2013 there will be relatively lower salinities around the confluence (c. 30 g/L) and in the north-east (45 to 50 g/L). At the same time, salinities south of Point Sturt and in the western section of the lake will range from 55 to 60 g/L. The same pattern will repeat each following winter with salinities increasing such that the main lake will have a salinity range of 60 to 75 g/L in winter 2014 and 70 to 90 g/L in winter and early spring 2015. Winter freshening from River Murray inputs will be contained to the immediate vicinity of the confluence and the salinity in the main lake will increase year to year reaching > 90 g/L by summer 2014/15.

Salinities in summer 2011/12 will increase across the main lake body such that by April – May 2012 the northern parts of the lake under River Murray influence will be around 35 to 40 g/L whereas south of Point Sturt salinity will range between 35 and 45 g/L, Goolwa channel will be around 50 g/L and the rest of the lake between 40 and 49 g/L with an east-west gradient. The lowest salinity will be in the River Murray channel just upstream of the confluence where salinities will vary between 20 and 25 g/L.

The highest salinities between October 2012 and April 2013 will be in the main lake body with fresher areas in the north under River Murray influence and south of Point Sturt where incoming seawater will provide a ‘freshening’ effect (35 to 40 g/L; see Figure 5.1).

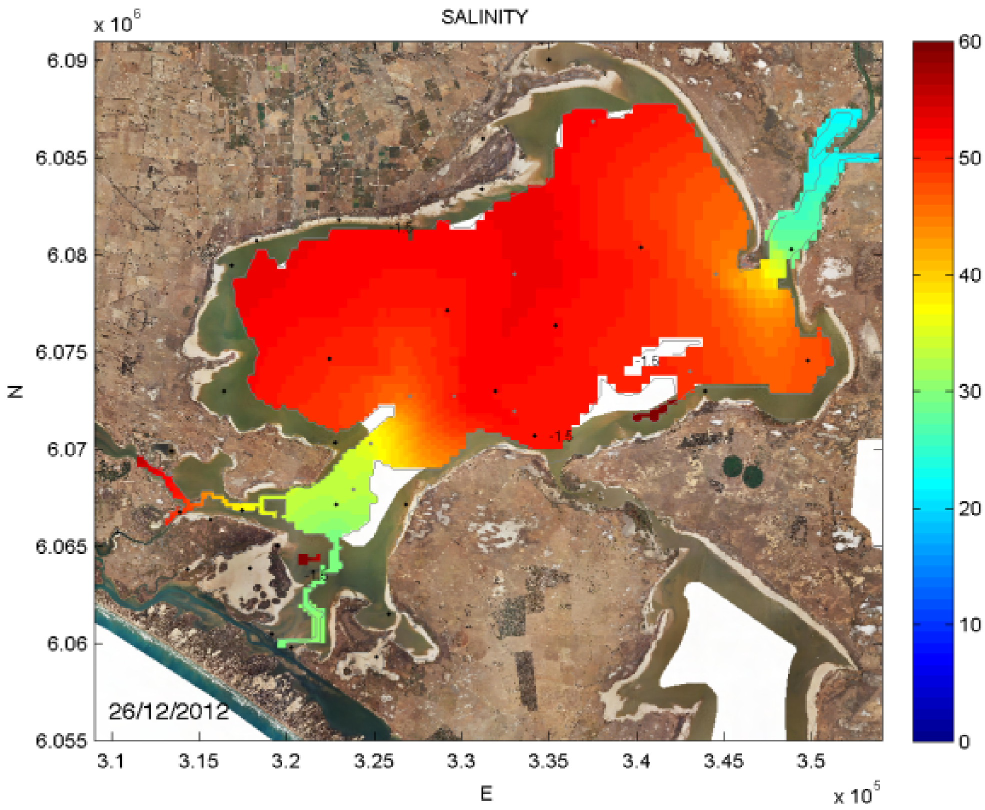


Figure 5.1: Lake Alexandrina Salinity Seawater pumping at December 2012 showing the freshening effect of River Murray water in the north and seawater in the south.

Note that salinities increase beyond this in subsequent years. Scale is in g/L.

The channel connecting Tauwitchere barrages to the lake will drop to 35 g/L, which is typical of seawater concentrations and approximately ten times the salinity concentration in Lake Alexandrina at the beginning of the action period. By the end of April 2013, the area below Point Sturt will increase to 55 g/L while main lake body will be over 55 g/L with some areas up to 67 g/L. A salinity gradient will occur with salinity higher in the western part of the lake. Salinity will be lowest near the River Murray confluence at 35-40 g/L, equivalent to seawater.

In December 2013 the "freshening" effect of seawater will occur again with salinity around Point Sturt dropping to 35 to 40 g/L while the rest of the lake will be 60 to 70 g/L. River Murray inputs will also have a localised freshening effect around the confluence with the lake reducing in salinity to between 40 and 45 g/L at site 60, which is just inside the river channel (see Attachment E). Similar freshening will occur in November 2014 at site 60 (45 to 55 g/L) from River Murray influence and site 64 (40 to 45 g/L from seawater inputs). The rest of the lakes will range from 75 to 90g/L with the majority of sites being above 85 g/L.

By April 2015 the whole lake will be 75 to 97 g/L (approximately 2.7 times seawater concentrations and 33 times the starting concentration in Lake Alexandrina). South of Point Sturt salinity will increase rapidly during April 2015 from 40 to 80 g/L as the 'freshening' effect of seawater ceases and mixing with the main lake body occurs. The River Murray will have little freshening effect and salinities in the confluence will remain between 65 and 70 g/L (approximately 1.8 times seawater and 75 times River Murray water salinities).

Water levels

Water levels in Lake Alexandrina will drop to the target management level (c. -1.3 m AHD) in March 2011 and will then be maintained around this level by seawater inputs. There will be some occasional increases in level from winter inputs but variation will be minimal with regard to improving habitat area. It is assumed that the drop from October 2009 to March 2011 water levels represents a loss of open water habitat of c. 20 - 24% lake area (i.e. 76 - 80% remains).

The opening of the barrages to allow seawater entry will create a hydrological connection between the lakes and the Coorong but at the ECA workshops the experts considered it to be uni-directional (Coorong to Lake Alexandrina). Movement of biota across this connection will be strongly affected by factors such as salinity and pH on either side of the barrages as well as the active movement of water. This uni-directional connectivity during periods of seawater entry was considered unlikely to facilitate life history processes that depend on free, bi-directional movement (e.g. completion of diadromous fish life cycles) or provide migration cues.

pH

Patches of low pH will occur from January to June 2010 in the west and north of Lake Alexandrina. These patches together represent approximately 5% of the lake edge and will persist for less than two weeks at a time. After these events the lake will remain greater than pH of 7 throughout the action period (i.e. to end of March 2015) other than an area < 1% of Lake Alexandrina that will acidify briefly in June 2011.

5.1.2. Primary stressor trends when pumping ceases

Salinity

In the cease pumping scenario, salinity will rapidly rise to > 30 g/L in the channel connecting the lake to Tauwitchere barrage once seawater is introduced in October 2010. By 10th November 2010 the whole area south of Point Sturt will have a salinity > 20 g/L with the very southern areas having salinities of > 30 g/L. A strong salinity gradient will occur from west to east in the main lake body with higher salinity in the west and south of Point Sturt.

In winter 2011, salinity at site 64 (south Point Sturt) will be around 20 g/L whereas the main body of the lake it will be 15-20 g/L with a weaker gradient from west to east (higher in the west) than over summer. This is consistently 5 g/L lower than in the pumping scenario. The lowest salinity in winter 2012 will occur between August-September when salinities in the areas under River Murray influence will drop to 10 g/L (half of that at the same time in the pumping scenario). However, the main lake body will remain at salinities of 30 to 40 g/L (which is very similar to the pumping scenario). There will only be very localised freshening around the River Murray confluence and the fresh river water will not penetrate into the lake. In winter 2013 there will be only very minor freshening in the north-east from River Murray inputs to salinity of around 48 g/L at the confluence gradating to 59 g/L below Point Sturt and in the western parts of Lake Alexandrina.

In summer 2011/12 salinities will increase across the main lake body such that by April – May 2012 the northern parts of the lake under River Murray influence will have salinities of around 30 g/L; Goolwa channel will be around 50 g/L and the rest of the lake will be between 35 and 40 g/L. The River Murray channel just upstream of the confluence will have the lowest salinities of between 15 and 20 g/L. As for the winter periods above, these salinities will be consistently 5 to 10 g/L lower than in the pumping scenario at the same time and places. During December 2012 the highest salinities will be in the main lake body with fresher areas in the north under River Murray influence and south of Point Sturt where incoming seawater will provide a 'freshening' effect (dropping salinities to 37 g/L). Salinity in the channel connecting Tauwitchere Barrages to the lake will drop to 35 g/L, which is typical of seawater concentrations.

By the end of summer 2012/13 (April 2013) the main lake body will be over 60 g/L with areas having salinities > 73 g/L, which is approximately 5 g/L higher than in the pumping scenario. The lowest salinity will occur near the River Murray confluence at 36 g/L, which is the concentration of seawater (similar to pumping). A salinity gradient will be thus occur with the western side of Lake Alexandrina higher. In October 2013 the freshening effect of seawater will occur again with salinity around Point Sturt of approximately 45 g/L whilst the rest of the lake will be between 60 and 70 g/L. River Murray inputs will also have a localised freshening effect in 2013 reducing salinity to 35 to 40 g/L near site 60. In the pumping scenario, the area south of Point Sturt will be 5-10 g/L lower in salinity but the effect of River Murray water will be much less so that the northern parts of the lake (near site 60) will be 5 – 10 g/L greater in the pumping than cease pumping.

The overall summer patterns repeat in both scenarios during summer 2014/15. In the cease-pumping scenario, salinities will be 55 to 65 g/L near sites 60 (River Murray influence) and 64 (seawater influence) while the rest of the lake will range from 85 to > 100 g/L. The majority of sites will be above 95 g/L (November 2014). In April 2015 (Figure 5.2) the main lake body will be 95 to 100 g/L with the area south of Point Sturt having salinities of 80 to 90 g/L and the River Murray confluence ranging from 60 to 70 g/L. These salinities will be 10 g/L higher than pumping in November 2014 but 5-10 g/L lower than pumping in April 2015.

The hydrological modelling outputs in the cease-pumping scenario stop on 09/09/2015 so there was no salinity modelled for the seawater entry in spring 2015. The available model outputs show there will be some localised freshening from River Murray inflows in August-September 2015 (down to 50 to 55 g/L near the confluence) with 5% of the lake under River Murray influence dropping to 70 g/L. The rest of the lakes at that time will be between 80 and 95 g/L. Overall the salinity regime will be very similar (less than 10 g/L difference) whether pumping to Lake Albert ceases or not.

Water levels

Seawater will be first introduced in October 2010. Water levels will be maintained around 100% of the September 2010 lake area until February 2011 when levels will drop to 78% of that baseline area. This will lead to pools around the western end of Lake Alexandrina disconnecting and then drying as well as an overall contraction of the water body. The lake will refill to > 91% of baseline lake area in winter/spring 2011 then drop again to 78% from January to July 2012. This pattern will repeat in 2012. From November 2012 to September 2015, water levels will oscillate between 77 and 80% lake area. There will be no significant differences in water levels between the pumping and cease pumping scenarios.

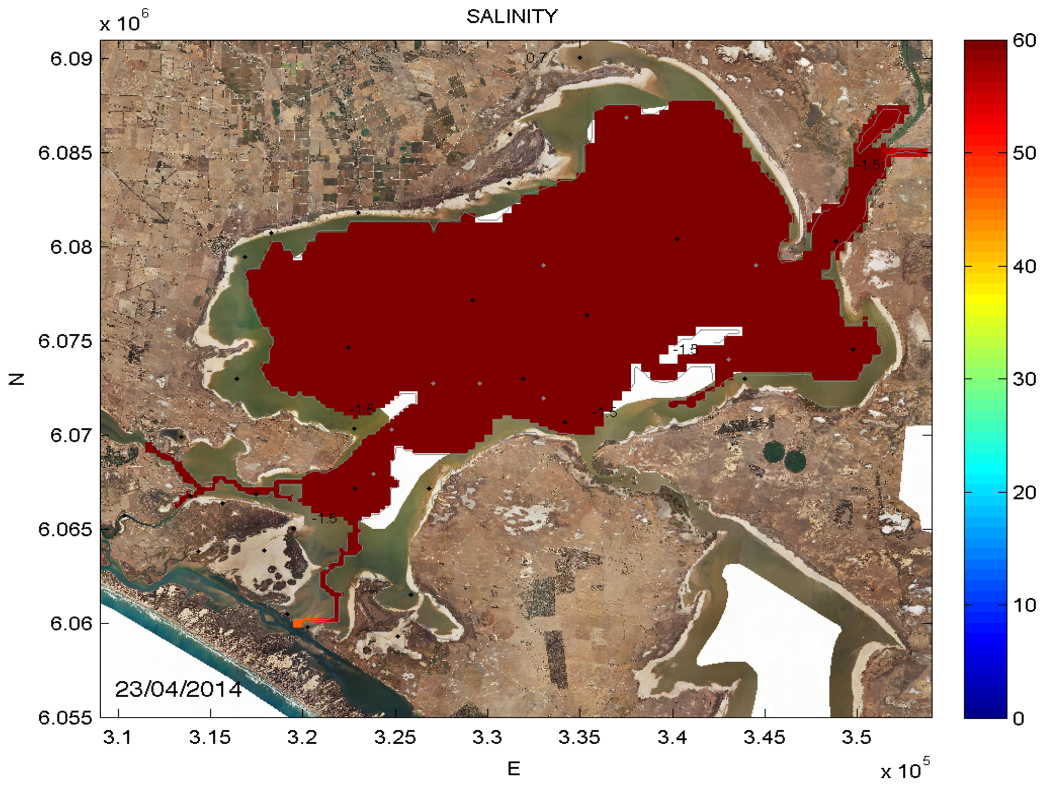


Figure 5.2: Lake Alexandrina salinity in the Seawater cease-pumping scenario at April 2015. Salinities at this time will range from 60 g/L in the south to around 100 g/L but the scale (in g/L) only extends to 60 g/L.

Water level changes will effect not only on the relative areas of inundated habitat but also the connections between various parts of the water bodies. Hydrological connections between the lake and barrages will be retained through Goolwa and Tauwitchere channels until seawater is let in (October 2010). The opening of the barrages to allow seawater entry will create a hydrological connection between the lakes and the Coorong but it was considered to be uni-directional (see above).

pH

Patches of low pH will occur between March and June 2010 in the west and north of Lake Alexandrina. These patches together represent approximately 5% of the lake edge and will persist for less than two weeks at any one time. Small patches of low pH will occur in isolated pools to the north of Goolwa Channel and west of Tauwitchere Barrages in May 2011 and October 2012 (< 1% of Lake Alexandrina). Other than these events the lake water will remain greater than pH of 7 throughout the action period (i.e. to end of March 2015) except for a small-acidified patch on the Polltalloch Plains from November 2014. There will be very minor differences in the timing of these short-lived acidification events between the pumping and cease pumping scenarios but overall the effect will be very similar.

5.1.3. Ecological receptor responses in Lake Alexandrina

Pumping and cease-pumping to Lake Albert

Water levels will be maintained at management levels and no significant acidification events will occur for Lake Alexandrina in the seawater scenario, therefore, salinity will be the key stressor driving ecosystem composition whether pumping to Lake Albert continues or not. In both scenarios, the typical Lake Alexandrina ecological communities will be at a very high risk of mortality from seawater introduction (Figures 5.3 and 5.4). Significant shifts in community composition towards more saline tolerant taxa will occur for all receptor groups within a few months of seawater being introduced for the first time in October 2010. By the end of summer 2011/12 only the most salt-tolerant receptors will persist.

After spring 2013, all remaining Lake Alexandrina receptors will perish except Insect larvae, Small-mouthed hardyhead and the birds that prey upon them (Generalist shorebirds and Fish-eating birds). The main difference between the pumping and cease-pumping scenarios will be that any given resident Lake Alexandrina receptor might persist for a few months longer in the cease-pumping scenario than in the pumping scenatio. Notwithstanding this, by the end of the action period, the overall results will be very similar.

Plankton communities will be highly variable and mixed across time and space as salinities change. Resident Lake Alexandrina plankton will progressively die out by the end of summer 2011/12. Those phytoplankton receptors with the potential to form algal blooms will most likely have an advantage in the salinity regimes induced by seawater introduction. Salinities will be suitable for Estuarine ostracods, Estuarine plankton and Marine plankton for brief and progressive stages between winter 2011 and winter 2014. However, by the end of the action period (March 2015) salinities will have increased to levels only suitable for the most salt tolerant of the Estuarine ostracods and Hypersaline plankton, biota that may not be able to colonise anyway.

In Lake Alexandrina's Ramsar state, River-sourced and Low salinity plankton dominate in varying relative proportions depending on inflow regime (Section 3; Attachment A). At the beginning of the action period, Estuarine plankton were observed in Goolwa channel behind the Clayton regulator (Attachment B) and were assumed to be in Lake Alexandrina, indicating that the site was in poor condition before October 2009. The introduction of seawater, however, will lead to a complete transition in the plankton community from predominately fresh-brackish through estuarine to hypersaline within one year. This does not mean that the net productivity will change but there will be a series of complete transitions in plankton assemblages, which will be likely to significantly alter this fundamental level of the food web. Different plankton may provide a significant source of food for higher trophic levels when present but the increasing salinities and the probable high levels of predation will severely limit their capacity to establish robust populations. The palatability of highly salt-tolerant plankton to fish, birds and other predators is unknown and thus they may not represent a replacement of consumable plankton.

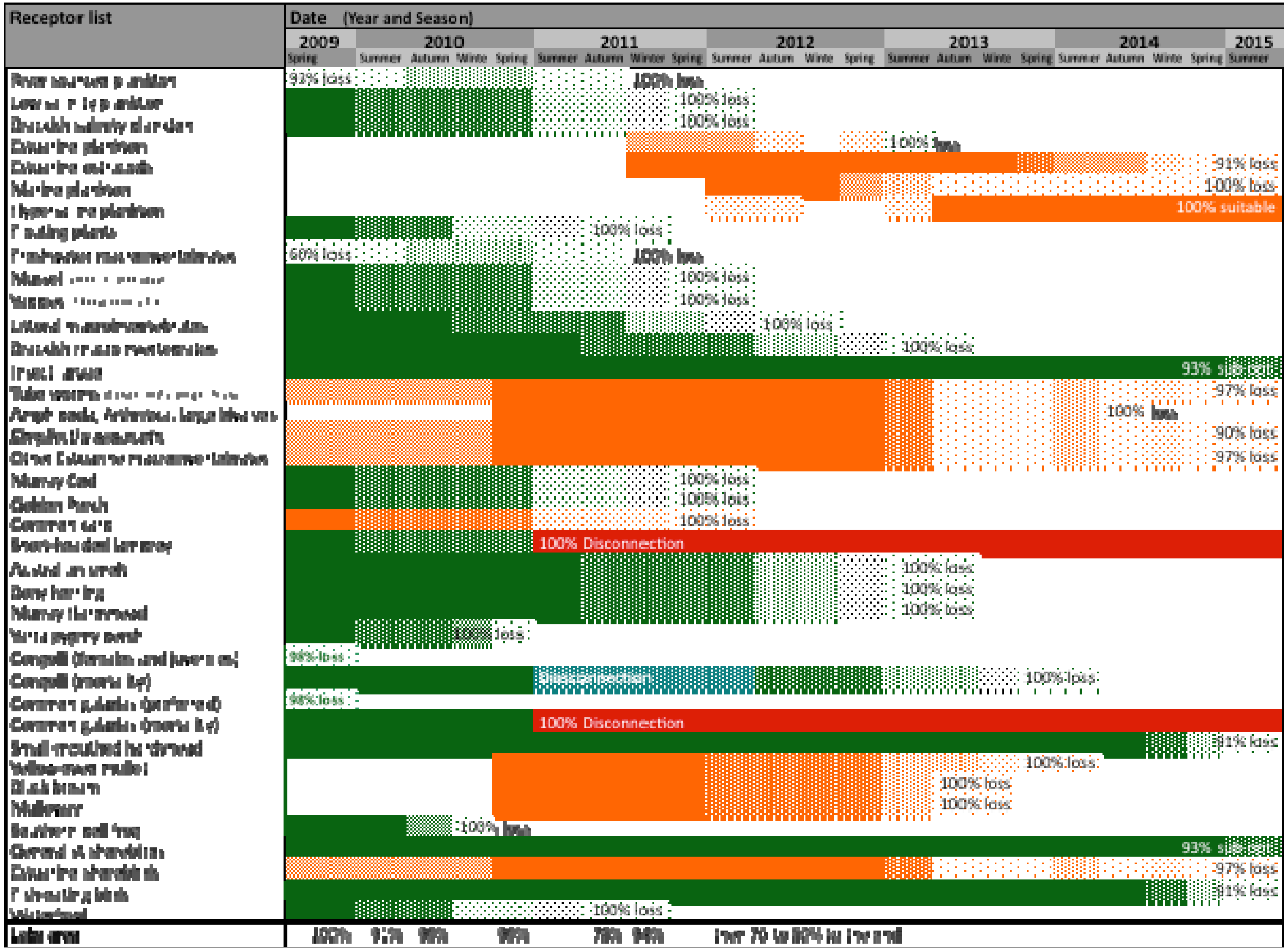


Figure 5.3: Consolidated effects of salinity on receptors under the Seawater Pumping (SW_P) scenario in Lake Alexandrina.

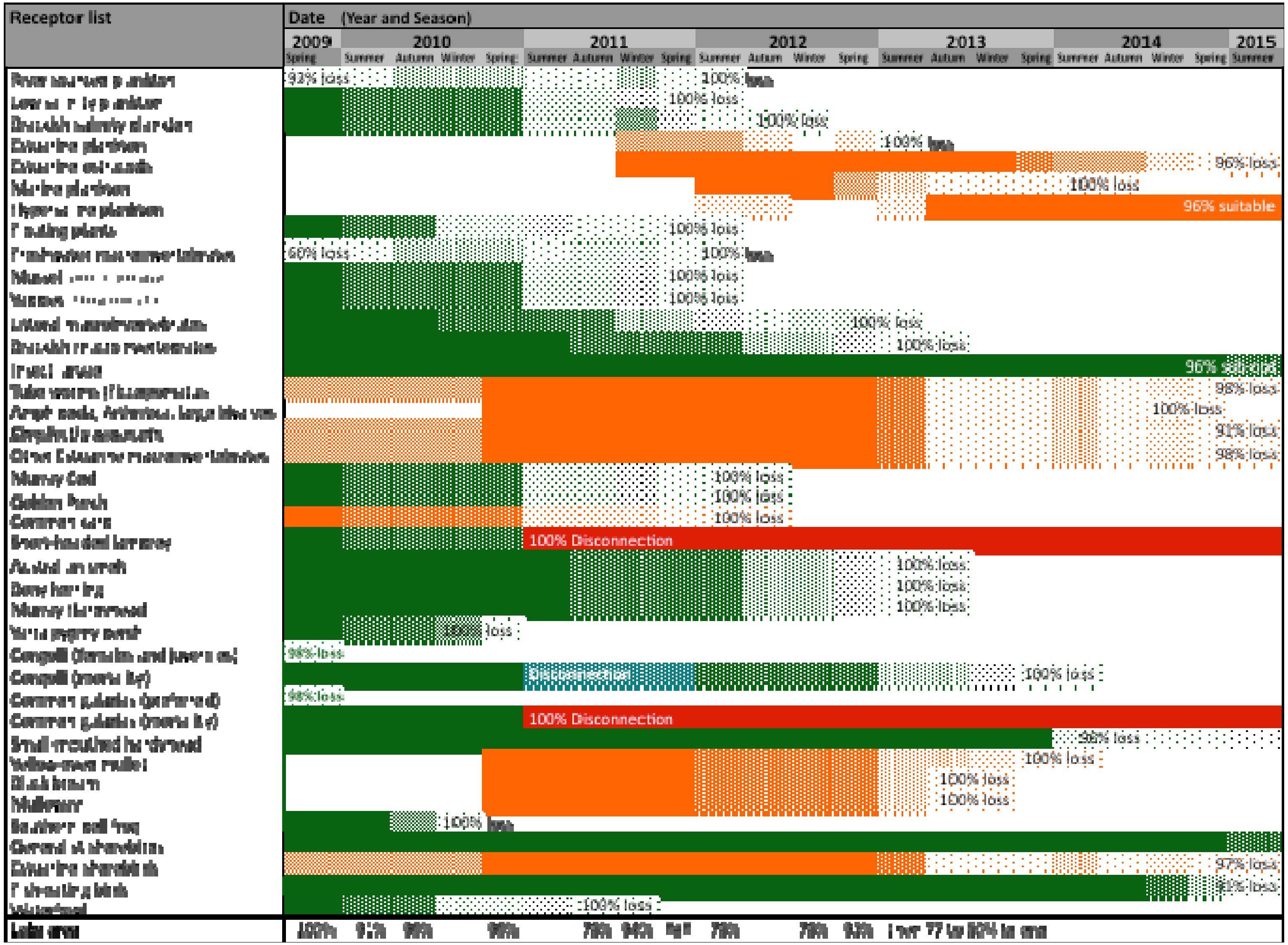


Figure 5.4: Consolidated effects of salinity on receptors under the Seawater Cease-Pumping (SW_CP) scenario in Lake Alexandrina.

The only vegetation remaining in Lake Alexandrina at the beginning of the action period (Floating plants) will be lost to high salinity by winter 2011 and no other vegetation will establish. Conditions will be so transient that estuarine vegetation communities are considered unlikely to establish. Seagrasses are not predicted to establish due to very poor germination and colonisation potential even if conditions will be more stable and suitable (Nicol ECA workshops). Similarly, the majority of the Lacustrine macroinvertebrates will be lost or significantly reduced within months of the seawater entering the lake.

Salinity concentrations induced by seawater introduction will be suitable for proliferation and/or survival of the reef forming Tubeworms (Ficopomatus enigmaticus) from 2010 until 2013, which will increase the pressure on already stressed organisms upon which they grow (e.g. freshwater turtles) during that period. Salinities at those times will also be suitable for colonisation by Estuarine macroinvertebrates that might enter the lake with seawater. Greater than 97% of all of the Estuarine macroinvertebrates will be lost due to salinities greater than their thresholds by the end of the action period, therefore any that may establish will perish. It is likely that larvae will be the major life stage being transported into Lake Alexandrina with the seawater and given that larvae are thought to be not as well protected from physical and chemical damage as adults (Dittmann ECA workshop participant), they may suffer substantial losses entering the lakes. As stated in the methods recruitment of estuarine and marine species under the two seawater scenarios was not assessed, therefore, the assessment of positive effects was confined to determining whether the lake habitats will be suitable for adults rather than for self-supporting populations.

If the timing of seawater introduction were to be different (i.e. occurring in winter rather than summer in the current proposal) the sediments upstream of the barrages would be most likely inundated and thus colonisation and survival could be markedly different from that predicted here, particularly for receptors such as Simpliesta aequisetis, Capitella sp. and Nephtys australiensis that are strongly controlled by water level. However, the salinity in the lake will increase to greater than the Estuarine macroinvertebrates' thresholds so the timing of seawater delivery may not be as consequential as it might be if salinities were lower and successful colonisation of Lake Alexandrina by Estuarine macroinvertebrates was more likely.

All the fish representative of the Ramsar-state for Lake Alexandrina perish from increasing salinity. Given that the Wellington weir will be in place, escape to the River Murray could only partially be facilitated through the fishways and thus potential for avoidance was low. Aggregation around the fishway was considered likely (Bice and Zampatti ECA workshops), which will most likely make the fish more susceptible to predation by Fish-eating birds and other predators. However even if the Wellington weir were not in place and river access could be optimised, it is likely that seawater will still cause a loss of at least some fish from the lakes given that the seawater entry point is 30 km from the river confluence (a considerable distance for smaller or less mobile fish) and salinities will rise so rapidly. Thus exposure to lethal (or sub-lethal but damaging) salinity concentrations, whilst trying to escape, is highly likely.

For estuarine or marine fish that enter in October 2010 with the first introduction of seawater (Yellow-eyed mullet, Black bream and Mulloway), the salinity regime will improve such that the best times for estuarine and marine species will be spring 2010 and spring 2012. However, salinities will rapidly rise to higher than their thresholds during summer 2012/13 and thus they will perish. Conditions for estuarine and marine fish will be generally more favourable in the Coorong than Lake Alexandrina therefore if the fish has a choice it will avoid the high salinity water, and either not enter the lakes and remain on the downstream side of the barrages or exit when the barrages are open albeit against the flow. Therefore it was predicted that overall there will be an initial increase in suitable habitat for estuarine and marine receptors in Lake Alexandrina but establishment will not occur because salinities will continue to rise beyond their thresholds.

5.2. Lake Albert under the Seawater scenario

5.2.1. Primary stressor trends when pumping

Salinity

Salinities in Lake Albert in October 2009 were modelled as greater than 8 g/L across 98.4% of the main lake with only Narrung Narrows being fresher. By the end of the reliable salinity modelling (October 2012), salinities in Lake Albert will be greater than 95 g/L the majority of the lake, greater than 110 g/L in 16% of the lake (central and south) and up to 115 g/L (which is approximately 3.2 times seawater) in a small patch around site 38. At this time the modelling ceased to be reliable. Thus no predictions were provided for 2013 and beyond (Wainwright and Hipsey, 2010 p. 101).

The increases in salinity during the action period will be rapid. By January 2010, 95% of the lake will have salinities greater than 20 g/L. Pumping Lake Alexandrina water in from Lake Alexandrina will freshen the northern parts of Lake Albert and set up a north-south salinity gradient ranging from 5 to 30 g/L in March 2010 (with higher salinities in the south). Over winter the salinity will become more homogenous although a gradient will persist, ranging between 12 and 20 g/L across the main lake body.

The north-south gradient will strengthen in summer 2010/11 with the southern portion of the lake exceeding 35 g/L from February 2011. Salinity across the main lake will then increase to greater than 40 g/L in the southern areas in March 2011. Winter freshening will occur again in 2011 but salinity will remain above 30 g/L for most of the main lake body and between 15 and 20 g/L in Narrung Narrows. From October 2011, salinity will rapidly increase so that by April 2012 the main lake body will have concentrations ranging from 70 to 94 g/L. There will be a minor freshening in Winter 2012 but the main lake body will still have salinities in the order of 75 g/L.

The maximum salinities will be > 110 g/L across 16% of Lake Albert and > 115 g/L in the southern parts of the lake in October 2012 (Figure 5.5). The failure of the model in October 2012 will make direct comparisons with other scenarios more difficult than if modelling was reliable until the end of the action period but given that salinities in late 2012 will be approximately 14 times greater than at the beginning and 3 times seawater concentration, the ecological effects from high salinity will be so catastrophic that all the Lake Albert receptors will perish. Thus the differing periods of modelling reliability was of little consequence to assessing the ecological effects of seawater introduction.

Water levels

Water levels in Lake Albert will be maintained near the management level of c. -0.5 mAHD throughout the action period from seawater inputs to Lake Alexandrina and pumping from Lake Alexandrina to Lake Albert.

pH

Lake Albert will not be affected by acidification because pH will stay above 6.5 throughout the action period due to maintenance of water levels by pumping of water from Lake Alexandrina.

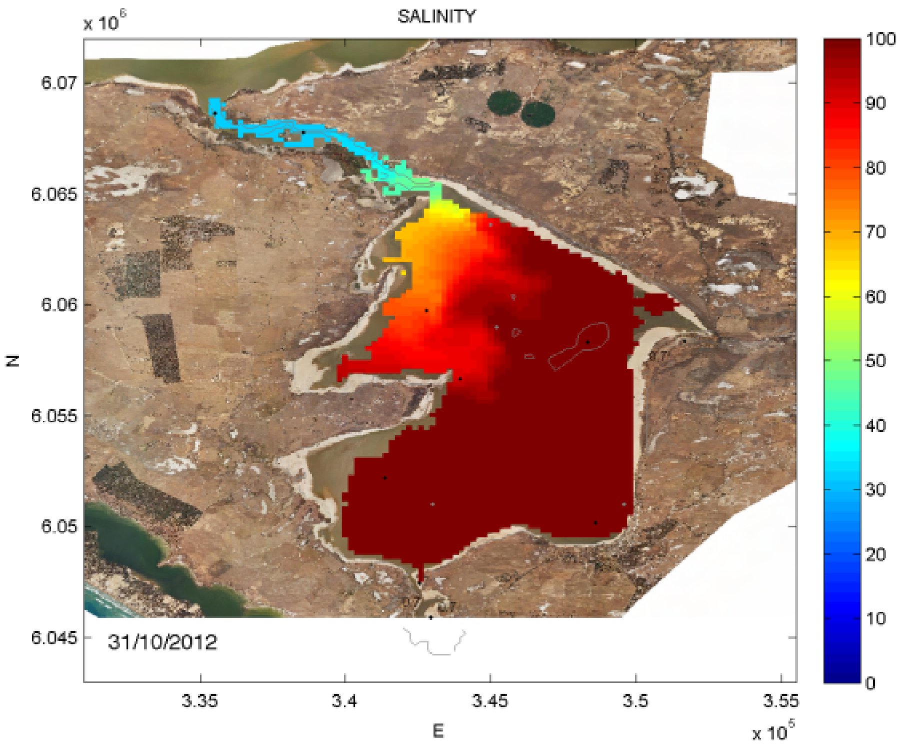


Figure 5.5: Lake Albert salinity in the Seawater-pumping scenario at October 2012. Note scale is in g/L and extends to 100 g/L. The Narrung Narrows will be fresher at this time.

5.2.2. Primary stressor trends when pumping ceases

Salinity

Concentrations in the main lake started slightly lower in the cease-pumping scenario (> 5 but < 8 g/L) than in the pumping scenario (> 8 but < 10 g/L) but in both cases, starting concentrations were lower in the Narrung Narrows.

In the cease-pumping scenario, a gradient across the lake from 10 g/L in the north to 35 g/L in the south will occur between January and April 2010. Over winter 2010 there will be a freshening back to between 8 and 25 g/L, again with a north-south gradient. The next summer (2010/11) when pumping ceases, salinity will rapidly rise from around 35 g/L in December 2010 to greater than 180 g/L in April 2011 (approximately 5 times seawater concentration).

Rainfall in winter 2011 will lead to a dilution back to 100 g/L from June to August but then salinity will increase to 180 g/L in November 2011 after which the lake will dry. Narrung Narrows will typically be less saline than the main lake but will still reach 152 g/L before the lake dries (approximately 4.2 times seawater concentration).

Salinity modelling was unreliable after October 2012 in the pumping scenario. During that time salinities increased markedly from the baseline in the pumping scenario but did not increase to the same level as predicted in the cease-pumping scenario. In winter 2010, the salinities will be very similar in the two scenarios but will diverge after October 2010 when pumping ceases in the cease-pump scenario. For example, in the cease-pumping scenario, the salinity will rise rapidly to 180 g/L by April 2011 and only drop back to 100 g/L in winter 2011. Whereas in the pumping scenario, salinities will be around 40 g/L in March 2011 and drop back to 15-20 g/L in winter 2011. This represents a 4 to 5-fold increase in salinity when pumping ceases across the same time period.

By the end of the reliable modelling the salinity in Lake Albert in the pumping scenario will be in the order of 70 g/L with patches over 110 g/L (16% of Lake Albert). It is not known what concentration would be reached by the end of the action period (March 2015) if reliable outputs for that time were provided. Regardless, the salinity regime in the cease-pumping scenario in Lake Albert will be very hostile within 15 months of pump cessation.

Water levels

When pumping to Lake Albert continues, water levels will be maintained between 76% and 98% of the baseline throughout the action period. By contrast when pumping to Lake Albert ceases in October 2010, the water level will drop very quickly so that by April 2011 lake area will be only 27% of the baseline. After a brief winter recovery to 44% of the baseline in June 2011, water levels will decline to 10% by December 2011 and 0.2% by March 2012 at which time the lake will be essentially dry. This shows that pumping water from Lake Alexandrina is essential to the persistence of any surface water in Lake Albert.

pH

At the beginning of the study period, pH was > 7 across the whole of the lake. When pumping ceases (October 2010) the lake begins to contract and by February 2011, pH starts to drop in the south-western corner of Lake Albert. The acidification will spread across the main body of the lake so that by early March 2011 all but the Narrung Narrows will have a pH < 5. By April 2011 the entire main body of the lake will have a pH of around 4 and the Narrung Narrows will be beginning to acidify (Figure 5.6). In winter 2011, pH increases to between 5.3 and 6.9 across the whole lake but in spring 2011 the main lake body begins to contract and pH drops. By the end of October 2011, the lake and the Narrung Narrows will have disconnected and the remaining water will have pH of 4 to 5. The drying continues so that from November 2011 pH will be < 3.5 across the remaining water body. The lake will be completely dry by early April 2012. By contrast, in the pumping scenario there will be no significant acidification events, suggesting that provision of water to Lake Albert is essential if acidification is to be avoided.

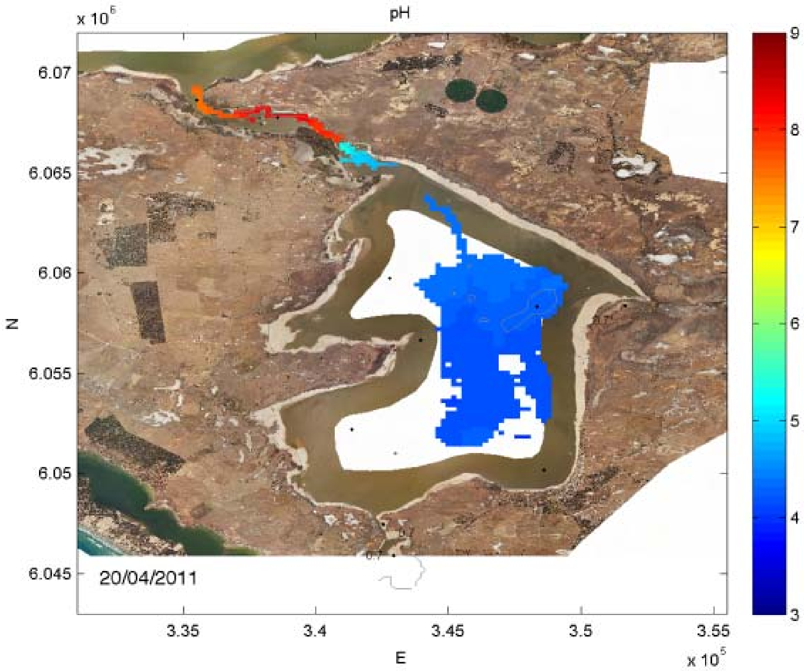


Figure 5.6: Lake Albert pH in the Seawater cease-pumping scenario at April 2011. Note that the water remaining in the main lake is acidic (blue) but Narrung Narrows is not at this time (red).

5.2.3. Ecological receptor responses in Lake Albert

Pumping

When pumping to Lake Albert continues, water levels and acidification will not be significant stressors thus salinity will be the key driver of ecosystem composition. Salinities will rapidly increase to concentrations that will be progressively too high for all resident Lake Albert receptors by the end of the action period (Figure 5.7). The most salt sensitive taxa will be lost by the end of summer 2009/10. Murray cod, Golden perch, Common carp and Short-headed lamprey ammocoetes will perish in summer 2010/11 as will the

Brackish plankton, Mussels and Littoral macroinvertebrates. The more salt-tolerant Lake Albert residents will progressively die out during 2012. Colonisation of Lake Albert by receptors with higher salinity tolerances (i.e. Estuarine, Marine and Hypersaline plankton and Estuarine macroinvertebrates) will be unlikely but even if they do enter the lake they will be lost to high salinities across at least 92% of the lake in spring 2012 when the salinity modelling became unreliable. At the end of the reliable salinity modelling (October 2012), the only receptors expected to remain in Lake Albert will be some Small-mouthed hardyhead and Insect larvae as well as the Fish-eating birds and Generalist shorebirds that feed upon them. All other receptors, whether they are resident or more salt-tolerant colonisers, will have most likely perished.

Cease-pumping

If pumping to Lake Albert ceases under the seawater scenario, complete ecological collapse was predicted to occur from the combined effects of high salinity, low pH and lake drying. Salinity will be too high for most Lake Albert receptors by spring 2010 and for all the resident Lake Albert receptors by autumn 2011 (Figure 5.8). Widespread acidification will begin in summer 2010/11 covering first the southern 25% and then moving north to cover the whole lake by autumn 2011 at which time only 27% of the lake area remains. The lake will dry completely resulting in loss of all aquatic habitat during summer 2011/12.

5.3. Murray Mouth and Coorong under the Seawater scenario

5.3.1. Primary stressor trends

The modelling outputs show that introducing seawater to Lake Alexandrina via the Murray Mouth and Tauwitchere barrages has only a minor effect on salinities in the Murray Mouth area and the Coorong against the very high (hypermarine) background concentrations. In the Murray Mouth, salinities will change by less than 8 g/L when seawater is introduced. The Murray Mouth and sites 4 and 5 (Attachment E) in the North Lagoon will maintain salinities of 25-50 g/L at all times. In North Lagoon the change will vary across the sites but will not be more than 14 g/L at any site (range 50 -150 g/L) and in the South Lagoon the change will be even smaller (up to 4 g/L) against a background salinity of > 150 g/L.

Water levels on the sea-side of the barrages will decrease during the periods that the barrages are open to let seawater into Lake Alexandrina (spring and summer each year from October 2010). This will lead to drying out of sediments. Water levels will be most variable in the Murray Mouth and North Lagoon regions. The TU-FLOWS model runs provided for the Murray Mouth and Coorong did not contain predictions for any parameters other than water levels and salinity.

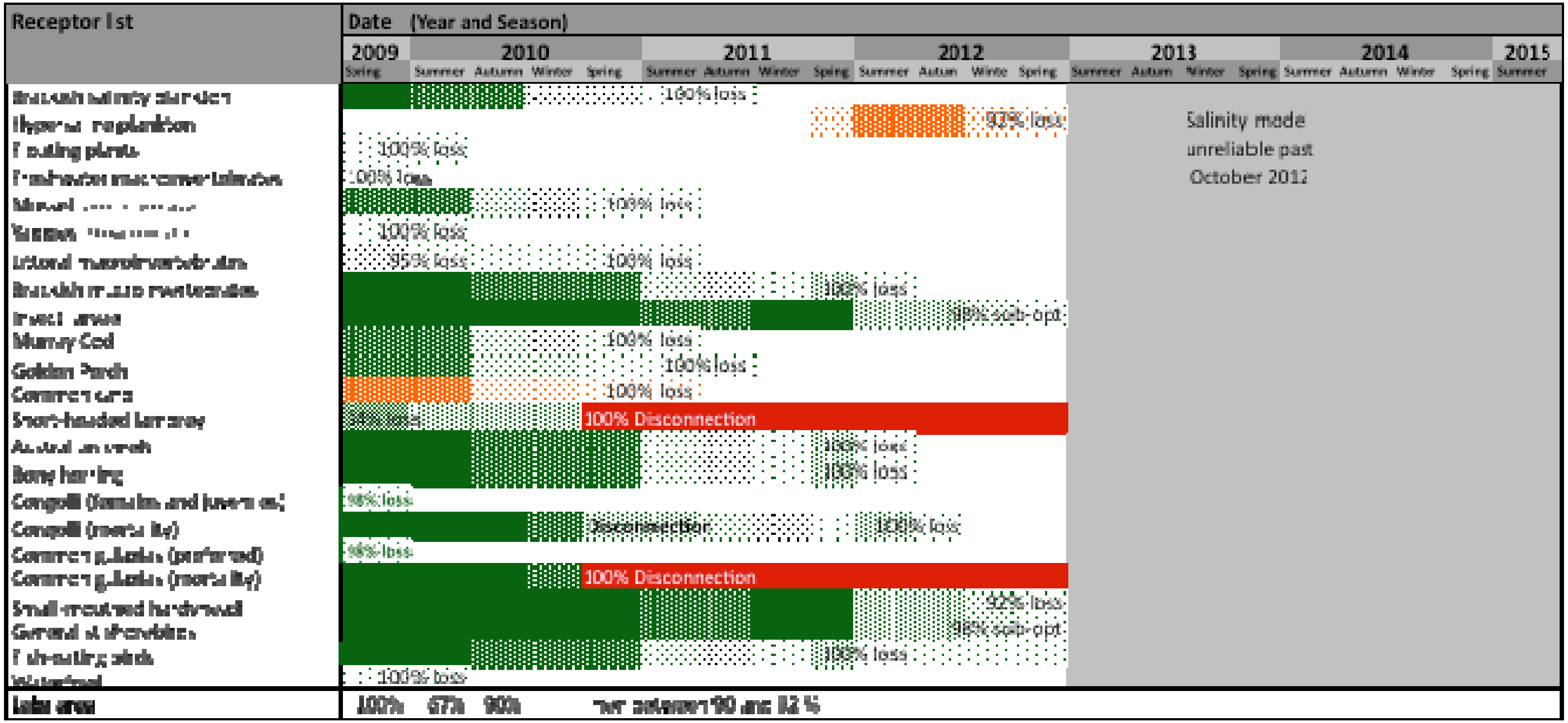


Figure 5.7: Consolidated effects of salinity and water levels on receptors under the Seawater Pumping (SW_P) scenario in Lake Albert.

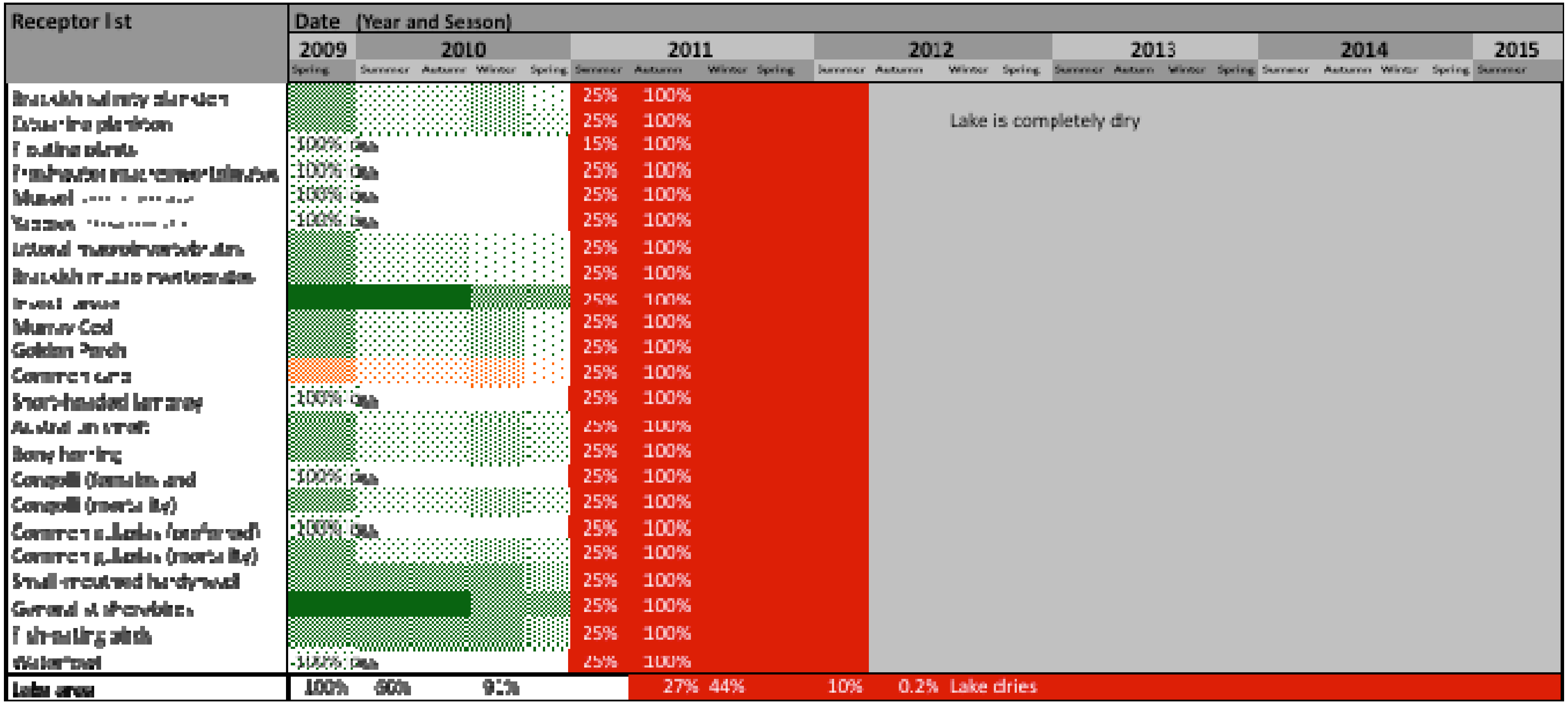


Figure 5.8: Consolidated effects of salinity, pH and water levels on receptors under the Seawater Cease-Pumping (SW_CP) scenario in Lake Albert.

5.3.2. Ecological receptor responses

Murray Mouth

It is unlikely that plankton communities in the Murray Mouth area or the Coorong will be significantly affected. The small decrease in salinity concentration in the Coorong may be enough to increase growth of Enteromorpha spp. in parts of the North Lagoon in April each year, and almost all of the South Lagoon during the period the South Lagoon Salinity Reduction Scheme is operating (June 2010 – June 2013). This growth and the small drop in water level (3-4 cm) may have a minor adverse effect on Ruppia spp. if the mudflats are prematurely exposed.

All Estuarine macroinvertebrates (except Insect larvae) will be lost across most of the Murray Mouth area from January to March annually due to hypermarine conditions. Mundoo Channel populations may survive the annual spikes in salinity and act as refuge populations. Water level drawdown during seawater introduction may also threaten populations of Estuarine macroinvertebrates on the sea-side of the barrages. Boccardiella limnicola may take advantage of periods with salinities between 50-60 g/L by colonising empty Ficopomatus enigmaticus tubes but overall there will be very low diversity.

The loss of Capitella spp. will be catastrophic given that they will have been providing the main food source for higher trophic levels as well as the main benthic activity that will be maintaining soil quality. Annual periods of drying out in the Murray Mouth and North Lagoon areas (December to March) will result from water level variation under the Seawater scenarios, leading to a boom-bust sequence. Opportunities for growth and colonisation will occur in winter, but mortality will occur in summer each year. These effects will compound over the years.

In addition, the drying of sediments over summer from water level fluctuations will affect juvenile Estuarine macroinvertebrate survivorship. It is not known whether recruitment occurs through the Murray Mouth or if it is an internal process within the Coorong therefore this is identified as a major knowledge gap. It is not known how much of this water level effect may be due to the South Lagoon Salinity Reduction Scheme as opposed to the action of introducing seawater.

North and South Lagoon

The combination of high salinities and low water levels will lead to loss of all Estuarine macroinvertebrates in August 2009 except for Insect larvae. The rate of change in salinities will be greater than what has been observed under typical conditions since regulation of the River Murray. Introduction of seawater will not directly lead to changes in the fish or bird populations. However, the extensive losses of Estuarine macroinvertebrates will lead to major food shortages for fish and birds and thus major adverse effects are likely.

The effect of cease-pumping to Lake Albert

Ceasing to pump to Lake Albert will have a positive effect on Estuarine macroinvertebrates in the Murray Mouth region by reducing the habitat areas adversely affected by high salinity from 80% to 65%. However, at a population scale this salinity benefit may be offset by the increased loss from desiccation as their habitat dries through reduced water levels further into the North Lagoon of the Coorong when pumping to Lake Albert ceased. Ceasing to pump to Lake Albert did not have any significant effect on Ruppia tuberosa in the Coorong. The experts did not assess any other ecological effects in the Murray Mouth and Coorong under either the pumping or cease-pumping seawater scenarios at the ECA workshops.

5.4. Conclusions for the seawater-pumping scenario

Lake Alexandrina

In Lake Alexandrina under both the pumping and cease-pumping seawater scenarios, salinity will be the major driver of a series of ecological changes through brackish-estuarine, then marine and finally hypersaline salinity conditions. This will result in mixed and depauperate assemblages in Lake Alexandrina over space and time rather than promote establishment of a healthy, resilient estuarine-marine ecosystem.

Importantly, despite the occurrence of salinities within the estuarine range across the majority of the lake between spring 2010 and spring 2012, the very poor condition of the former estuary below the barrages at the beginning of the action period will severely limit establishment of estuarine taxa in Lake Alexandrina. However, even if estuarine-marine organisms could colonise Lake Alexandrina during that period they will be lost to on-going salinisation. The only receptors likely to be abundant in Lake Alexandrina at the end of the action period are Hypersaline plankton and Insect larvae, with Generalist shorebirds likely to remain to prey on the Insect larvae. Very small populations of Estuarine macroinvertebrates may persist if indeed they can establish and Small-mouthed hardyhead may also persist although they will experience almost complete loss of habitat and food. Overall, the receptors typical of the Lake Alexandrina ecosystem will perish under the seawater scenario regardless of whether pumping to Lake Albert ceases or not and a healthy replacement ecosystem will not form.

Lake Albert

If pumping to Lake Albert continues, water levels will be maintained and acidification will not occur. However, salinities will rapidly increase and cause the progressive loss of all resident Lake Albert receptors by the end of the action period except for Small-mouthed hardyhead, Insect larvae and some predatory birds. It is highly unlikely that other more salt-tolerant taxa will establish a new, complex ecosystem.

If pumping ceases, complete ecological collapse will occur from the catastrophic cascade of increasing salinity, acidification and then drying of the lake.

Murray Mouth and Coorong

Introduction of seawater will not induce salinity driven changes in the ecology of the Murray Mouth and Coorong because the increase in salinity resulting from the action will be ecologically insignificant compared to the already high salt concentrations. However, there will be consequences to the Coorong ecosystem associated with introduction of seawater in the longer term such as further increasing salt load and decreased opportunities to release freshwater from the lakes to the Coorong through the barrages.

From an ecological perspective, letting seawater in during winter would be preferable to the current proposal to let seawater in during spring/summer. Introducing seawater to Lake Alexandrina in spring/summer is the worst timing for Estuarine macroinvertebrates because of rapid drying of sediments on the sea-side of the barrages when submergence is critical. Sediment drying will most likely be less severe if seawater is introduced in winter because productivity is not expected to be as high in winter compared to summer and juvenile survivorship will be higher. Before a recommendation on timing of seawater introduction is made on ecological grounds, there is a need to better understand the effects of winter introduction of seawater on over-wintering migratory birds. If it is feasible to introduce seawater in winter rather than summer, the consequence assessment for Estuarine macroinvertebrates and many other receptors downstream of the barrages may be very different.

6. Freshwater scenario in Lakes Alexandrina and Albert: primary stressor trends and receptor effects.

In the Freshwater scenario, freshwater will be sourced from the River Murray in the north of Lake Alexandrina. The trends in the primary stressors: salinity, water levels (lake area) and pH are presented below followed by the receptor responses to those stressor trends. Copies of the consequence scoring sheets appear in Attachment D grouped under scenario and lake.

6.1. Lake Alexandrina under the Freshwater scenario

6.1.1. Primary stressor trends when pumping to Lake Albert

Salinity

Salinity of Lake Alexandrina at the beginning of the action period (October 2009) was greater than 3 g/L across 95% of lake but was less than 3 g/L near the river confluence (e.g. Site 60 below Wellington). In the model outputs, the lake is well mixed in winter and generally in the order of 3 to 5 g/L with the lowest concentrations in the north near the River Murray confluence. Each summer, salinities will increase particularly in the southern parts of the lake so that a gradient will establish with the area south of Point Sturt being the saltiest, the western quarter being slightly less salty and the northern-eastern-central areas being the least salty (Figure 6.1a). Summer salinities will range from 5 to 7 g/L in the main lake body to around 8 g/L south of Point Sturt and > 10 g/L in Goolwa Channel.

Water levels

Water levels will drop to the management level (approximately -1.3 m AHD) in March 2011 in Lake Alexandrina. There will be an annual loss of around 24% of lake area in March/April each year (compared to October 2009) before recovery in late winter/spring to around 92% of baseline area when River Murray flows occur. Winter recovery will be minimal with regard to improving habitat area and will not facilitate improved connectivity.

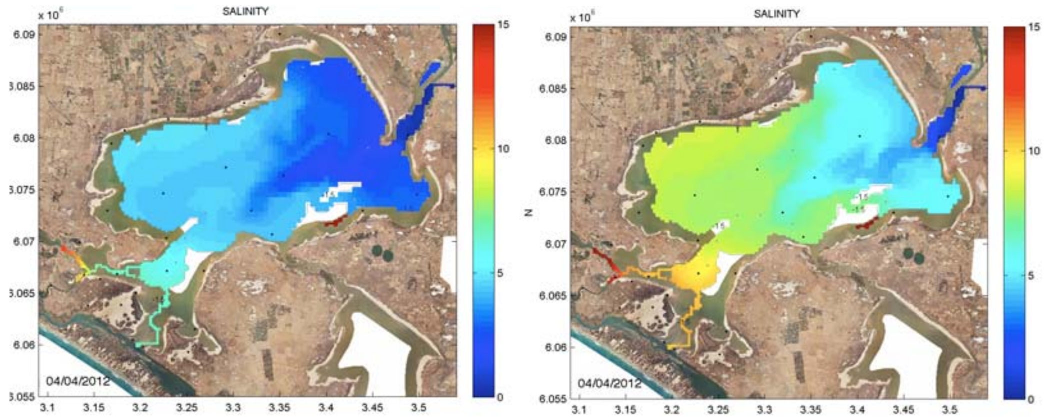
pH

Less than 1% of Lake Alexandrina area will be affected by low pH and only for a week or two at a time. This was not considered to be ecologically significant and thus acidification was not considered a stressor in Lake Alexandrina in this scenario.

6.1.2. Primary stressor trends when pumping ceases

Salinity

Starting concentrations and the overall trends in salinity in Lake Alexandrina will be similar in the pumping and cease-pumping scenarios. The salinity will be generally 2-5 g/L higher in the cease-pumping scenario in any one location or time. For example in April 2012, salinities in the main lake will be 5 to 7.5 g/L in the cease-pumping compared with 3 to 5 g/L in the pumping scenario (Figure 6.1 a and b). The maximum salinities (south of Point Sturt) will be 14.5 g/L (4.3% of Lake Alexandrina, March 2015) in the cease-pumping and 8 g/L in pumping scenario (0.9% Lake Alexandrina, February 2010).



(a) (b)

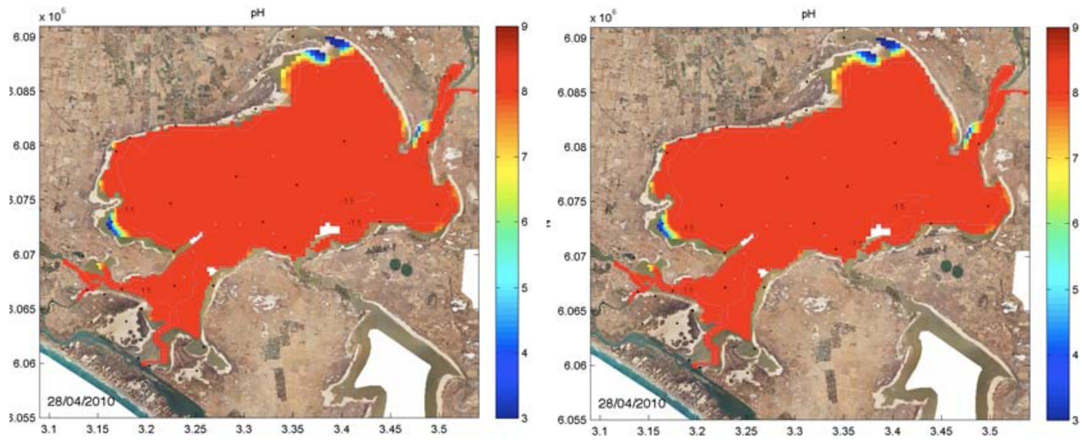
Figure 6.1: Lake Alexandrina salinity in the Freshwater pumping (a) and cease-pumping (b) scenarios at April 2012. Note that salinity patterns will be similar but salinities will be higher in the cease-pumping than the pumping scenario.

Water levels

Water levels in Lake Alexandrina will be effectively the same regardless of whether pumping to Lake Albert ceased or not, differing by 1% or less of lake area within any comparative season, because the model will demand as much River Murray water as needed to maintain the target level in Lake Alexandrina. Water levels will drop to the management level
(c. -1.3 m AHD) in March 2011 and will show an annual cyclical loss of around 24 % of lake area in March/April of each year (compared to October 2009).

pH

There will be no difference in pH effects between the pumping and cease-pumping scenarios. The acidic patches will occur in approximately the same places (north-western and western fringes) for approximately the same periods of time (Figure 6.2). In both cases the effects of low pH will be negligible for all receptors except for Lacustrine macroinvertebrates. For these receptors up to 5-10% of habitat may have been affected which the experts considered minor to insignificant in terms of population effect.



(a) (b)

Figure 6.2: Lake Alexandrina pH in the pumping (a) and cease-pumping (b) scenarios at April 2010. Note that the acidic patches (blue) are very similar.

6.1.3. Ecological receptor responses in Lake Alexandrina

Pumping

Water levels will be maintained at management targets and no significant acidification events will occur in Lake Alexandrina, therefore, salinity will be the primary driver of community composition. Salinities will be suitable to support communities typical of low River Murray inflow periods such as those that occurred at the October 2009 baseline (Figure 6.3). River-sourced plankton will have sporadic periods of suitable salinities in the northern parts of Lake Alexandrina when and where it is under the immediate influence of River Murray inflows. Low salinity plankton (typical Lake Alexandrina plankton) will increasingly dominate Lake Alexandrina with salinities becoming too low for Brackish plankton (usually found in the more saline Lake Albert) in spring 2012.

Freshwater macroinvertebrates start of with 60% of their habitat unsuitable and this will rapidly rise to 91% by the end of summer 2009/10 with only short-lived increases in suitable habitat during winter freshes. Southern bell frog will be lost in summer 2011/12 but considering that it was only found at one southern location in October 2009 (Mundoo Channel) the lake was assumed to not be optimal habitat from the start. Salinities will not exceed the thresholds of any of the other Ramsar receptors present in Lake Alexandrina, although many will be adversely affected by the losses of fauna such as Freshwater macroinvertebrates.

The invasive tubeworm (Ficopomatus enigmaticus) will be unlikely to proliferate and may reduce in cover over time as will other Estuarine macroinvertebrates that colonised Lake Alexandrina since the salinities increased above the Limit of Acceptable Change for salinity (i.e. 700 EC in Phillips and Muller 2006). This represents a shift towards the freshwater Ramsar State in which Estuarine macroinvertebrates would only occur downstream of the barrages. Since 2009 the Murray Mouth estuary has been too saline for many Estuarine macroinvertebrates (Attachment B). If Lake Alexandrina freshens and the barrages remain closed areas then the Murray Mouth will remain saline, estuarine salinity concentrations will not occur anywhere and Estuarine macroinvertebrates will not be able to persist at the site (i.e. lakes will be too fresh and Murray Mouth region will be too saline).

Cease-Pumping

The salinity regime in Lake Alexandrina will be marginally more saline if pumping to Lake Albert ceases presumably because less River Murray will be drawn through it, which will affect the most salt-sensitive receptors (Figure 6.4). For some receptors such as plankton there will be little overall effect although there may be shifts in community compositions within the receptor groups. From summer 2011/12 onwards, salinities will be less suitable for Floating plants, Mussels, Yabbies, Yarra pygmy perch and Southern bell frog across greater areas of Lake Alexandrina if pumping to Lake Albert ceases. Murray cod, Golden perch, Common carp and Short-headed lamprey ammocoetes will be likely to experience greater salinity-induced stress but salinities remain lower than their thresholds. As a result the only bird receptor likely to be affected by ceasing to pump to Lake Albert will be Waterfowl.

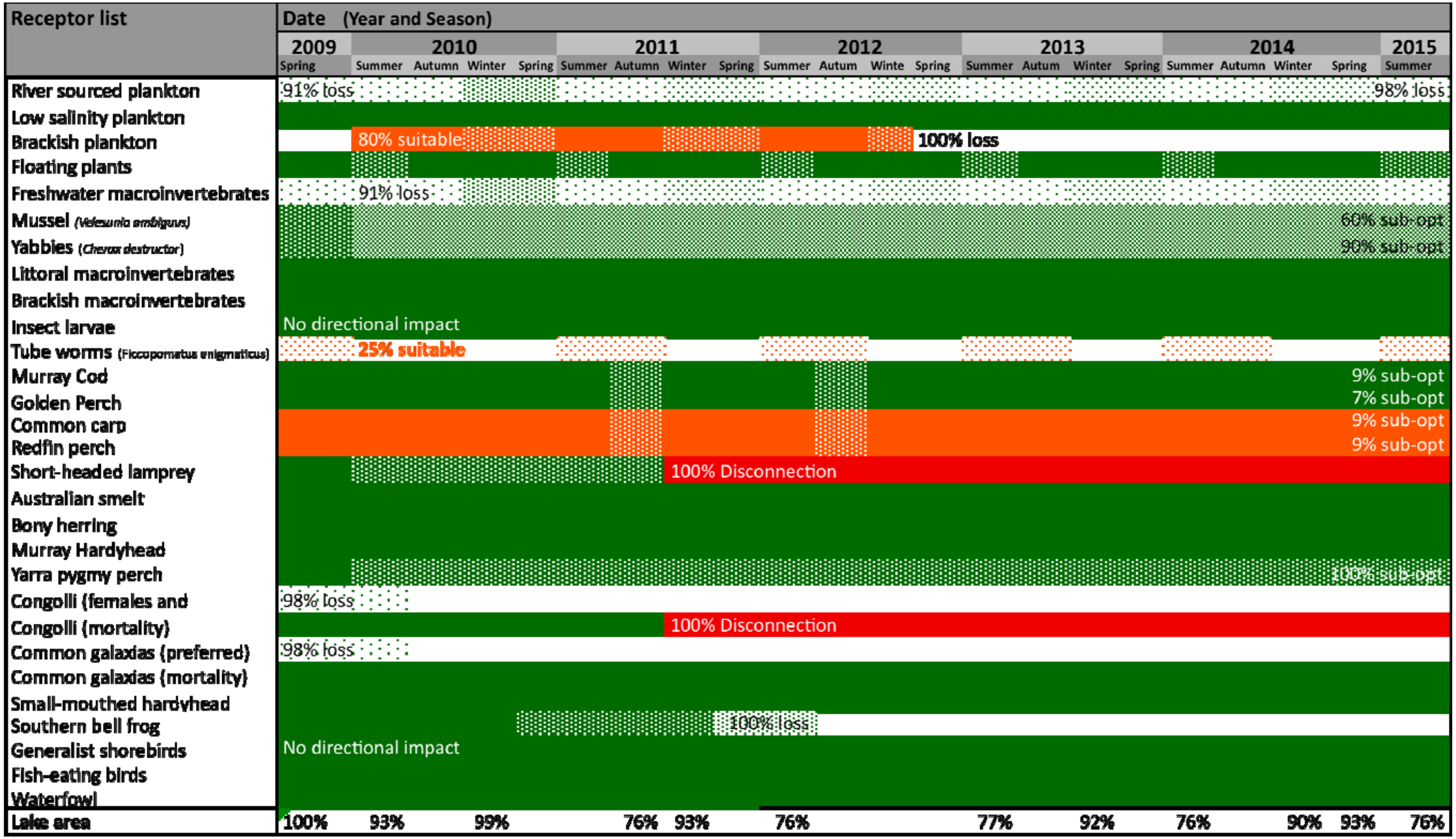


Figure 6.3: Consolidated ecological effects of salinity and water levels on receptors under the Freshwater Pumping (FW_P) scenario in Lake Alexandrina.

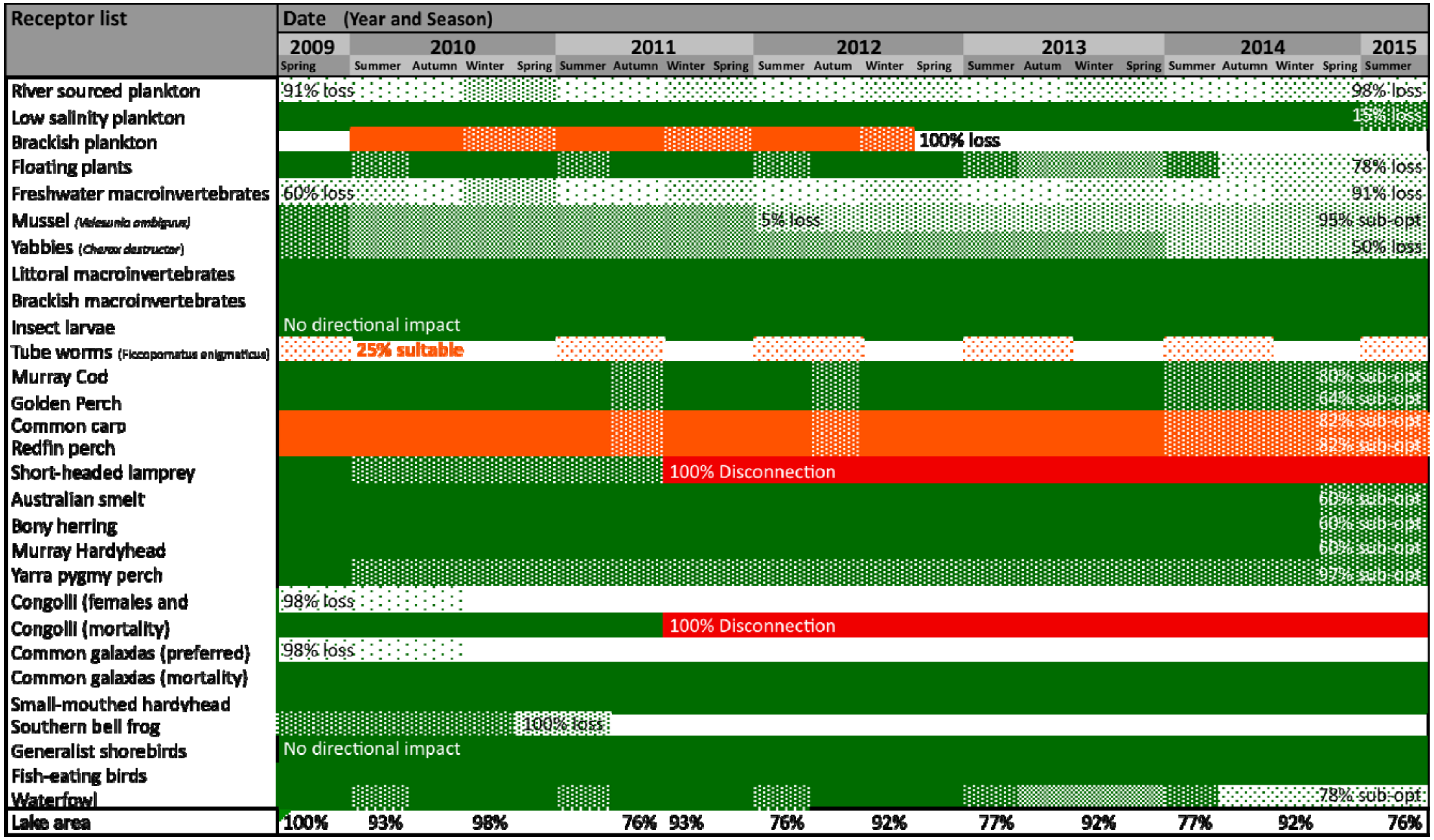


Figure 6.4: Consolidated ecological effects of salinity and water levels on receptors under the Freshwater Cease-Pumping (FW_CP) scenario in Lake Alexandrina

6.2. Lake Albert under the Freshwater scenario

6.2.1. Primary stressor trends when pumping

Salinity

The model predicted salinities to be around 5 g/L across most of Lake Albert at the beginning of the action period. A strong salinity gradient will develop from lowest in the north to highest in the south in summer 2009/10 (maximum salinity of 28 g/L in February 2010). In winter 2010, the gradient will weaken and the average salinity will drop to approximately 15 g/L. The seasonal patterns will repeat with increasing salinity from year to year such that the summer peaks will be: 40 g/L in March 2012 in the southern part of the lake; 50 g/L in February 2013; 59 g/L in February 2014; and 64.5 g/L in February 2015 (Figure 6.5). In winter 2015, the salinity gradient will dissipate and the lake will become quite homogenous with salinities around 40 g/L.

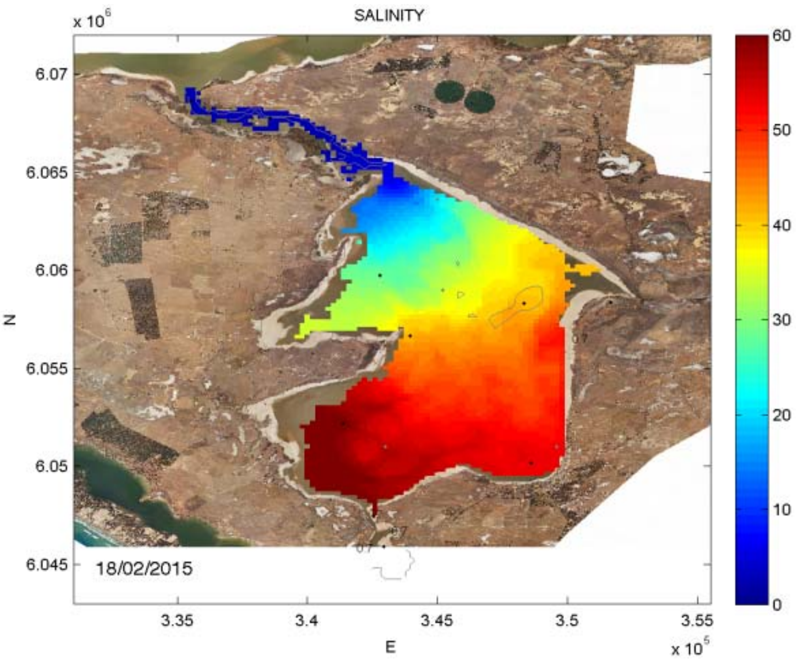


Figure 6.5: Lake Albert salinity for the Freshwater-pumping scenario at February 2015 showing the north-south gradient. Note the scale is in g/L and extends to 60 g/L even though salinities will be higher at this time.

Water levels

Pumping freshwater from Lake Alexandrina will maintain water levels in Lake Albert around the target (92% of the October 2009) throughout the action period. The exception will be summer 2009/10 when water levels will drop to 67% of the baseline before recovering to 92% by June 2010.

pH

All inundated areas of Lake Albert will have a pH > 6.5 throughout the action period which is above the threshold for all ecological receptors. This is likely to be due to pumping sufficient water in from Lake Alexandrina to maintain water levels above the acidification trigger level.

6.2.2. Primary stressor trends when pumping ceases

Salinity

Starting concentrations were modelled as 4.5 to 8.8 g/L with lower concentrations in the Narrung Narrows. These salinities are slightly higher than the starting conditions for the pumping scenario (3 to 6 g/L). In summer 2009/10 salinities will increase to similar levels in both scenarios (28 in pumping vs. > 30 g/L in cease pumping) and in winter 2010 similar freshening occurs in both. However once pumping ceases in October 2010, salinity will rapidly rise to greater than 41 g/L by December 2010. By April 2011, the lake water will have salinities around 180 g/L. Over winter 2011 the salinity will drop back to around 80 g/L before returning to 180 g/L by November 2011. Salinities will remain this high until the lake completely dries in March 2012.

Water levels

When pumping to Lake Albert continues water levels were maintained at between 67% and 92% of the baseline area throughout the action period. By contrast, when pumping to Lake Albert ceases in October 2010, the water level will drop very quickly so that by April 2011 the lake area will be only 28% of the baseline lake area. After a brief winter recovery to 44% of the baseline in June 2011, water levels will decline to 5% lake area by December 2011 and 0% by March 2012 (i.e. the lake will be dry). Again this shows that pumping water from Lake Alexandrina is critical for persistence of any surface water in Lake Albert given the low regional water levels and the presence of the bund across Narrung Narrows.

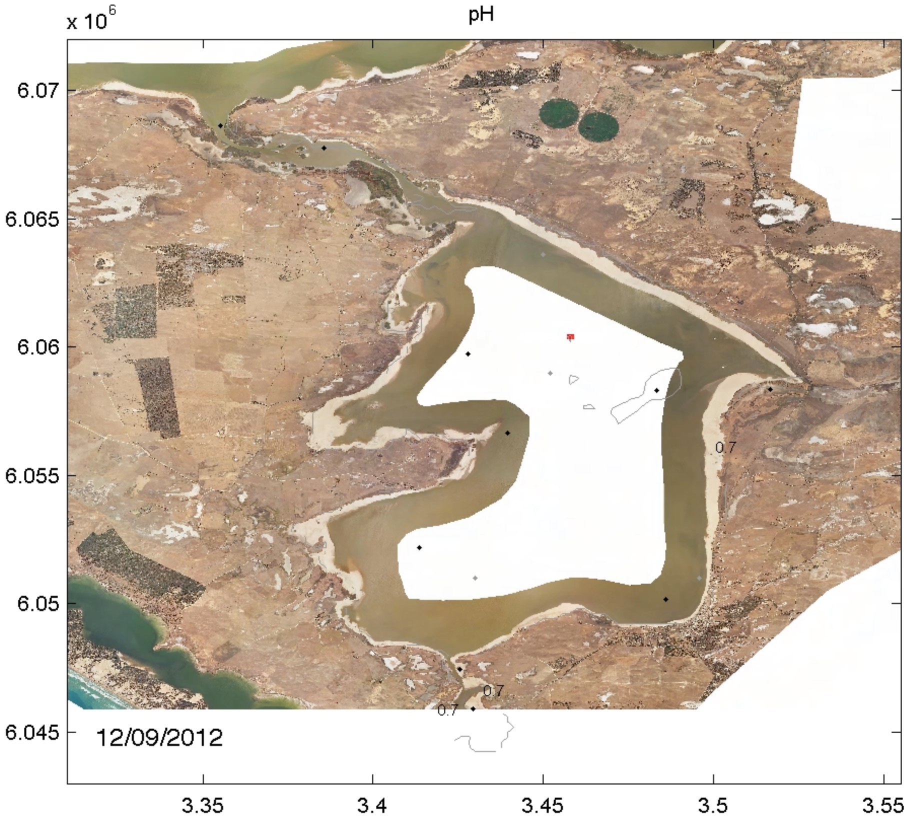


Figure 6.6: Typical illustration of Lake Albert when dry under any of the cease-pumping scenarios. The white outline shows the acidification tipping point (-0.5 m AHD).

pH

When pumping to Lake Albert ceases in October 2010, the water level drops rapidly via evaporation. In March 2011, pH will start to drop. A strong north-south gradient will establish with the south having a pH of between 6.5 and 5 and the north having pH greater than 6.5. The acidification will spread across the main body of the lake such that by early April 2011 all but the Narrung Narrows will have a pH of around 5.

During winter 2011, the pH will rise to 6 or greater across the whole lake. Acidification will begin again in late September 2011 when the main lake will have a relatively homogenous pH of 5 to 5.5. The main lake will contract from October 2011 onwards becoming progressively drier and more acidic. From November 2011, the pH in the main lake will drop to < 4.5. The lake will dry completely during February and March 2012. The model predicted high pH in the remaining pools in the final few weeks. The water in Narrung Narrows will remain above pH of 6.5 until November 2011when it will drop pH 6.1 before drying out.

6.2.3. Ecological responses in Lake Albert

Pumping

Water levels and acidification will not be significant stressors in Lake Albert under the Freshwater-pumping scenario. Salinity will, therefore, be the key driver of ecosystem composition. Salinities will increase very rapidly in Lake Albert so that all but the receptors capable of withstanding salinities in the brackish range or higher will perish in summer 2009/10 (Figure 6.7). Among these will be the almost immediate loss of Murray cod, Golden perch and Common carp, which suggests that fish kills will occur. Brackish macroinvertebrates, Australian smelt, Bony herring, Common galaxias and Congolli will experience major and increasing salinity stress throughout the action period with only 8 to 14% of their habitats still suitable at the end of the action period. Salinities will not exceed the threshold of the most salt-tolerant fish, Small-mouthed hardyhead, although they will be likely to experience significant salt stress. As a result, the only birds predicted to remain at Lake Albert will be Fish-eating birds and Generalist shorebirds that feed on Insect larvae, which were not predicted to be adversely affected as a group.

Cease-pumping

If pumping to Lake Albert ceases, complete ecological collapse will occur from the combined effects of high salinity, low pH and lake drying (Figure 6.8). Salinity will be too high for many Lake Albert receptors by autumn 2010 and for all the resident Lake Albert receptors by spring 2011. Widespread acidification will begin in autumn 2011 covering the whole of the remaining water, rendering the lake suitable for acidophilic microbes and very little else. When the lake dries completely over the summer of 2011/12, all aquatic biota and habitat will be gone.

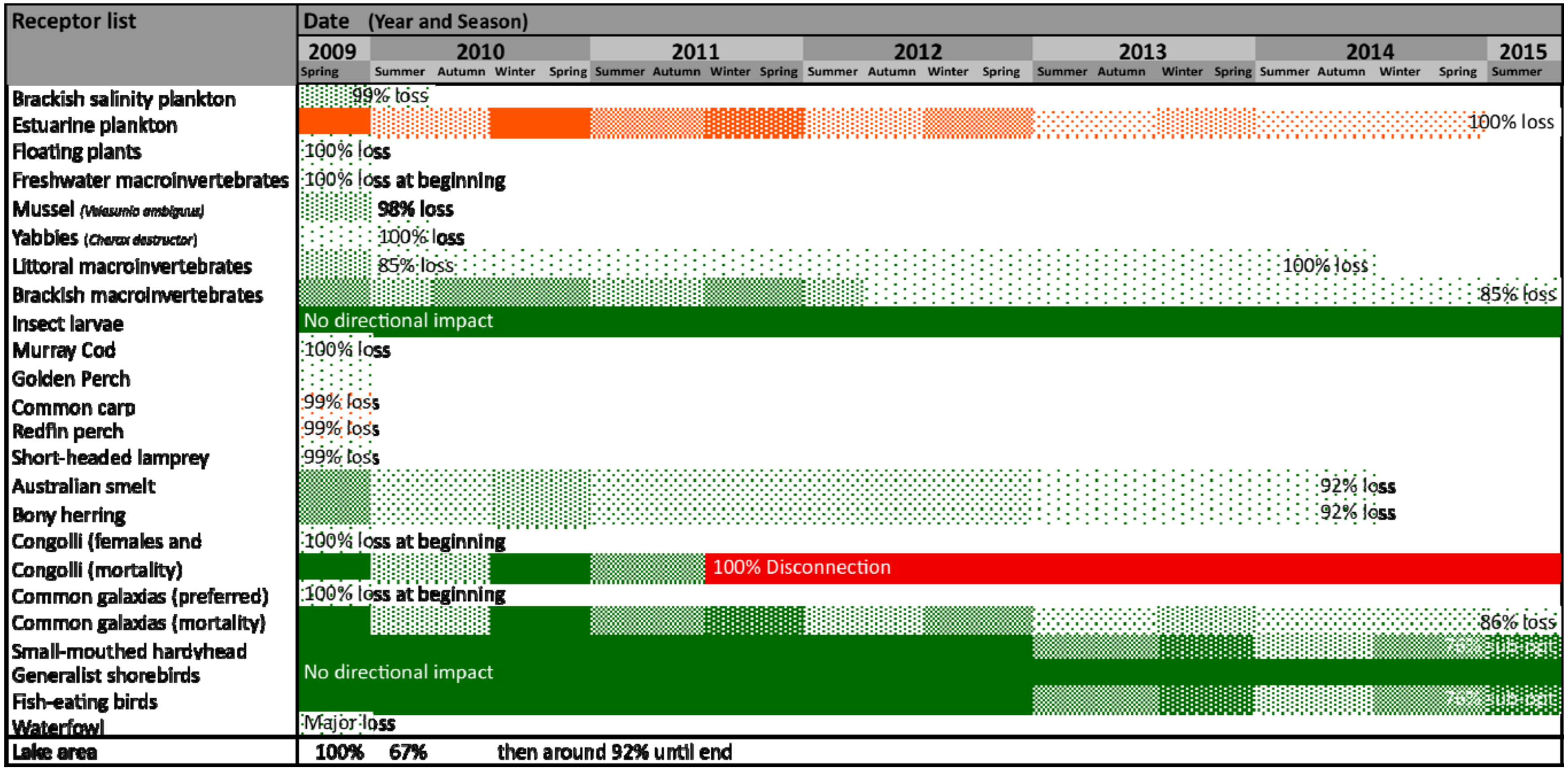


Figure 6.7: Consolidated ecological effects of salinity in receptors under the Freshwater Pumping (FW_P) scenario in Lake Albert.

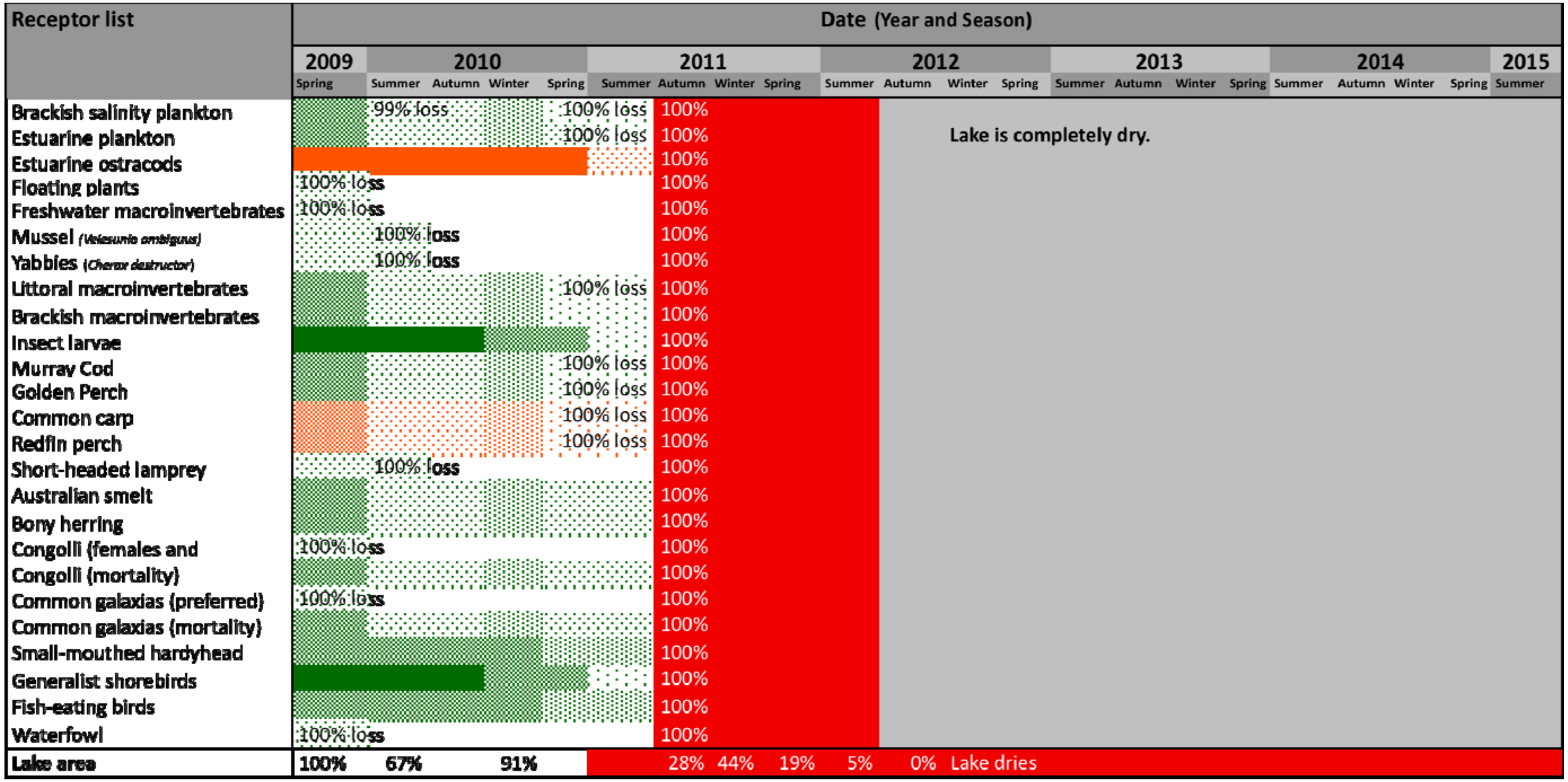


Figure 6.8: Consolidated ecological effects of salinity in receptors under the Freshwater Cease-Pumping (FW_CP) scenario in Lake Albert.

6.3. Conclusions for the Freshwater pumping scenario

Lake Alexandrina

Delivery of freshwater to maintain target water levels will not be sufficient to prevent further decline in the freshwater character of Lake Alexandrina during the action period. Even though salinities in Lake Alexandrina will remain relatively fresh there will be on-going decline, particularly in the most salt-sensitive receptors. This decline will be more marked in the cease-pumping than the pumping scenario, presumably because under the pumping scenario more freshwater will be delivered to and flow through Lake Alexandrina, effectively flushing salts into Lake Albert.

Lake Albert

Pumping water from Lake Alexandrina into Lake Albert will prevent acidification but it will also transfer salt into Lake Albert leading to significant increases in salinity. This will lead to losses of the most salt-sensitive of the relatively tolerant Lake Albert biota and further degrade the ecosystem. However, if pumping ceases then Lake Albert is without any source of freshwater and it rapidly dries causing sequential loss of all aquatic habitat from salinity then acid then desiccation.

7. Evaluation of capacity to recover

7.1. Introduction

In the preceding Sections (4-6) the ecological effects of the five-year action to Do-Nothing, introduce Seawater or deliver Freshwater to control acidification were evaluated.

To determine the full ecological consequences of these management actions, the ability of the ecology to recover after the action period must also be considered. Only Lakes Alexandrina and Albert are being assessed for the recovery period. For the purposes of evaluation, full ecological recovery will be defined as a return to the Ramsar state (Attachment A; Section 8). Initiation of full recovery would thus require a return to the physico-chemical conditions specified for the Ramsar-state: typical operating water levels (around +0.6 mAHD), circum-neutral pH and salinity levels < 0.64 g/L [<1000 µS cm-1] in Lake Alexandrina and < 0.84 g/L [<1400 µS cm-1] in Lake Albert. Partial ecological recovery will be defined as a return to the Freshwater connected state, initiation of which would require return to typical operating water levels (around +0.6 mAHD), circum-neutral pH and salinities < 10g/L.

This section analyses the ten-year 'recovery period' (winter 2015 to 2025) that follows the five-year action period (2009 to autumn 2015). The relative capacity of the lakes' ecological receptors to recover during this recovery period from any detrimental effects incurred during the action period are evaluated for each management scenario. Evaluations of recovery are based upon simulations for water level and salinity, which were generated using a combination of ELCOM/CAEDYM models and mass balance calculations for the recovery period until lake levels reached 0.0 mAHD (if that occurred within the relevant section). Once lake levels were greater than 0.0 mAHD, a TU-FLOW model of the combined lake areas was used (Wainwright and Hispey, 2010).

These hydrological models simulated recovery of water and salinity levels in Lakes Alexandrina and Albert under two different River Murray flow regimes: Entitlement flows (defined as 1,850 GL/y over the South Australian border) compared with Average flows (4,000 to 5,000 GL/y over the South Australian border; Wainwright and Hipsey 2010). Hydrological modelling outputs have not been provided for the Coorong and Murray Mouth estuary for the recovery period. In interpreting the modelling for the recovery period, it was assumed that:

- All barrages and biopassages (fishways) were closed throughout the recovery period until lake levels reached at least +0.4 mAHD, if that level was reached, at which time the TU-FLOWS model explored barrage outflows, and
- All flow-regulating structures were removed from the region during the recovery period when lake levels reached +0.3 mAHD. These structures are:
  - o Pomanda Island Weir near Wellington that separated the River Murray from Lake Alexandrina,
  - o Narrung Narrows Regulator separating Lakes Alexandrina and Albert, and
  - o Goolwa Channel regulator located near Clayton separating the main body of Lake Alexandrina from Goolwa Channel and the Finniss River, Currency Creek and Tookayerta Creek tributaries.

The capacity for each ecological receptor in Lakes Alexandrina and Albert to recover under entitlement and average flow conditions is evaluated here based upon:

- the modelled changes in water level and salinity (ELCOM/CAEDYM & TU-FLOWS);
- literature-sourced recovery strategies (Section 3, Attachments A, B and C);
- selected recent biotic monitoring data (Section 7.3); and
- expert observations of ecological change in the lakes since refilling in 2010 (Section 7.3).

7.2. Receptor strategies and conditions required for recovery

Life history strategies such as persistence, establishment and maturation mechanisms are important inputs to any recovery assessment (Noble and Slatyer 1980). In this section these life history strategies (sensu Noble and Slatyer 1980) have been used to develop a predictive analysis of the timeframe and pre-conditions required to support recovery in the Lakes. It is assumed that these mechanisms, combined with the antecedent population condition, will determine a given receptor's capacity to respond during the recovery period from adverse effects that may have been experienced during the action period (Sections 4 to 6). Table 7.4 shows the typical habitats and broad recovery strategies for the lakes' receptors derived from information in Section 3 and Attachments B and C. All receptors nominated by the scientific experts as useful for the consequence assessment were included, not just those that were present at the beginning of the action period (October 2009). Redfin perch, an introduced predatory fish, has also been included for the reasons outlined in Section 7.3.4 below.

7.2.1. Plankton

Plankton populations are dynamic and influenced by many environmental characteristics. They show cycles or community shifts in response to environmental drivers such as salinity and flow regime. For that reason, Oliver and Sheil (ECA Workshop participants) categorised plankton into receptor groups at the ECA workshops that were based on broad responses to flows and salinity regime at the site rather than individual species responses (e.g. River-sourced plankton, Hypersaline plankton). All types of phytoplankton and zooplankton that have occurred in the Murray-Darling Basin are likely to readily disperse throughout the Murray-Darling Basin if sufficient hydrological connectivity exists.

River Murray inflows should act as a source of plankton that would be expected to recolonise the lakes under typical, variable flow regimes (Sheil pers. com.). Thus it is reasonable to assume that plankton communities typical of the pre-drawdown phase will be reseeded into the lakes from the River Murray during flow events. If conditions in the lakes are suitable for growth and survival, then plankton communities should re-establish rapidly after River Murray flows recommence. Plankton would be defined as DT species using the Noble and Slatyer (1980) classification systems (D for dispersed propagules and T for tolerant of competition; see Figure 7.1). This mechanism would become unavailable if River Murray inflows ceased for longer than the populations can survive in the lakes, which will depend on physico-chemical conditions.

7.2.2. Vegetation

Vegetation characteristics

At the start of the action period, the only plant receptor group considered likely to be still present was Floating plants. Floating plants, like plankton, are considered likely to disperse readily throughout the connected parts of the Murray-Darling

Table 7.4: Typical habitats and recovery strategies for Lakes' receptors.

*** indicates a receptor in poor condition at the beginning of the action period. Invasive or atypical receptors are indicated with a Δ symbol.**

Receptor	Typical habitat	Recovery strategy
Plankton		
River sourced plankton*	River-influence, Lx	Reseeded from River Murray and wetlands
Low salinity plankton	Typical Lx taxa	Reseeded from River Murray and wetlands
Brackish salinity plankton (Δ Lx)	Typical Lb taxa	Reseeded from River Murray and wetlands
Vegetation		
Floating plants	Edge, open water	Reseeded from River Murray, tributaries & wetlands
Samphire	Floodplain	Long-lived, seedbank, germinate on saturated soil
Paperbark woodlands	Floodplain	Long-lived, seedbank, germinate on damp or flooded soil
Lignum	Floodplain	Long-lived, seedbank, germinate on damp or flooded soil
Gahnia sedgelands	Fringing wetlands	Long-lived, seedbank, germinate on damp or flooded soil
Δ Spiny rush	Floodplain	Long-lived, seedbank, germinate on damp or flooded soil
Water milfoil	Littoral	Germinate underwater, seedbank, dormant shoots
Water ribbons (T. procerum)	Riparian, Littoral	Tubers & rhizomes, floating seed capsules
Ribbonweed (V. spiralis)	Permanent water	Germinate underwater, soil seedbank, floating seed
Diverse reed beds	Riparian, Littoral	Tubers & rhizomes, blown & floating seed, seedbank.
Lacustrine macroinvertebrates		
Freshwater macroinvertebrates*	Littoral vegetation	Eggbank, Migration
Mussel (Velesunio ambiguus)	Littoral, open water	Eggbank, Migration, dormant adults (acid risk)
Yabbies (Cherax destructor)	Littoral vegetation	Eggbank, Highly mobile, burrow, migration of juveniles
Littoral macroinvertebrates	Littoral vegetation	Eggbank, Mobile adults, widespread, hardy
Brackish macroinvertebrates	Littoral vegetation	Eggbank, Wholly aquatic, multiple dispersal vectors
Insect larvae	Littoral vegetation	Flying adults able to lay eggs when conditions favourable
Δ Tube worms (Ficcopomatus enigmaticus)	< 1.5 m depth	Hard substrates, mobile larvae, highly fecund.
Fish		
Murray Cod	Open water	Lake recruitment unknown, poor migration. Rare.
Golden Perch	Open water	Pelagic eggs, spawn (spring & summer flows), Migration.
Δ Common carp	Littoral, open water	Adhesive eggs, spawn (spring & summer), Migration.
Δ Redfin perch	Littoral, open water	Egg ribbons on submerged structures, spawn in spring, short maturation, migration.
Short-headed lamprey	Diadromous	Winter upstream migration to spawn, ammocoetes in river & lakes. Rare.
Australian smelt	Open water	Adhesive eggs, spawn late winter & spring, migration.
Bony herring	Littoral, open water	Spawning in shallows (late spring & summer), migration.
Murray hardyhead	Littoral, sheltered edges	Eggs adhere vegetation, spawn (spring & summer), migration, declining but formerly abundant.
Yarra pygmy perch	Littoral	Eggs scattered on vegetation, spawn spring, lakes & tributaries only MDB population, locally extinct 2007.
Congolli	Diadromous	Downstream migration to estuarine/marine for autumn-spring spawning, juveniles migrate upstream, abundance and distribution declined since barrages constructed.
Common galaxias	Diadromous	Downstream migration to estuarine/marine for autumn-spring spawning, juveniles migrate upstream, eggs deposited on vegetation.
Small-mouthed hardyhead	Estuary, Lakes	Spawns in Lakes and Coorong (spring & early summer), eggs adhere submerged surfaces, migration.
Frogs		
Southern bell frog	Littoral, streams	Breed in flooded vegetation spring/summer; metamorphosis in summer/autumn. Migration possible.
Birds		
Generalist shorebirds	Lake shores	Highly mobile and opportunistic
Fish-eating birds	Littoral, open water	Highly mobile and opportunistic
Waterfowl	Littoral, open water	Highly mobile and opportunistic
Terrestrial birds	Fringing wetlands	Rare. Strong association wetland & floodplain plants.
Fringe dwelling birds	Fringing wetlands	Strong association riparian & floodplain plants.

Basin being reseeded through water exchanges between the lakes and the River Murray, fringing wetlands and/or tributaries (Nicol pers. com.). Therefore they are also classified as D (dispersed propagules), however, Floating plants are less tolerant of competition than plankton so they are classified as I, yielding DI (Figure 7.1). As for plankton, effective dispersal of plant propagules from upstream sources will not occur during periods of no River Murray inflow.

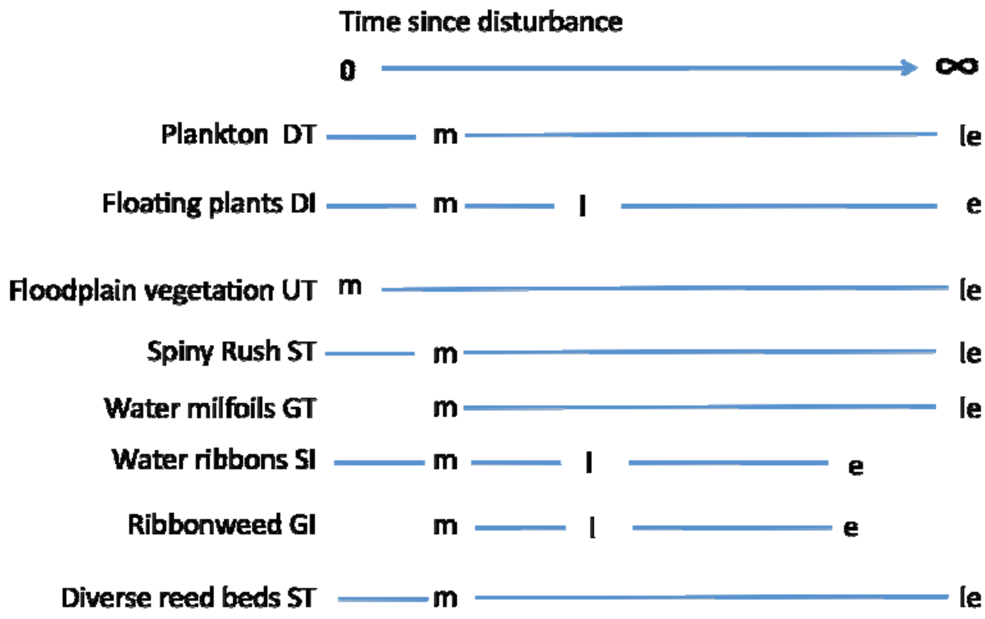


Figure 7.1: Life stage parameter characteristics for plankton and the vegetation receptors.

D = dispersed propagules, T = tolerant of competition, I = intolerant of competition, U = unaffected, S = long-lived seedbank and/or storage tissue, G = long-lived seedbank readily exhausted by germination and death.

Other vegetation receptors had been disconnected and desiccated for nine years at the beginning of the recovery period (i.e. since drawdown began in 2006). They may recover from underground organs such as rhizomes (e.g. reeds) or from the seed bank (e.g. water milfoil). Alternatively they may persist through the disturbance caused during the action period as non-recruiting adults (e.g. samphires). Small patches of emergent plants may persist where soil moisture remains at field capacity due to high organic matter, dense thatching acting as mulch, groundwater seepage and/or rainfall run-off (as observed in Dunn's Lagoon by Gehrig *et al.* 2011) but more typically it is expected that the rhizomes of most plants will not be viable at the end of the action period. Therefore all of the riparian and littoral plants will depend on dispersal of propagules or recovery from the seedbank for re-establishment.

The seed bank is defined as the reserves of viable seeds (and spores) in and on the soil surface and associated litter (e.g. Thompson and Grime 1979; Roberts 1981). It is an integral part of an ecosystem's flora although it is not readily visible. The main purpose of the seed bank is to ensure that plant populations recover after disturbance or loss. Seeds are the only life cycle stage of most submerged aquatic plant's life cycle that can withstand desiccation. Therefore, the seed bank is vital in recovery of diverse aquatic plant communities after severe adverse effects such as sustained drought or periods where salinities are greater than that tolerated by adult plants (e.g. Casanova and Brock 1990; Brock and Britton 1995; Brock and Rogers 1998; Leck and Brock 2000). If a viable seedbank exists, then re-establishment of those plants contained within the seed bank is not reliant on migration or dispersal from other aquatic habitats. Once established from seed, most aquatic plants can rapidly increase their populations via asexual reproduction (sensu Grace 1993).

The two submerged plant receptors used in ECA, Water milfoils and Ribbonweed, are likely to germinate en masse when inundation initiates the reproductive process, if seed is available. Prior to drawdown these two species were confined to a narrow littoral band around +0.4 to +0.6 mAHD (Gehrig and Nicol 2010), therefore, it is likely that their seed bank occurs at or around this elevation. This suggests that submerged vegetation recovery would have the greatest chance of success once lake levels returned to at least that level. Water milfoils are classified as a GT, meaning that the seedbank is long-lived but is likely to become exhausted by germination (G) and death after first disturbance or early on if the disturbance is prolonged or catastrophic (Figure 7.1). The T stands for tolerant of competition. Ribbonweed is classified as GI: the same as Water milfoil but intolerant of competition in the lakes because of high turbidity and the consequently narrow littoral/riparian band (Gehrig and Nicol 2010). These mechanisms would not be available if disturbance occurs when the populations are dominated by juvenile plants or if seedbank exposure renders seeds unviable (e.g. extended drawdown and acidification).

The species composition has been shown to vary in seed banks from different parts of the lake environment (Nicol and Ward 2010 a and b), thus some level of vegetation diversity may be preserved in the seed bank at a lake scale due to spatio-temporal variation in stressor effects, even if much of the above-ground vegetation was lost to desiccation. However, Brock *et al.* (2005) have shown that elevated salinity reduces seed bank germination and as salinity increases the time required for germination of many submergent species also increases (Sim *et al.* 2006). A longer hydroperiod may also be required for plants to complete their life cycle and replenish the seed bank if the seedbank viability declines during drawdown. Seedbanks significantly decline after ten years in terms of diversity and numbers of germinants and even when seeds are stored optimally in dry containers that there are reductions in viability of submerged plants (Brock 2011). Therefore it is unlikely that seed will remain viable for the approximately twelve years it takes to rewet the seedbank between drawdown and recovery, particularly given that in the meantime the seeds will be resting in exposed, saline, acidic sediments.

The other key aquatic plant receptors, Water ribbons and Diverse reeds beds, are likely to recover from underground organs such as rhizomes if the period of drawdown is not so long that the dormant organs perish (likely extent of viable periods are unknown). These plants reproduce asexually forming bands around the water's edge and persist through drought as underground storage organs (e.g. rhizomes). The main bands of reeds circled the lakes at an elevation of around +0.6 mAHD, thus their recovery is also likely to be optimized if lake levels return to +0.6 mAHD and levels become relatively stable around that elevation (+0.4 to +0.7 mAHD). Water ribbons (SI) and Diverse reed beds (ST) would both be classified as S because they have long-lived seedbanks and underground storage organs that can persist when mature above-ground tissue has been lost. Water ribbons are classified as I because they are less tolerant of competition in the narrow littoral/riparian band than diverse reed beds, which are far more tolerant of competition (T).

Floodplain receptors (Samphires, Paperbark and Lignum) tend to form stands behind the riparian and littoral zones. They require damp, saturated or flooded soils and thus recruit best when freshwater inundates the floodplain. Therefore they also require lake levels to recover to at least +0.7 mAHD, preferably up to or above +0.85 mAHD, in order for the floodplain to be connected to the lakes and their seedbanks to be inundated. They were classified as UT. The U meaning that they are unaffected by the disturbances associated with the action period due to their disconnection from the water body and were likely to persist as populations dominated by long-lived adults. The T refers to their relatively high tolerance of competition in their respective water and salinity regimes. Gahnia sedgelands are scattered in the fringing wetlands around Lake Alexandrina and the tributaries (Seaman 2003). It is generally considered a poor recruiter and appears to need extended periods of seedbank inundation to recruit (Ganf pers. comm.). So although it is classified as UT, it is more susceptible to loss than the other floodplain vegetation because of its more specific recruitment requirements.

It should be noted, however, that all the Floodplain will have been strongly and negatively affected by nine years of on-going disconnection and desiccation. So although they may not be affected by the different water management options, they are coming into the recovery period in very poor condition affected by a different disturbance, lake drying.

The introduced Spiny rush has been observed to colonise the exposed lakebed since the drawdown began in 2006 (Mallen unpubl. data) and thus appears to be more tolerant of lower soil moisture (and possibly low pH) when germinating than the other floodplain receptors. It is also unpalatable to stock (Mason pers. com.) and so is able to recruit where other germinants are being eaten. It is classified as ST: long-lived seedbank that is available at all times and highly tolerant of competition (and predation). This suggests that it may become a more dominant part of the emergent vegetation over time now that it has become established.

Probable vegetation cascade during recovery

The vegetation characteristics above could be used to determine a probable vegetation cascade under a range of recovery scenarios. In the best-case, physico-chemical conditions would rapidly return to Ramsar-state following the commencement of recovery flows. The probable vegetation cascade that would occur in such a recovery scenario is described below and in Figure 7.2. Vegetation response will be primarily governed by elevation, physio-chemical conditions and propagule availability, as well as the characteristics of the receptors.

The Floodplain vegetation receptors persisted through the action period as populations dominated by adults. They were not healthy and resilient (Lester *et al.* 2011) at the beginning of the action period in terms of population demographics. The last significant recruitment events are thought to have occurred in the 1990s when successive floods occurred although data is not available. They are expected to decline over time because the main stands did not get inundated during the action periods and are unlikely to gain diversity and abundance unless there are frequent (ARI = 3) of periods of inundation to greater than +0.85 mAHD for more than three months during the recovery period.

Lignum and Gahnia sedgelands are typically further down the elevation gradient than Samphire and Paperbark woodlands and therefore have a greater likelihood of being inundated more frequently, for longer under any given water regime. Lignum was considered likely to increase in abundance near the shoreline where inundation occurs via seed brought in with river water and by stimulation of long-lived plants that may survive around the lake margins until they become inundated. Lignum is not likely to fully recover though because the resident plants and the seedbank will be in very poor condition after twelve years of dessication. Dispersal of new seed will take time and emerging recruits will have to compete for space with terrestrial plants and early-colonising aquatic plants. Gahnia sedgelands are not as widespread as Lignum, therefore it is likely to have lower dispersal success and consequently decline over the recovery period except for those plants that have access to Lake Alexandrina water, fresh groundwater or rainfall run-off.

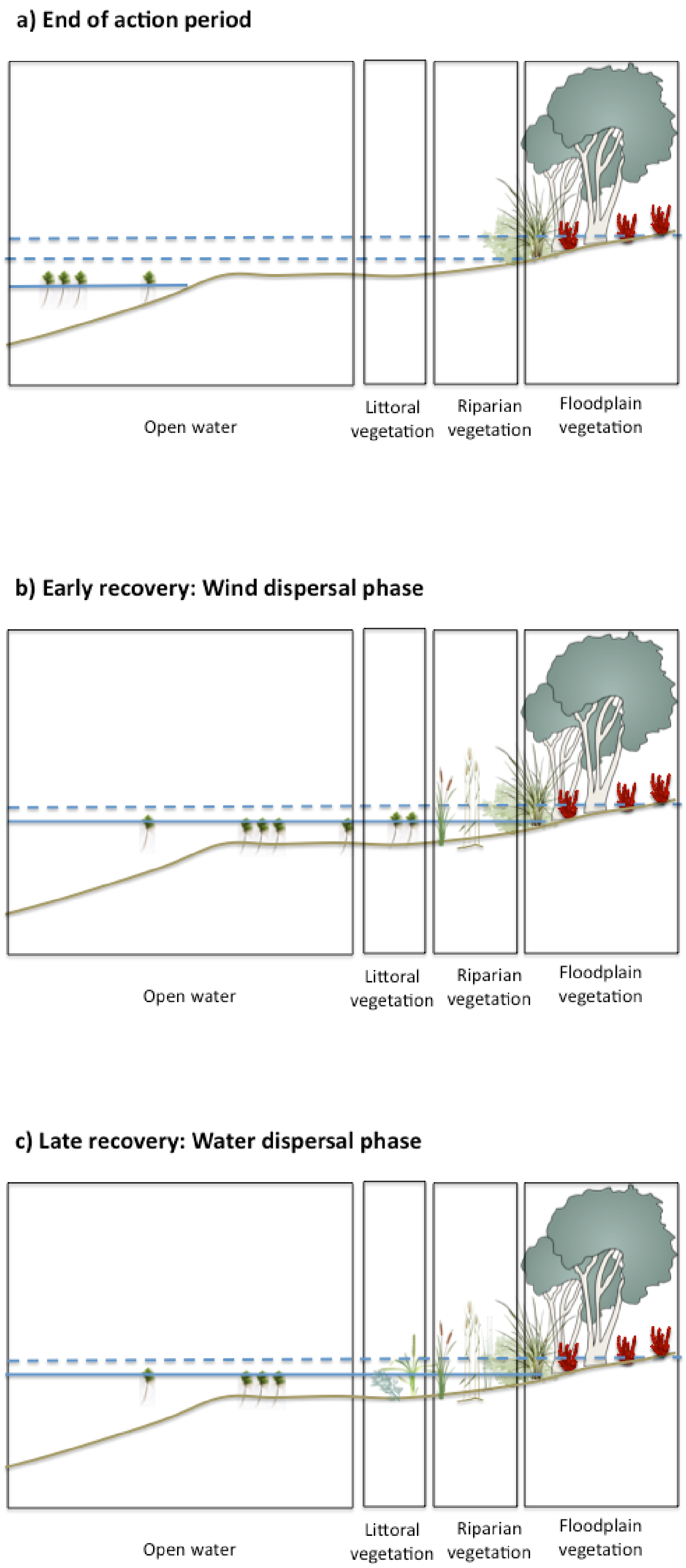


Figure 7.2: Schema of the probable vegetation cascade during recovery if lakes return to the Freshwater connected or Ramsar ecosystem states.

Vegetation receptors are shown at the end of the action period (a) as a baseline for recovery as well as during the two stages of re-establishment: early recovery from wind dispersal (b) and late recovery from water dispersal (c) of propagules. Dashed blue lines represent typical lake levels prior to drawdown (2006) and solid lines represent water level at the given stage of recovery.

It was concluded in Section 7.2.2 that all the littoral and riparian vegetation receptors would be dependent on dispersal of propagules from other habitats to initiate re-establishment (except for Floating plants in scenarios where they persisted). It is likely that species with wind-borne seed such as the common emergents, Phragmites australis and Typha domingenesis, will re-establish first because their DT life history strategies will facilitate rapid re-establishment (Figure 7.1). Other reeds that make up the Diverse reed bed receptor group (e.g. Schoenoplectus sp., Baumea sp. Eleocharis sp.) may take longer to establish via river-borne seed and by the time seed accumulates in the riparian zone, the early-colonising P. australis and T. domingensis stands may be so dense and dominant that these other species cannot occupy sufficient space to form strong populations. This will lessen the ecological functionality of these reedbeds (e.g. as nurseries for fish and Southern bell frog).

Water ribbons (Triglochin procerum) rhizomes are not expected to withstand twelve years of desiccation and their seeds preserve poorly in the seedbank, therefore they were not likely to persist. Fresh seeds will enter with river and tributary inflows and float until they reach the shoreline where they will attempt to germinate. Space is likely to be limited by growth of early-colonising plants and herbivory on young germinants is expected to be high. In addition, turbidity would be high and erosion will cause disturbance along the lakeshore where the plants are trying to establish. Therefore, it is predicted that Water ribbons may re-establish later in the vegetation sequence once P. australis and T. domingensis have provided some shelter from wind and wave actions and a 'new' lakeshore consolidates on the water's edge. Ribbonweed (Vallisneria spiralis) is common in the river and wetlands and so it is likely that fresh seed will enter the lakes with river flows. Full recovery is not expected without significant time delays, however, because of the limitations listed above for Water ribbons. Being able to germinate underwater may be advantageous for Ribbonweed but it is still unlikely that they will form strong populations, primarily because of high turbidity and lakeshore instability.

Certain species such as the water milfoil, Myriophyllum caput-medusae, have not been observed in the lakes since 2006 (Gehrig *et al.* in prep.) even though other water milfoils re-established following four years of desiccation behind the Clayton regulator (Nicol and Ward, 2010B). It is, therefore, highly unlikely that they will re-establish in the modelled recovery period after twelve years of desiccation. Although other, related submerged plants may eventually re-establish, (e.g. Ceratophyllum sp. or Myriophyllum salsagineum), the ecological function of the extremely important littoral vegetation would be altered. Myriophyllum caput-medusae forms much denser beds than other submerged plants and also has emergent leaves as well as submerged leaves. This means that the water under Myriophyllum caput-medusae is dark and thus offers excellent cover for prey from predatory birds. The emergent leaves also provide landing platforms for insects and frogs and improve aquatic-terrestrial connectivity that other fully submerged species cannot. Thus although submerged plants may re-establish, they were not considered to have recovered in terms of diversity, abundance or ecological function.

Changes in water levels during critical times can affect recruitment of all aquatic vegetation. As well as having specific water dependent germination requirements, aquatic plant seedlings or new vegetative shoots tend to grow to match water levels (e.g. Denton and Ganf 1995) and thus timing of inundation compared to seasonality of germination and reshooting is important. The high turbidity of the water in the lakes is also likely to limit recruitment to very shallow water as well as adversely affecting survivability of recruiting plants due to low light climate and susceptibility to algal smothering. Flowering and seed set will provide fresh seeds after existing seeds and vegetative propagules complete their life cycles (at least one year). Therefore, if water levels are not maintained long enough to allow seed set and distribution then seed availability will be limited in future years. This will affect the long-term resilience of the site and will reduce the site's capacity to recover from any future adversity.

Overall, recovery of the vegetation will not be initiated until the site transitions to the Freshwater connected state and may not fully recover for many decades, if ever, even if the lakes transitioned to the Rasmar state. Vegetation will re-establish across the elevation gradient to the extent determined by the euphotic depth but diversity and ecological functionality are likely to be much reduced.

7.2.3. Lacustrine Macroinvertebrates

Macroinvertebrates are the major consumers of all types of organic matter (Bunn *et al.* 1999) and are important food sources for fish, birds, frogs and other vertebrates, thus they are a critical part of the aquatic food web (Souter and Stead 2010). More than 100 taxa of macroinvertebrates have been identified in the lakes to date even though there are no long-term or comprehensive data sets and there are many gaps in our understanding (Napier 2010). Little is known about the macroinvertebrates of Lake Albert due to a lack of sampling effort.

Most Lacustrine macroinvertebrates are strongly associated with vegetated littoral zones where they find shelter and food. It is considered unlikely that most macroinvertebrates will respond to changes in water level per se but they will respond to changes in habitat availability (i.e. aquatic vegetation), pH and salinity regime (Napier 2010). If catastrophe strikes a macroinvertebrate community and re-establishment is required then early colonisers, such as chironomid larvae (Danell and Sjöberg 1982; Layton and Voshell 1991; Solimini *et al.* 2003) are likely to the most abundant group in the first few years following the disturbance. The colonisation of aquatic bugs and beetles, also usually among the first colonizers (Popham 1964; Danell and Sjöberg 1982; Layton and Voshell 1991; Jeffries 1994) is likely to be strongly limited by fish predation and the absence of macrophytes.

The structural complexity of diverse littoral vegetation and its importance as habitat for periphyton means that littoral vegetation provides food, habitat and shelter from fish predation for many aquatic macroinvertebrates. The presence of diverse vegetation in the littoral zone, therefore, greatly increases invertebrate survival and diversity (Dvořák & Imhof 1998; Solimini *et al.* 2003) and changes in littoral vegetation composition are likely to affect functional and taxonomic shifts in the macroinvertebrate assemblage (Sychra and Adámek 2011). Given this strong association with littoral vegetation, it can be assumed that recovery for Lacustrine macroinvertebrates will be dependent upon the prior re-establishment of vegetation for which there will be a time delay. Recovery would be optimal when lake levels have returned to approximately +0.6 mAHD, a wide and diversely vegetated littoral zone has re-established and there is strong connectivity to dispersing populations.

In general, macroinvertebrate life cycles are short (e.g. weeks to months) making them good indicators of environmental change (Norris *et al.* 2001). Benthic macroinvertebrates are known to respond quickly to changes in water quality, sediment structure and other environmental changes due to their habitation of sediments (Norris *et al.* 2001) and thus are likely to be strongly affected by soil acidification. Freshwater mussels (Velusunio ambiguus) are known to bioaccumulate heavy metals (Napier 2010), which are likely to have been released as ASS oxidation products, and thus their consumption can transfer heavy metals to other trophic levels. Shells of dead mussels have been observed to provide substrate for invasive tubeworms (Dittman *et al.* 2009b). It is unknown whether the tubeworms contributed to the death of the mussels. Mortality may well have been caused by high salinities and lack of littoral vegetation.

Freshwater mussels can tolerate low dissolved oxygen, high water temperatures and periods of exposure by sealing their shells (Napier 2010). Although the period they can wait for is not recorded, Thorp and Rogers (2010) suggest that North American mussels can remain closed for hours to days. Given that their shells are dissolved by acid it is unlikely that they could tolerate the acidified sediments around the lakes during drawdown, particularly given that they would burrow to escape poor water quality and thus survivability is likely to be very low. Freshwater mussels are common in the River Murray system and can occupy open water; therefore, they should begin to migrate in the first two years of the recovery period. Levels of predation may be very high in the first few years of recovery when prey abundances are low. Establishment of aquatic vegetation will improve their recovery capacity but it is unlikely that they will form strong populations particularly in Do-Nothing cease-pumping and Seawater scenarios within which they perished during the action period.

The consequence assessments in Sections 4 to 6 are based on salinity, water levels and pH of the water. However, the losses of aquatic vegetation from 2007 onwards, soil acidification in the exposed lake bed and extended drawdown of the lake levels would compound the impacts of the three primary stressors. This suggests that resident lacustrine macroinvertebrates would be lost and recovering populations will be strongly dependent on dispersal from other habitats as well as prior recovery of wide and diverse littoral vegetation (Figure 7.3). Dispersal mechanisms and likely success will be species-specific. Examples of specific dispersal mechanisms in Napier (2010) are: 1) Oligochaeta that resuspend or swim in the water column to migrate to more favourable areas and 2) bivalve larvae that parasitise fish, dropping off into the sediments when reaching maturity.

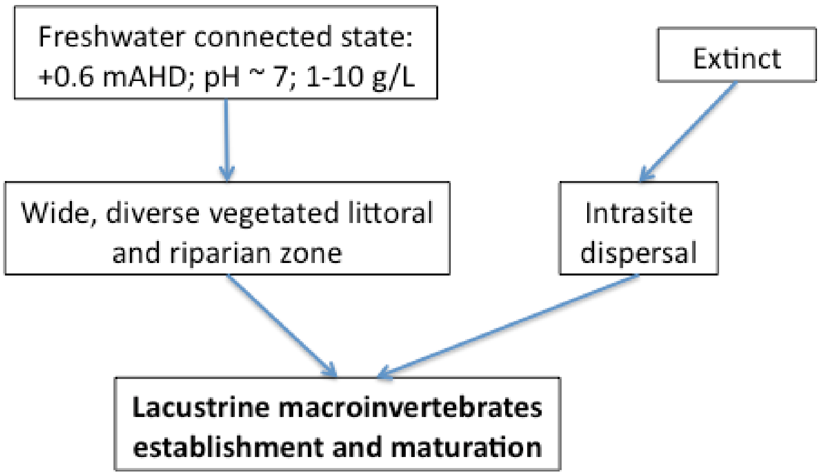


Figure 7.3: Recovery pre-conditions for Lacustrine macroinvertebrates.

Yabbies are one of the more mobile Lacustrine macroinvertebrates having the ability to re-populate the lakes by travelling downstream and migrating from wetlands and dams in the Eastern Mount Lofty Ranges. They will not, however, tolerate salinities in the upper band of the Freshwater state and there is great uncertainty around their ability to tolerate acidic soil conditions. As yabbies rely on burrows as key habitat, the presence of acidic soil conditions in the exposed lakebed is likely to limit their ability to successfully persist through drought.

Yabby populations were poor at the beginning of the study period (October 2009). Yabbies are also prime food sources for a variety of fish, birds and other predators and given that the food resources in the lakes during the action period was so poor it is likely that yabbies suffered very high rates of predation. Consequently, it is unlikely that many individuals survived the adverse conditions experienced during the action period in most scenarios (except perhaps in Lake Alexandrina under the Freshwater pumping scenario) and they will be assumed to be dependent on larvae or adults migrating from other habitats for recovery. Significantly, Yabbies have not been seen in the lakes since prior to 2006 and have not been observed since the 2010 recovery (McEvoy ECA workshop participant).

Not all Lacustrine macroinvertebrates have entirely aquatic life cycles nor are they all dependent on recovery of aquatic vegetation to initiate their recovery. Many insects, in particular, have only their larval stages being truly aquatic (e.g. mosquitos) and thus they can rely on flying adults to reseed the aquatic larval populations following adverse impacts (Napier 2010). Therefore Insect larvae populations will act like a DT plant receptor (see Figure 7.1).

Only Lacustrine macroinvertebrates have been evaluated for their capacity to recover because only the lake management units are included. Estuarine macroinvertebrates are closely linked to the Coorong and Murray mouth for which hydrological simulations for the recovery period are not available thus their recovery has not been evaluated. The exception is *Ficcopomatus enigmaticus* (Tube worms) that have invaded the southern parts of Lake Alexandrina since 2006 due to increasing lake salinities. Tube worms are very successful recruiters and were likely to have proliferated during the action period in all the scenarios expect for the Seawater scenarios in which salinities became too saline for them (> 60g/L) during 2013. They are able to tolerate quite fresh water down to 1.5 g/L. Given this it is likely that they will persist or re-establish during the recovery period, therefore their capacity to recover is evaluated below even though they are invasive and not part of the Ramsar state.

7.2.4. Fish

Knowledge of the recruitment and dispersal strategies of the various fish receptors in the lakes is summarised by Bice (2010). Murray Cod are not known to recruit in the lakes and the nearest known recruitment areas are the free-flowing creeks on the Chowilla floodplain, greater than 500 river kilometres upstream from Lake Alexandrina. Murray Cod are poor recruiters and have non-motile eggs that are guarded by the males until they hatch which requires very specific niches (Table 7.4). Therefore it is considered highly unlikely that they will recruit in the lakes (regardless of pre-conditions) and will be dependent on direct migration of juveniles to recover populations. By contrast, Golden perch have pelagic eggs that can be carried downstream with River Murray flows as are adults and juvenile fish. Adults remaining in the lakes could also be induced to spawn by river flows in spring and summer. As such they have few ecological pre-conditions for recovery other than availability of suitable food resources. Common carp are very good recruiters and although their eggs are adhesive and thus will benefit by recovering vegetation (for which there will be a time delay), resident and immigrating adults can be induced to spawn in spring and summer and thus recruitment within the lakes is highly likely to occur and will be optimised if water levels and littoral vegetation recovers.

Australian smelt, Bony herring and Murray hardyhead have staggered spawning times through late winter to summer. All have adhesive eggs and thus have the greatest recruitment success when they spawn in shallow vegetated areas for which they need littoral vegetation to recover first. Yarra pygmy perch are considered locally extinct having been absent from lake samples since 2007 (Hammer *et al.* 2009), which is before the beginning of the action period (October 2009). They were included as receptors because to omit them was considered remiss by Bice and Zampatti at the ECA workshops given that their low salinity tolerance makes them an indicator of the Ramsar state and their conservation status. Given that Yarra pygmy perch do not occur in other parts of the Murray Darling Basin their recovery from local extinction is not possible without intervention. DENR have bred Yarra pygmy perch in captivity and now have 10,000 individuals ready to release when salinities are suitable and submerged vegetation has recovered (Hall pers. com.). The capacity of these released fish to survive is not being considered here.

Small-mouthed hardyhead are the most salt-tolerant of all the fish receptors and they will readily spawn in the lakes, Murray Mouth region and the Coorong in spring and summer, although their eggs attach to submerged vegetation so recruitment will be optimised if submerged vegetation recovers first. The diadromous receptors (Short-headed lamprey, Congolli and Common galaxias) need connectivity between the lakes and the estuary to complete their life cycles (although there is a land-locked population of Common galaxias in South East of South Australia, Bice 2010). That means they are dependent on connectivity through the barrages, which are closed during the recovery period until lake levels reach at least +0.4 mAHD when the fishways can be opened.

The introduced Redfin perch (*Perca fluviatilus*) has been included as a fish receptor in this assessment of capacity to recover even though the experts did not select it as a receptor for ECA. It has been included in the recovery assessment because they are known to dominate the fish population in the regulated areas behind the Clayton regulator (Bice and Zampatti ECA workshop) and because of the following characteristics reported by Rowe *et al.* (2008). These characteristics show that Redfin perch have few recovery pre-conditions and thus they are likely to dominant the fish populations in the recovering ecosystem if they become well-established.

Redfin perch:

- are voracious predators able to eat prey one third their size due to their protrusible mouth;
- can tolerate salinities up to 10 g/L;
- are able to rapidly populate and dominate impoundments if populations of other fish are low (as would be the case in the lakes at the beginning of the recovery period);
- impact negatively on many native fish if submerged vegetation cover is low through predation and competition for food and habitat resources;
- use a variety of habitats including aquatic vegetation as well as submerged objects;
- can reproduce without submerged vegetation if submerged objects occur to hold egg strings. Eggs are also unpalatable to other fish due to a gelatinous coating;
- are a host for and are affected by the epizootic haematopoietic necrosis virus (EHNV), which is also highly pathogenic to silver perch, mountain galaxias, Macquarie perch, and Murray cod;

- have juveniles that can become schooling and pelagic and thus have high dispersal success; and
- can alter their reproductive strategies to suit the environmental conditions and competition levels. In a fast-growing, Western Australian population, males matured in their first year of life whereas the majority of females matured in their second year. Such a short generation time enables rapid population growth and potential domination.

These characteristics of Redfin make them a dominant competitor and once established, it will be much more difficult for other fish and macroinvertebrates to recover at any time under any flow conditions without intervention (e.g. selective fishing program). The exception may be a large flood that washes large numbers of lake fishes through the barrages where they are likely to be consumed before returning to the lakes against the outgoing water flows.

In general, optimal recovery of the fish receptors will be dependent on recovery to a Freshwater connected state and prior establishment of wide and diverse littoral and riparian zones (Figure 7.4). The exceptions are Murray Cod that will be primarily dependent on dispersal of juveniles and adults to increase population size and Golden perch and Red fin perch that have few recovery pre-conditions. All fish will benefit from the enhanced recovery of food resources if vegetated littoral and riparian zones re-establish early.

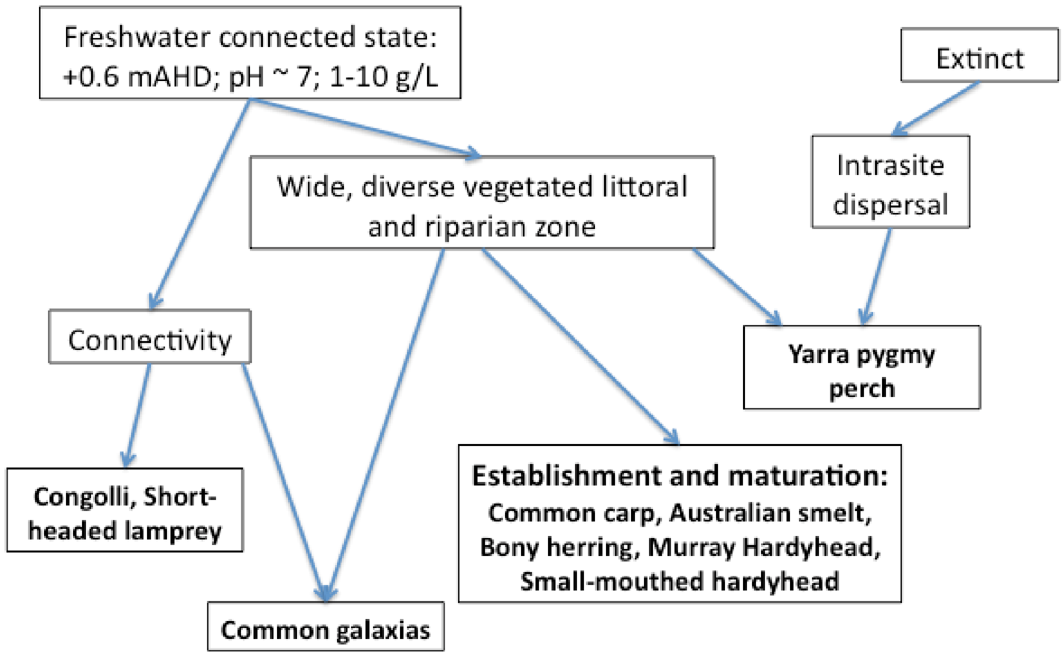


Figure 7.4: Recovery pre-conditions for Fish.

7.2.5. Southern bell frog

Southern Bell Frog (*Litoria raniformis*) is the largest of the 12 frog species known in the Lower Murray. They are responsive to flooding and readily occupy shallow, newly inundated vegetated areas to breed (Mason 2011). The lack of flooding, disconnection of key habitat and increasing salinity has resulted in major reductions of the known populations in the region. In comparison to other Southern Bell Frog sites in South Australia, such as wetlands and floodplains of the South Australian Riverland and South-East, overall population abundance for the lakes is considered low (Mason 2011).

Southern bell frogs are opportunistic predators that reside near the edges of wetlands (DEH 2006). Males call in spring and summer from within aquatic vegetation or in open water. Inundation of suitable breeding habitat is one of the known important cues for calling. Females lay jelly-like masses of up to 400 eggs usually after local flooding or rain (DEH 2006). Tadpoles take approximately two days to hatch and then hide within littoral vegetation until metamorphosis occurs in summer and autumn. Alien predatory fish, habitat loss, disease, accumulation of pollutants and possibly increased exposure to ultra-violet-B radiation are thought to be the main factors causing decline of the species (Mason 2011). Their preferred habitats in the lakes and tributaries have generally been Lignum (*Muehlenbeckia florulenta*) shrublands, diverse reedbeds, inundated grasses and dense floating aquatic plants including filamentous algae (Mason 2011).

Southern bell frogs will be highly dependent on dispersal from other sites given their absence at the end of the action period in all scenarios. They will also require the lakes to be in the Freshwater connected state and recovery of vegetated littoral and riparian zones to initiate their recovery.

7.2.6. Birds

The bird receptors selected for ECA tend to be highly mobile and opportunistic. They will come when suitable food and other resources are available and leave when they are not (Rogers ECA workshop participant). Paton (2011) states that bird species may respond differently to the refilling of the lakes and reconnection to the Coorong. Some may disperse to other sites. Others may adjust their distribution, abundance or behaviour to changes in the distribution of suitable habitat and or food and stay at the site. Different birds have different ecological responses and hence different habitat requirements, and their responses may vary spatially and temporally. Furthermore, Paton (2011) states that the response of birds to flows may differ when flows have occurred annually and the ecological conditions of the wetlands are typical compared to when flows return after sustained drought and ecological conditions are degraded when the flows return. There may also be temporal delays in their responses because of the time required for key aquatic food resources and/or habitats to recover. Similarly, birds using the lakes may also respond differently when water levels have been maintained at higher and more consistent levels compared to when they have reached extremely low levels prior to flow events.

Waterbirds that use aquatic vegetation for breeding and feeding (e.g. Waterfowl) are likely to be dependent on initial recovery of aquatic vegetation before they can breed (Figure 7.5). The wide range of waterbirds that use paperbark woodlands as nesting and foraging grounds (Jensen *et al*. 2000) would not be as greatly affected with regard to nesting opportunities because the paperbarks are long-lived and changes in nesting tree availability is likely to happen over many decades of environmental degradation not years. However, food resources appropriate for different life stages, may not be available which would limit recruitment. Habitat suitability maps for the Coorong and Lakes are currently being devised (Paton 2011).

Terrestrial and Fringe-dwelling birds typically occur in fringing wetlands and reed beds. Terrestrial birds, such as Southern emu wren (*Stipiturus malachurus intermedius*) and the EPBC-listed Orange bellied parrot (*Neophema chrystogaster*), tend to be associated with tributary wetlands and are now considered rare and declining (Section 3 and Attachment B). Fringe-dwelling birds occupy reed beds and other dense riparian vegetation and thus have lost their habitat since 2006 when the reed beds were disconnected and desiccated. Both of these bird receptors, Terrestrial and Fringe-dwelling birds will be unlikely to recover until diverse reed beds are re-established and the fringing wetlands are reconnected and vegetated with a diversity of aquatic plants.

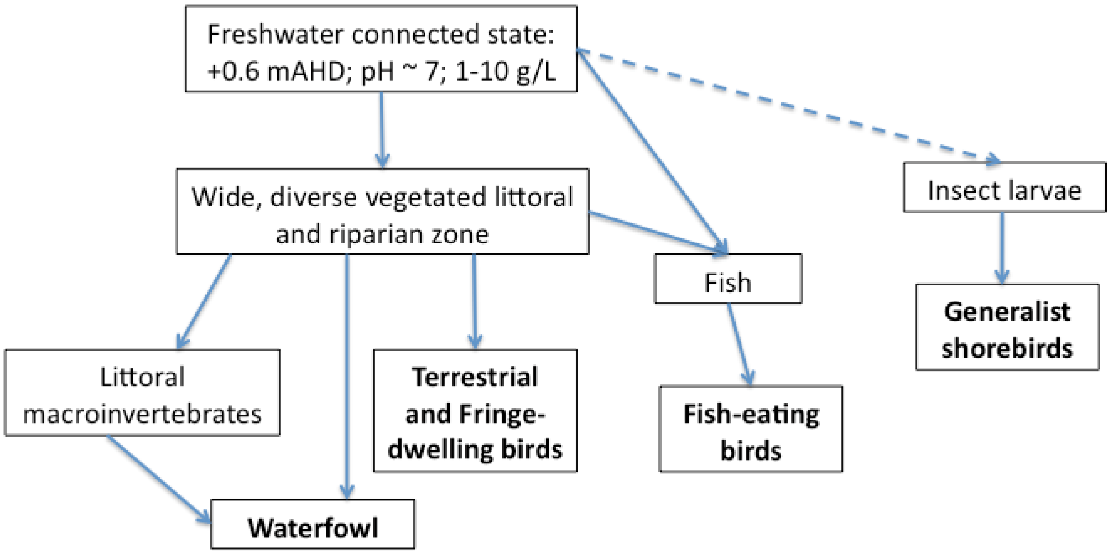


Figure 7.5: Recovery pre-conditions for Birds.

The dashed arrow shows that the Insect larvae community composition will be affected by the ecosystem state.

7.2.7. General requirements for recovery

As well as having specific recruitment and dispersal mechanisms (discussed above), each receptor also has nominal salinity and pH tolerance bands and preferred lake water level ranges (outlined in Table 3.10) which affects their capacity to recover. It is assumed that the capacity of an individual receptor to recover will be nil or negligible if the salinity, water level and/or pH values are outside of their tolerance bands.

Souter and Stead (2010) present detailed biotic group conceptual models as well as state-and-transition models and food webs for the various ecosystem states in the lakes (Attachment 1; Figures 3.1 and 3.2). Lester *et al.* (2011) documents a suite of ecological indicators of health and resilience in the lakes communities and a summary of their known characteristics. Based upon these models and indicator information as well as the expert literature reviews, other literature and above observations, a set of general recovery requirements at a lake-wide scale that are required by all receptors can be devised.

The following requirements would need to be met in order for recovery to be initiated but achievement of these requirements does not necessarily infer recovery:

- export of accumulated salt in the lakes and recovery of lake water salinities to less than 1 g/L for full recovery (Ramsar-state) or less than 10 g/L for partial recovery (Freshwater connected state),
- neutralisation of acid and export of heavy metals, metalloids and other pollutants to within specific receptor tolerances,
- recovery of water levels to at least +0.6 mAHD for riparian zone and to between +0.65 and at least +0.85 mAHD for the floodplain receptors,
- variable water regime that supports wide, well-vegetated riparian and littoral zones,
- presence of viable propagules (resident or migrant) or reproductively functional individuals that can provide new recruits and temporal connectivity of populations,
- successful recruitment often enough to sustain and build the populations,
- suitable habitats for breeding, feeding, shelter and growth of individuals that accommodate all life stages,
- suitable resources to provide energy requirements for all life stages of all receptors (e.g. food, nutrients, light, organic matter), and
- functional connectivity to facilitate exchange of receptors between the river, lakes, Coorong, estuary, Murray Mouth, fringing wetlands, EMLR tributaries and the ocean as required to meet life cycle needs.

7.3. Observations from 2010/11 recovery

Within the lakes area local experts have observed ecological changes post-inundation both behind the Clayton Regulator which was in place during the sustained drawdown and in the lakes themselves as water levels rose over 2010/11. The sustained drawdown began in mid-2006 when water levels in Lakes Alexandrina and Albert began dropping. Lake levels remained lower than sea level (< 0.0 m AHD) from late 2007 to mid 2010. From March 2007 to July 2010, the lakes were hydraulically disconnected from the Coorong and Southern Ocean and salinities in some areas of Lake Alexandrina rose to ≥ 20,000 $\mu S.cm^{-1}$ EC (approximately 12 g/L) (DWLBC 2010). The Clayton regulator was installed in August 2009 and water was pumped from Lake Alexandrina to raise water levels in the Goolwa Channel behind the regulator to +0.7 mAHD in spring 2009, which inundated the previously disconnected and desiccated fringing vegetation (DENR 2010).

River Murray inflows, in the order of 10,000 GL/y during 2010/2011 (Higham pers. comm.), led to rapid increases in lake levels such that by August 2010 typical pre-drawdown lake levels of around +0.7 mAHD had been restored (Muller 2010c). Part of the Clayton Regulator was removed in 2010, re-establishing connectivity between Lake Alexandrina and the tributaries. In August 2010, releases of fresh lake water to the Coorong and Murray Mouth region occurred for the first time since March 2007. Summaries of some of the observed ecological changes that took place behind the Clayton Regulator and following the filling of the lakes are provided below to assist evaluation of the receptors' capacity to recover in the modelled recovery scenarios.

The ecological receptors in the Coorong and Murray Mouth region (e.g. estuarine fish, birds and macroinvertebrates) are not being assessed for capacity to recover here due to the lack of hydrological modelling data for those areas. However, brief notes on ecological changes in those areas are included to aid understanding of how distribution and abundance of freshwater fishes change as flows and connections change as well as understanding how the Lakes and Coorong Ramsar site may respond *in toto*.

7.3.1 Vegetation

Nicol and Ward (2010) stated that the disconnection and subsequent desiccation of the upper elevations of the lake bed resulted in significant adverse changes in the plant communities. Areas that were permanent freshwater wetlands typically containing diverse submergent, emergent and amphibious plant communities (Renfrey *et al.* 1989; Holt *et al.* 2005; Nicol *et al.* 2006) prior to 2007, changed to plant communities dominated by terrestrial species or bare soil (Marsland and Nicol 2009; Gehrig *et al.* 2011). The shift was rapid and extreme with regard to ecological functioning.

The exceptions were wetlands that received rainfall runoff or were filled by pumping (i.e. Narrung). The majority of the colonising terrestrial taxa were exotic agricultural weeds (generally pasture grasses and legumes). The areas inundated by the Clayton regulator which had formerly been dominated by terrestrial taxa and bare soil showed a strong response with amphibious, emergent and submergent plant communities evident within a year. Results from the Narrung Wetland and areas inundated by the Clayton regulator suggest that the aquatic vegetation around the lakes is relatively resilient and can recover after approximately 4 years of drawdown when water levels recovered. However, results from the Goolwa Channel seed bank trials showed a significant decrease in the number of germinants and species richness when salinities exceeded 5,000 $\mu S.cm^{-1}$ EC (approximately 3 g/L) (Nicol and Ward 2010b) which suggests that more prolonged drawdown or higher salinity levels may result in less rapid or complete recovery of the aquatic plant communities.

The reed beds around the lakes had been simplified by static lake levels under typical operating conditions between the 1940s and 2006 (Phillips and Muller 2006) and were not in a condition to optimally support the full complement of Ramsar ecological components (Lester *et al.* 2011). When the lake levels first returned to normal operating levels in winter 2010 reed beds began to re-establish and effectively recovered during spring 2010 and summer 2010/2011 to a condition similar to that prior to the drawdown (Gehrig *et al.* in prep.). More complex vegetation in areas such as fringing wetlands or sheltered parts of the littoral zone have not yet recovered and may take several years to recover in terms of abundance and richness (Nicol pers. comm.), if at all. Specialist lake plants like Myriophyllum caput-medusae have not been seen since 2006 (Gehrig *et al.* 2011) and may not re-establish in the foreseeable future because of a lack of propagules.

7.3.2. Lacustrine Macroinvertebrates

In February 2011, macroinvertebrate sampling around the tributaries and in both lakes by Goonan (pers. comm.) showed that the Lacustrine macroinvertebrate communities were generally in poor condition with dominance by early colonising, flying insect and crustacean groups that are tolerant of brackish salinity. Richness varied from 10 to 31 taxa at the various sites (compared to 100 taxa found prior to 2006, Napier 2011) with most taxa present in low numbers. There were indications of more complex communities forming in newly flooded habitats in Currency Creek and Finniss River which have been inundated for longer and contain more diverse, complex aquatic plant communities (Nicol and Ward 2010 a and b).

Goonan (pers. comm.) notes that the water column in the lakes was typically well-oxygenated but highly turbid due to large amounts of phytoplankton (including cyanobacteria) and/or incoming turbid water from the River Murray. The poor overall macroinvertebrate condition was attributed to high flow volumes passing through channel habitats quickly and a lack of habitats (typical of the pre-drawdown condition) for macroinvertebrate communities to occupy. The north-eastern corner of Lake Alexandrina (e.g. Boggy and Dog Lakes) was notable in that habitat was provided for chironomid larvae (Cladotanytarsus) and moderate numbers of freshwater shrimp (Paratya) and freshwater prawns (Macrobrachium) which appeared to be extending across the lake (Goonan in prep.). Goonan suggests that the macroinvertebrate community could become more diverse with a much higher abundance over the next year, provided that salinity remains fresh and water levels remain high enough to support re-establishment of well-vegetated riparian and littoral habitats.

7.3.3. Estuarine macroinvertebrates

Dittman *et al.* (2011) states that Goolwa Channel was primarily inhabited by freshwater (lacustrine) macroinvertebrates, with estuarine polychaetes occurring only near the barrages. Diversity was low, but insect larvae and amphipods occurred in high abundances at several sites. While abundances were significantly different across sites, no distinct assemblages were apparent. Sediments between the Goolwa barrage and North Lagoon were inhabited by 20 macroinvertebrate species, with approximately equal numbers of annelids, crustaceans and insects.

The presence of small and large sizes of polychaetes in December 2010, in particular, indicated that recruitment had occurred in spring, yet the juvenile samples provided little evidence for further recruitment in December and January. The absence of the pollution indicator Capitella from the sampling sites in the Murray Mouth can be seen as a sign of improved environmental conditions in the estuary following the flushing that accompanied the water release. There was no evidence of settlement or presence of tubeworms in February 2011 suggesting that their invasion of the lakes had been halted or gone into hiatus. Prolonged freshwater conditions reduced numbers of some estuarine benthic macroinvertebrates, however, increased connectivity with adjacent habitats together with improved environmental health of the estuary were considered likely to initiate recovery.

7.3.4. Fish

Bice and Zampatti (2011) investigated the freshwater fish response to the Clayton Regulator installation in 2010/11 and compared this to the response of fish in 2009/10. A total of 15,109 fish were sampled from 17 species in December 2010. The most abundant species in descending order were redfin perch, bony herring, flat-headed gudgeon, small-mouthed hardyhead, Australian smelt and common carp, which collectively contributed > 90% of all fish sampled. The presence of several estuarine species in December 2009 and April 2010 increased species richness compared to other sampling events. Redfin perch were much more abundant in December 2010 than during all sampling events in 2009/10 as a result of recruitment of young-of-year (YOY) fish. Common carp also successfully bred in 2009/10 and 2010/11. Partial connectivity between the Coorong and Goolwa Channel/Lake Alexandrina combined with significant freshwater flows in 2010/11 appears to have supported recruitment of Congolli as well. Murray hardyhead were in low numbers on both sides of the Clayton Regulator suggesting it was not recovering.

Ye *et al.* (2011) and Wedderburn *et al.* (2011) undertook fish sampling in the Coorong and Murray Mouth region. In winter/spring 2010, increased flows in the River Murray resulted in the first barrage releases into the Coorong since 2007. Ye *et al.* (2011) found that fish assemblage structure differed significantly during the barrage releases from those in no flow years (i.e. 2006 and 2007). This was mainly attributed to increased abundances of freshwater species, as well as several estuarine species. Preliminary results also indicated a southward range expansion of some key estuarine species, such as black bream, greenback flounder and yellow-eye mullet. In addition, there appeared to be successful recruitment of congolli with young-of-the-year fish collected throughout the Murray Estuary and Northern Lagoon.

The restoration of functional connectivity, at least in part, by barrage outflows is supported by data from Wedderburn *et al.* (2011) who found that the Coorong channels were inundated with fishes from the Lower Lakes in December 2010. Overall 38,055 fish representing 25 species were captured in the study. Freshwater fish dominated the samples in December 2010 (>60% of catch), especially young-of-year of the alien redfin perch. In February, redfin perch was less abundant and the catch was dominated by two native freshwater species, flathead gudgeon and bony herring. Smallmouth hardyhead was one of the most numerous estuarine species, which is typical in the Coorong. Wedderburn *et al.* (2011) affirm that breeding occurred for two diadromous fish species at the Coorong prior to December 2010: Congolli and Common galaxias. In February, an adult short-finned eel was captured moving upstream towards the Boundary Creek Barrage suggesting that flow-related migration cues were effective for this species.

7.3.5. Southern bell frog

Between October 2010 and February 2011, Mason (2011) found Southern Bell Frogs at five sites in the north and western areas of the study region within Pelican Lagoon, south of Wellington, Finniss River, Hindmarsh Island and Clayton Bay. The highest occupancy was within recently inundated, vegetated and sheltered areas, comprising of both inundated terrestrial, emergent and submerged vegetation. All sites found to contain Southern Bell Frog contained diverse plant assemblages and were not dominated by the Common Reed (Phragmites australis) or Bullrush (Typha domingensis). Successful recruitment was observed at only one location at Pelican Lagoon. Recruitment may not have occurred at remaining occupied sites due to only intermittent inundation of suitable breeding habitat.

7.3.6. Birds

Low lake levels and high salinities have changed food resources and habitats for most of the bird receptors. Despite these ecological changes, and despite changes in the distribution and abundance of many species within these wetlands, large numbers of waterbirds still use the lakes and Coorong, and they remained the key drought refuge within the Murray Darling Basin, accounting for over 95% of the waterbirds counted across The Living Murray icon sites over the last 2-3 years (Paton 2011). Paton (2011) suggests that caution is required in the analysis of bird data because of the myriad factors they may be responding to. For example, numbers of waterbirds using the Goolwa Channel in January 2010 were higher than in January 2009 when the water levels were exceptionally low, but increases for some species were also detected in the areas of the lakes outside of the regulator's influence that remained at low water levels. At least two waterbird species were found by Paton (2011) to have bred in the Goolwa Channel in spring 2009 (Black Swan and Pacific Black Duck) but not in the previous year in the Goolwa Channel or elsewhere across the lakes in either year. The increases in water levels in the Goolwa Channel in spring 2010 inundated littoral vegetation, providing suitable habitat for those species to breed, which was not provided elsewhere across the lakes. The lack of baseline data on birds negates assessment of whether the populations in Goolwa Channel had recovered due to installation of the Clayton Regulator.

7.4. Hydrological modelling outputs: Water levels and salinity during the entitlement and average flow recovery periods.

Two different River Murray flow regimes were analysed for the recovery period: Entitlement flows (1,850 GL/y over SA border) and Average flows (4,000 to 5,000 GL/y over SA border). Hydrological modelling output files were provided for the Average flows recovery scenario and these were analysed for spatial and temporal changes in water and salinity levels in the two lakes. Output files were not provided for the Entitlement flows recovery scenarios but Wainwright and Hipsey (2010) provide sufficient information on the timing of changes in lake water and salinity levels during the Entitlement flows recovery period to assess ecological recovery potential. The acidification risk due to refilling of the lakes was explored in detail by Wainwright and Hipsey (2010) and they concluded acidification will not be a risk during either the Entitlement or Average flow recovery periods, therefore, pH simulations were not provided.

The hydrological modelling assumed well-mixed conditions in each lake. Although there will be salinity gradients, Wainwright and Hipsey (2010) suggest that the very long nature of these recovery scenarios (ten years) make this a reasonable assumption for purposes of simulating salt accumulation or flushing which are the key drivers of salinity change in the lakes.

7.4.1. Salinity and water level recovery under Entitlement flows

Lake Alexandrina

When pumping to Lake Albert continues, water levels in Lake Alexandrina begin to increase, gradually rising to -0.75 mAHD (± 0.25m) over the first six years of recovery (by 2021). This level will be reached for all three management scenarios (Do-Nothing, Seawater and Freshwater) even though levels in the Do-Nothing scenario were lower during the action period. Water levels of -0.75 mAHD are approximately 75 cm lower than sea level and 1.35 m below the typical lake levels prior to the drawdown (+0.6 mAHD). Therefore, a recovery to pre-2006 water levels will not be achieved. Average salinity decreases to less than 2 g/L for the Do-Nothing scenario. For the Seawater scenario, salinities will be higher for longer, reducing to 20 g/L by 2017 and to < 4g/L by 2020. Conditions will be freshest under the Freshwater scenario, within which salinities will decrease to 1 g/L. These are all within the fresh concentration band (< 10 g/L) but are not as low as the Ramsar target salinities (< 0.64 g/L; Attachment A).

When pumping to Lake Albert from Lake Alexandrina ceases, water levels in Lake Alexandrina increase more rapidly during the recovery period and will reach higher levels, approximately sea level (0.0 mAHD) from 2020 onwards, than if pumping continues. Under the Do-Nothing scenario there will be a drop to 5 g/L by the time the lakes reach 0.0 mAHD. Under the Seawater scenario, salinities will drop to 40 g/L by 2017 and 16 g/L by 2020 when the lake will be at 0.0 mAHD. Salinity will not get as high in the Freshwater action period and it will decrease to ~ 4 g/L by the time water levels reach 0.0 mAHD.

Lake Albert

When pumping to Lake Albert continues, average water levels will rise to just below 0.0 mAHD in the first five years of the ten-year recovery period (2020). Salinities drop to 36 g/L (approximately sea water concentrations) for the Do-Nothing and Freshwater scenarios but only drop to 170 g/L under the seawater scenario. Pumping water to Lake Albert from Lake Alexandrina during the recovery period will remove salt from the former and accumulate it in the latter. Thus Entitlement flows will not recover pre-action salinities in Lake Albert. It is assumed that during this time the Narrung Narrows bund will stay in place and the lakes will remain hydrologically disconnected (aside from the pumping).

Recovery under Entitlement flows was not modelled for the Lake Albert cease-pumping scenarios because Lake Alexandrina water levels will only reach 0.0 mAHD and thus pumping from Lake Alexandrina to Lake Albert will not be possible during the recovery period. The Narrung Narrows will stay in place; therefore, Lake Albert will not receive any surface water from 2010 to 2025 under Entitlement recovery flows in the cease-pumping scenarios.

7.4.2. Salinity and water level recovery Average flows

Lake Alexandrina

Water levels will recover to 0.0 mAHD within six months (early spring 2016) in all scenarios. Commensurate reductions in salinities will occur such that salinities in the Do-Nothing and Freshwater scenarios will be approximately 5 g/L and salinities in the Seawater scenario will be approximately 15 g/L by spring 2016. Water levels will continue to rise above 0.0 mAHD in all scenarios such that by February 2017 (18 months) the lakes will reach approximately +0.6 mAHD, equivalent to the typical regulated lake levels prior to 2006.

Within six months of recovery starting, the whole of Lake Alexandrina will contain fresh water (< 2g/L) but salinities will not be low enough to meet the Ramsar target (Attachment A). The water will be well mixed so that within two years (winter 2017) no salinity gradients will be apparent and the whole of Lake Alexandrina will be < 1.5 g/L. Lake Alexandrina will remain fresh from then onwards.

Salinities will be lowest in winter, typically around 1 g/L and homogenous. In summer, there will be a slight gradient across the lake from lower in the north-west to higher in the south-east. Surges of water moving into and out of Lake Albert throughout the recovery period will cause minor, localised salinity plumes around the Polltaloch Plains in Lake Alexandrina of up to 3 g/L. Salinities in the northern most part of Lake Alexandrina will respond seasonally to river flows being typically 0.2 to 0.4 g/L during winter and rising over summer (NB: these are below the Ramsar target). The summer salinities will be greatest in the Seawater scenario although summer salinities in the river-influenced areas will stay below 2.5 g/L in all three pumping scenarios.

Salinity in Goolwa Channel will initially increase when water levels recover and previously dry and saline sediments become inundated. Within two years of recovery starting (January 2017), salinities will drop to < 1g/L in the Do-Nothing and Freshwater scenarios and remain fresh and near to the Ramsar target (< 0.64 g/L).

By contrast, it will take 12-18 months longer for the salinities to drop to < 1 g/L in Goolwa Channel under the Seawater scenario and there will be a notable difference that persists throughout the 10-year recovery period (i.e. until the end of 2025). A sudden spike in salinity that occurs after the initial inundation of Goolwa Channel during refill will not be as great when pumping to Lake Albert ceases but otherwise the rates and levels of salinity decrease will be very similar within the paired pumping and cease-pumping scenarios during the recovery period.

Lake Albert

When pumping continues, water levels in Lake Albert increase at a similar rate to that observed in Lake Alexandrina. Once the lake fills to greater than +0.3 mAHD (approximately 12 months into recovery period), it is assumed that the Narrung Narrows regulator will be removed and connectivity between the two lakes will be restored. Salinities in the Do-Nothing and Freshwater scenarios will drop from brackish-saline to fresh conditions (6 g/L in the Do-Nothing and 3.5-4 g/L in the Freshwater) within the 10-year recovery period (2025). During the Seawater action period, saline water will be pumped into Lake Albert and salinities will reach hypersaline concentrations (model failed at 115 g/L; Section 5). Lake Albert salinities will drop markedly under Average recovery flows although the lake will remain more saline under the Seawater scenario (10 g/L) than under either the Do-Nothing (6 g/L) or Freshwater (~4 g/L) scenarios at the end of the 10-year recovery period.

Under the cease-pumping scenario, the water that will remain in the isolated pools in Lake Albert will be hyper-concentrated and nearing saturation with salt. Once the lakes reconnect and relatively fresh water flows in from Lake Alexandrina, Lake Albert will refill and within six months salinities will drop to fresh concentrations in the Freshwater and Do-Nothing scenarios (~5 g/L) and saline conditions in the Seawater scenario (~20 g/L). The poor flushing between the lakes will result in a slow decline in salinity in Lake Albert. By the end of the 10-year recovery simulation (2025), salinities in Lake Albert will be around 3.5 g/L for Do-Nothing and Freshwater and 8.5 g/L for Seawater.

7.5. Assessment of Ecological capacity to recover

The following qualitative assessment of the capacity of ecological receptors to recover from the actions under Entitlement and Average recovery flows is based upon:

- antecedent conditions predicted from likely impacts on receptors during the action period in each scenario (Sections 4 to 6);

- knowledge of recovery strategies collated from the literature, primarily the literature reviews prepared by the contributing experts (Section 7.2);
- monitoring data and observations of ecological changes behind the Clayton Regulator in 2009/2010 and in the lakes during 2010/2011 as refill occurred (Section 7.3);
- health and resilience ecological indicator information (Lester *et al.* 2011)
- conceptual models and food webs of the lakes ecosystem (Souter and Stead 2010; Attachment A); and
- hydrological modelling outputs for water and salinity levels during the recovery periods (Section 7.4; Wainwright and Hipsey 2010).

7.5.1. Ecological recovery in Lake Alexandrina

Entitlement recovery flows

As discussed above, water levels will only return to a level of -0.75 mAHD under Entitlement recovery flows. This represents a short fall of 1.35 to 1.6 metres in lake level and several kilometres of exposed sediments around Lake Alexandrina compared to normal pre-2006 operating levels and optimal lake levels (Muller 2010c). As well as providing less open water habitat, the water will not be high enough to inundate the former littoral and riparian zones, which grew at approximately +0.6 mAHD.

Figures 7.6 to 7.8 show that even though salinities return to fresh concentrations (< 10 g/L) and pH is circum-neutral in Lake Alexandrina with Entitlement recovery flows, the receptors are not expected to make a full recovery primarily because the vegetation will not recover and therefore the ecological pre-conditions for recovery (Figures 3.1 to 3.3) of other receptors will not be met under any regional water management option. Habitat and food resources for survival, growth and recruitment of most, if not all, of the receptors will be extremely limiting and likely to become exhausted (see also Attachment G).

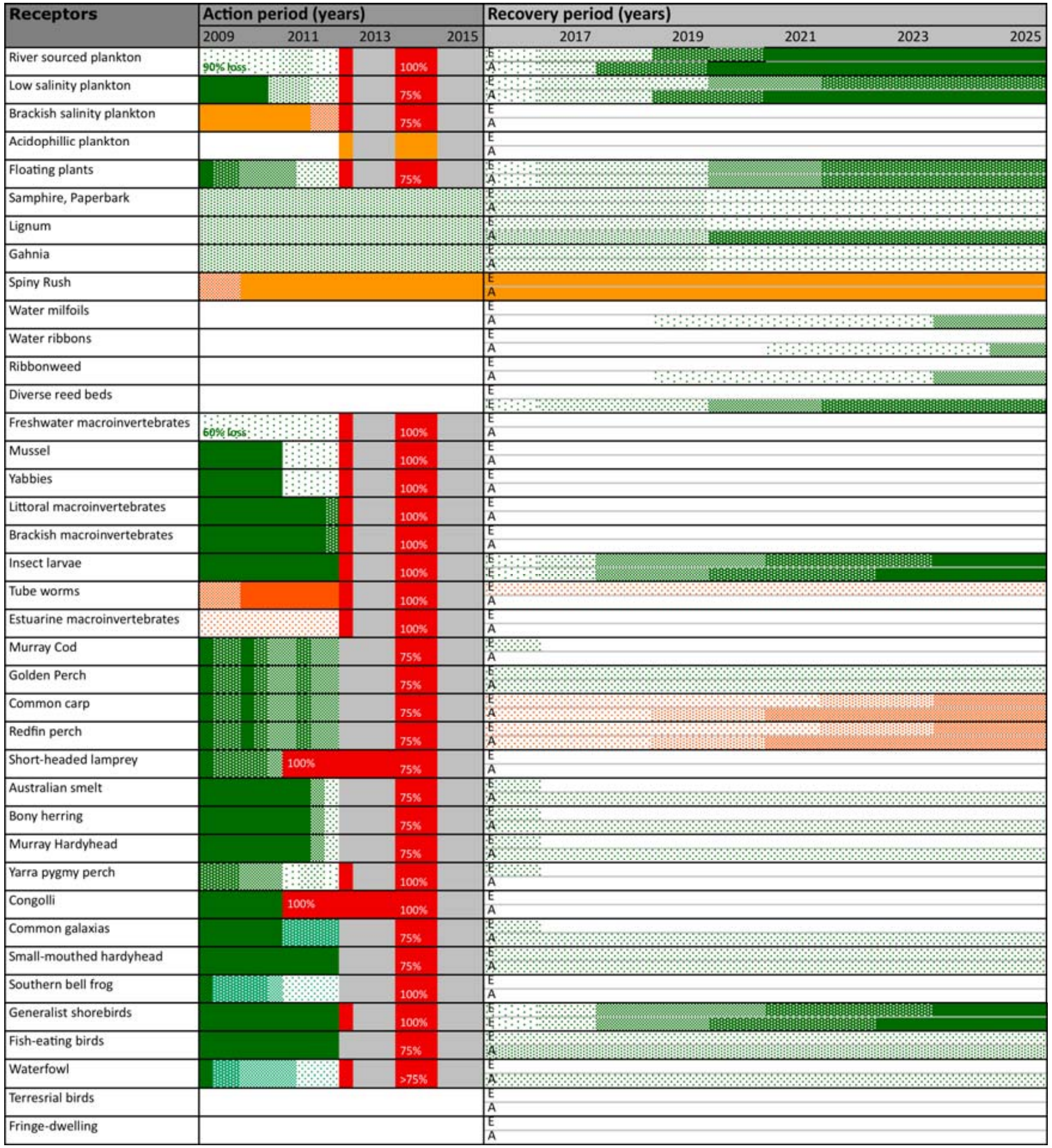


Figure 7.6: Consolidated effects on receptors during the action and recovery periods for Do-Nothing Pumping in Lake Alexandrina.

E = Entitlement recovery flows. A = Average recovery flows.

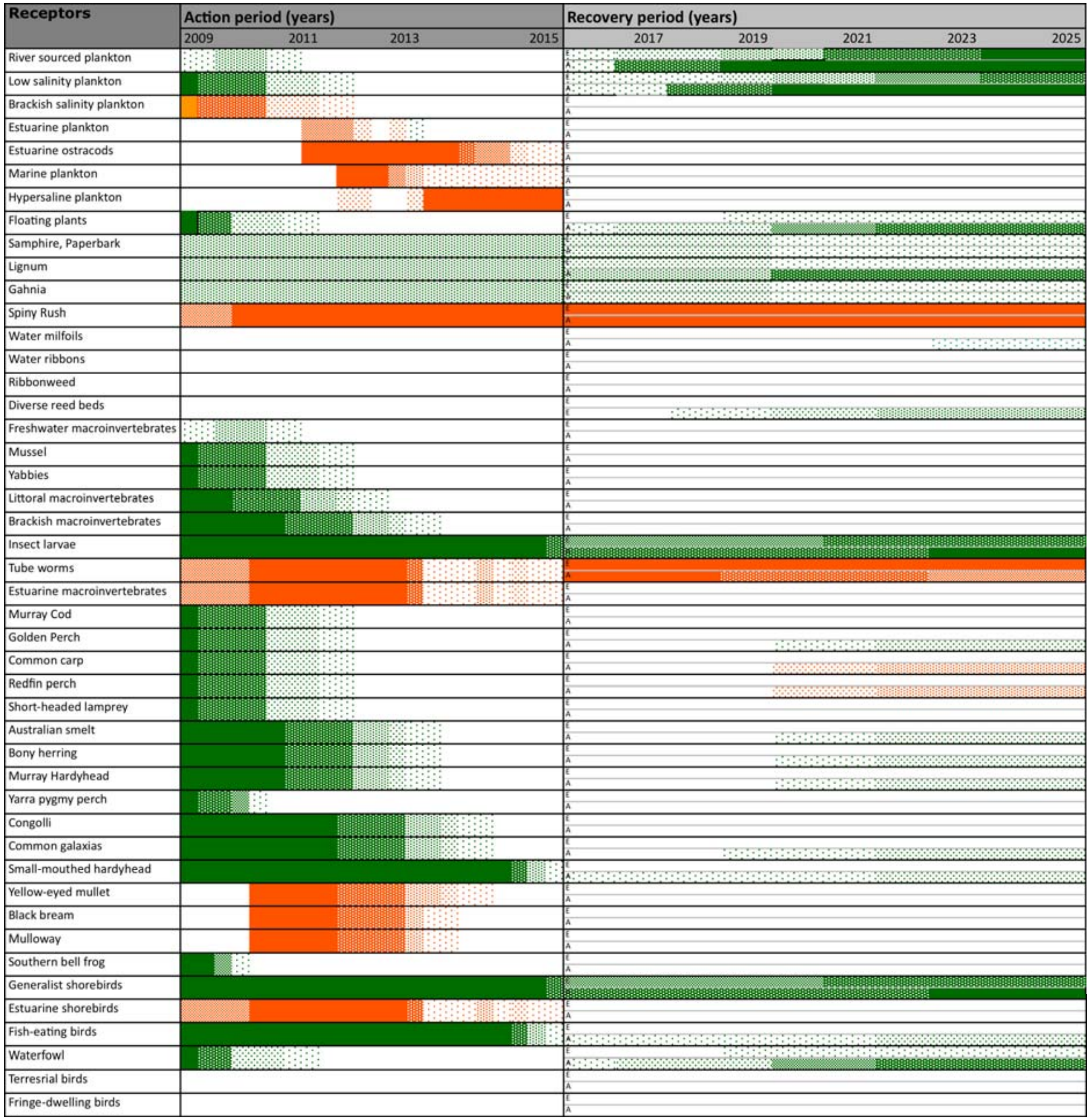


Figure 7.7: Consolidated effects on receptors during the action and recovery periods for Seawater Pumping in Lake Alexandrina.

E = Entitlement recovery flows.

A = Average recovery flows.

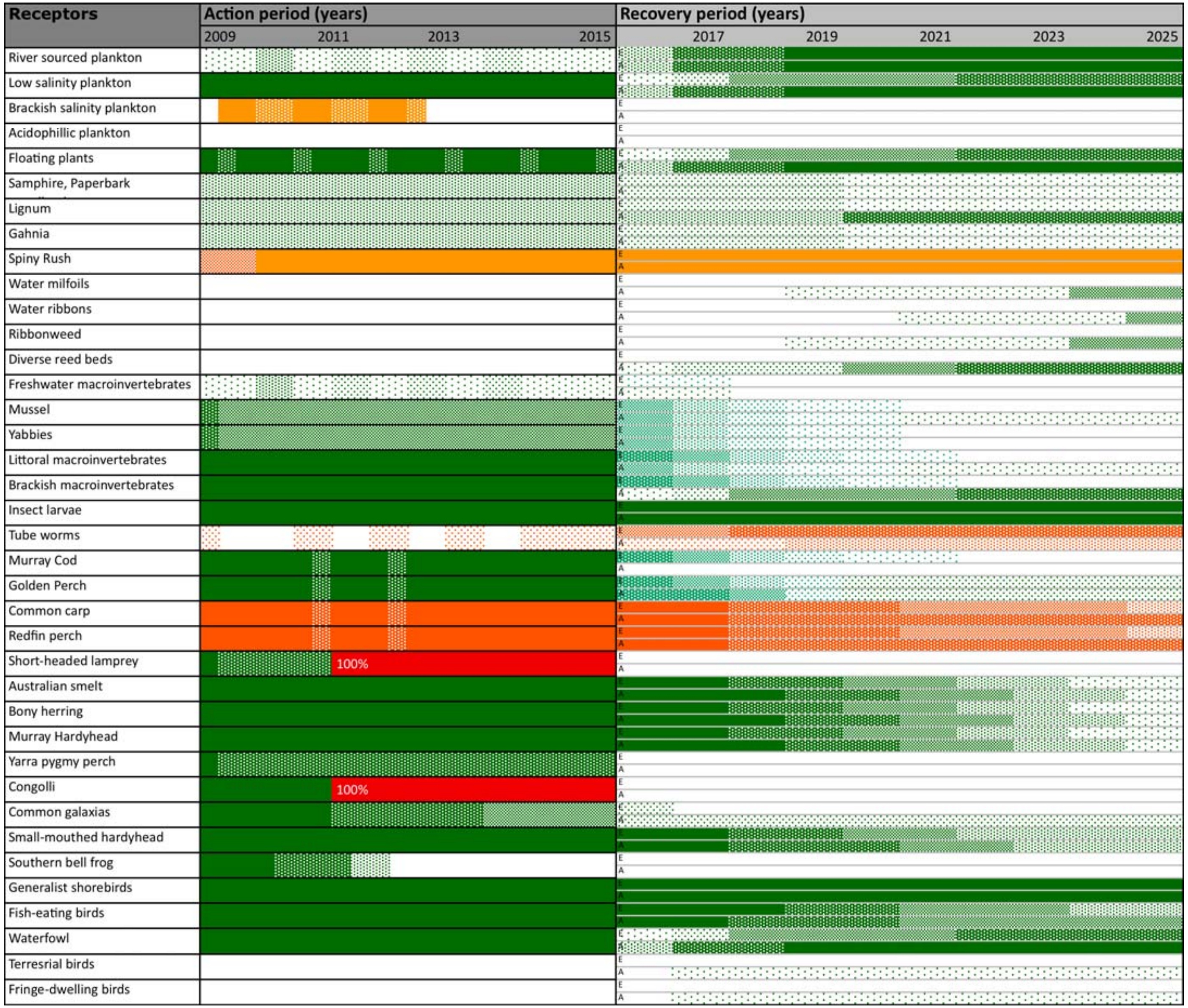


Figure 7.8: Consolidated effects on receptors during the action and recovery periods for Freshwater Pumping in Lake Alexandrina.

E = Entitlement recovery flows. A = Average recovery flows.

More of the resident lake receptors will persist through the action period under the Freshwater scenario than under either the Do-Nothing or Seawater scenarios. However, no receptors will recover to pre-action condition or significantly increase over the ten-year recovery period even in the Freshwater scenario. The exception is River-sourced plankton which will be reseeded each time the River Murray flows into the lakes. If Tubeworms re-colonise Lake Alexandrina, they are most likely to proliferate in the Do-Nothing and Seawater scenarios, causing on-going stress to the biota they damage (e.g. turtles).

All native fish that persist through the various action periods will decline under Entitlement recovery flows due to food and habitat limitations and the probable lack of recruitment. It is likely that Redfin perch (introduced) that are carried in with River Murray flows will come to dominate the fish populations in the latter stages of the recovery period because of their very high adaptability. Other fish, such as Common carp (introduced) and Golden perch (native) may survive being washed in with River Murray water but it is unlikely that strong and diverse fish communities will re-form.

If pumping to Lake Albert ceases, then water levels in Lake Alexandrina will increase to approximately 0.0 mAHD from 2020 onwards under Entitlement flows. This is significantly higher than if pumping continues but is not high enough to inundate the former lake edge where the aquatic plant propagules were and thus recovery of littoral, riparian and floodplain vegetation is unlikely (Figures 7.9 to 7.11). Consequently, those receptors dependent on recovery of aquatic vegetation will also not recover. Salinities in Lake Alexandrina will take longer to reduce when pumping to Lake Albert ceases because salt will not be exported to Lake Albert. This slower reduction in salinity will have adverse impacts on recovery of receptors, particularly the juvenile life stages that tend to be more salt-sensitive than older life stages.

Overall, recovery under Entitlement flows will be very similar in Lake Alexandrina whether pumping to Lake Albert continues or not for all receptors, except perhaps those that are able to utilise the greater volume of open water habitat in the cease-pumping scenarios (e.g. Low-salinity plankton, Floating plants and some fish). For these receptors, conditions will be better but still far more adverse than in the baseline state.

Average recovery flows

By contrast under Average recovery flows, water levels in Lake Alexandrina will return to pre-2006 typical operating levels (approximately +0.6 mAHD) within eighteen months of recovery commencing. Salinities will drop to fresh concentrations (< 10 g/L) in the Do-Nothing and Freshwater scenarios within six months of recovery and in the Seawater scenario within nine months (Section 7.4.2). Salinities will not drop low enough to meet the Ramsar target (< 0.64 g/L), except in winter within the northern areas directly under the influence of River Murray inflows. There were no significant differences in ecological recovery in Lake Alexandrina under Average flows between the paired pumping and cease-pumping scenarios.

Recovery will be better under Average flows than under Entitlement flows but it will still not be complete (Figures 7.6 to 7.8). Of paramount ecological importance, is the probable return of aquatic plants under Average recovery flows. Re-establishment of emergent aquatic plants will take time. Reed beds will probably grow into a semi-continuous band around the majority of the lake shore within five to seven years of Average recovery flows (i.e. by early 2020's), if salinities remain fresh and the water level fluctuations are not too great (i.e. levels remain between +0.4 and +0.8 mAHD).

Figure 7.9: Consolidated effects on receptors during the action and recovery periods for Do-Nothing Cease Pumping in Lake Alexandrina.

E = Entitlement recovery flows. A = Average recovery flows.

Figure 7.10: Consolidated effects on receptors during the action and recovery periods for Seawater Cease Pumping in Lake Alexandrina.

E = Entitlement recovery flows. A = Average recovery flows.

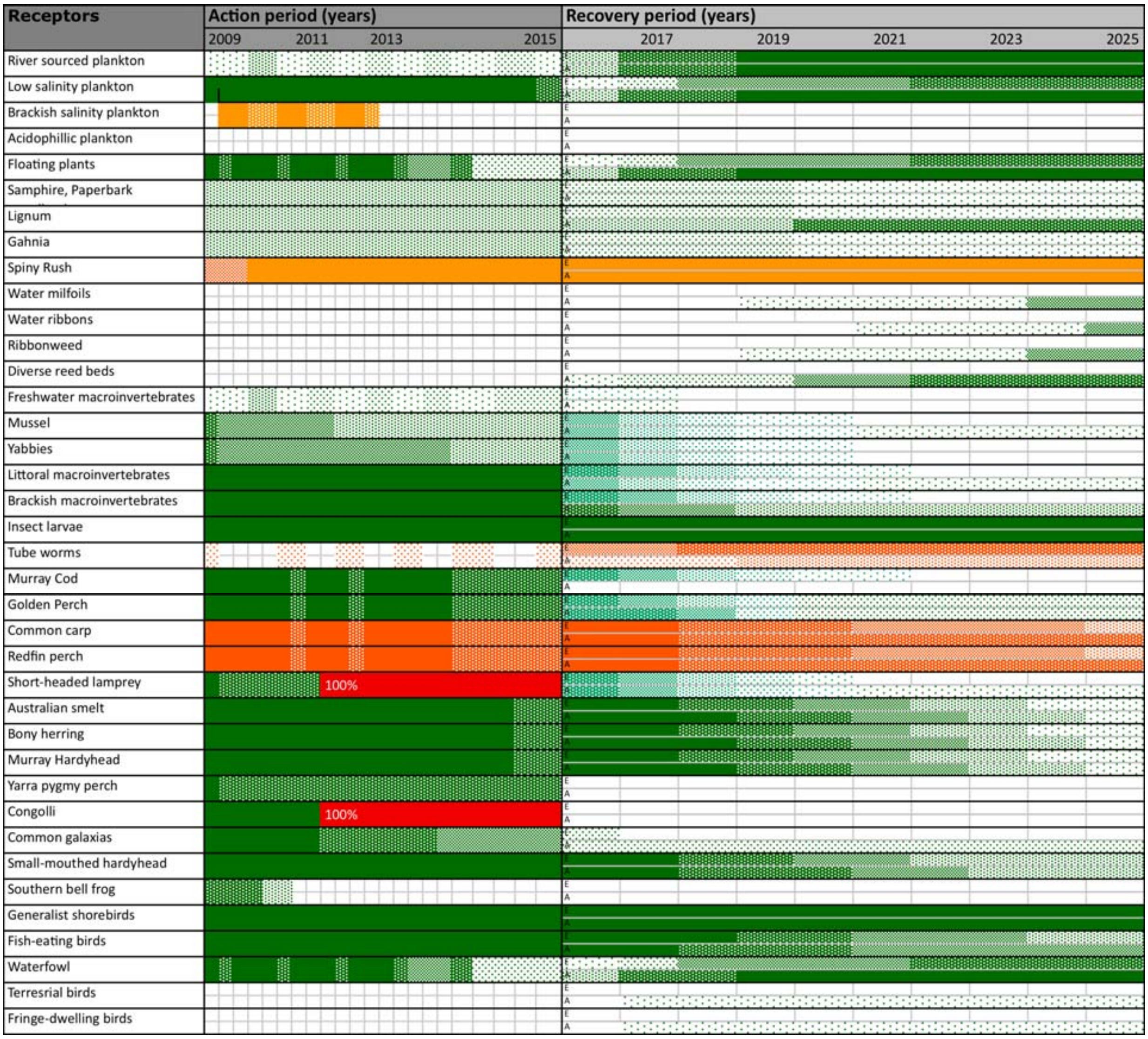


Figure 7.11: Consolidated effects on receptors during the action and recovery periods for Freshwater Cease Pumping in Lake Alexandrina.

E = Entitlement recovery flows. A = Average recovery flows.

However, these reed beds will most likely be less diverse and more simplified in structure and function than they were prior to 2006 at which time diversity of reed beds was declining and seen as a major threat to maintenance of Ecological Character (Phillips and Muller 2006).

Spiny rush (introduced) and the native P. australis and T. domingensis will mostly likely dominate the new riparian vegetation, providing a relatively sterile habitat that will not meet the objectives of a healthy and resilient wetland described by Lester *et al.* (2009). The fringing wetlands and sheltered embayments will have been salinised, acidified and desiccated for twelve years before being inundated and reconnected to the main lake body and thus may not fully recover for several decades, if at all. Plant species that were found in the lakes but not in the river, may not re-establish due to a lack of incoming propagules. Recovery of submerged and semi-emergent vegetation, particularly in the fringing wetlands and sheltered bays where the highest levels of diversity were found prior to the 2006 drawdown, is the least certain. Water ribbons may establish later in the sequence, within the shelter provided by the reed beds, from seeds washed in from the River Murray or the tribuatries. The recovery of faunal receptors (e.g. Lacustrine macroinvertebrates, fish, birds) will be more or less directly dependent upon the diversity and abundance of vegetation and thus will be limited or delayed.

7.5.2. Ecological recovery in Lake Albert

Entitlement flows

When pumping to Lake Albert continues under Entitlement flows, water levels will increase to an average level around 0.0. mAHD but salinities will remain very high throughout the recovery period, being marine (25-50 g/L) in the Freshwater and Do-Nothing scenarios and extremely hypersaline in the Seawater scenario (50 -150 g/L). Little or no ecological recovery will occur in Lake Albert under these conditions (Figures 7.12 to 7.14). The former riparian plants will not re-establish. Some Brackish plankton and Floating plants brought in through pumps may survive in the Do-Nothing and Freshwater scenarios but not in the Seawater scenario because salinities will remain too high. Spiny rush may colonise the exposed lake bed and could dominate the vegetation (along with invasive terrestrial plants) to the detriment of most other flora and fauna.

Fish receptors that persist through the various action periods will decline and ultimately be lost during the 10-year recovery period because of limited food and habitat resources (Figures 3.1 to 3.3). Fish numbers on both sides of the Narrung Narrows regulator will be lower in the Seawater scenario compared to the Do-Nothing and Freshwater scenarios. Fish-eating birds may sporadically increase in number, for example, when fish are easy to catch around the pumps. The extremely tolerant Insect larvae and potentially the Generalist shorebirds that feed upon them will be the only receptors likely to increase in abundance and/or diversity during the recovery period and then only in the Do-Nothing and Freshwater scenarios because the water will fresher than in the Seawater scenarios. The former Lake Albert ecosystem will not be restored under Entitlement flows even if pumping continues.

There will be little or no recovery by receptors in Lake Albert under Entitlement flows if pumping ceases during the action period (Figure 7.15). Water levels in Lake Alexandrina will not get high enough to recommence pumping and the Narrung Narrows regulator will remain in place throughout the recovery period, therefore, Lake Albert will remain disconnected. It will be an essentially dry expanse of exposed ASS with isolated pools of acidified, saline-saturated water that may support extreme acidophillic microbes, at best.

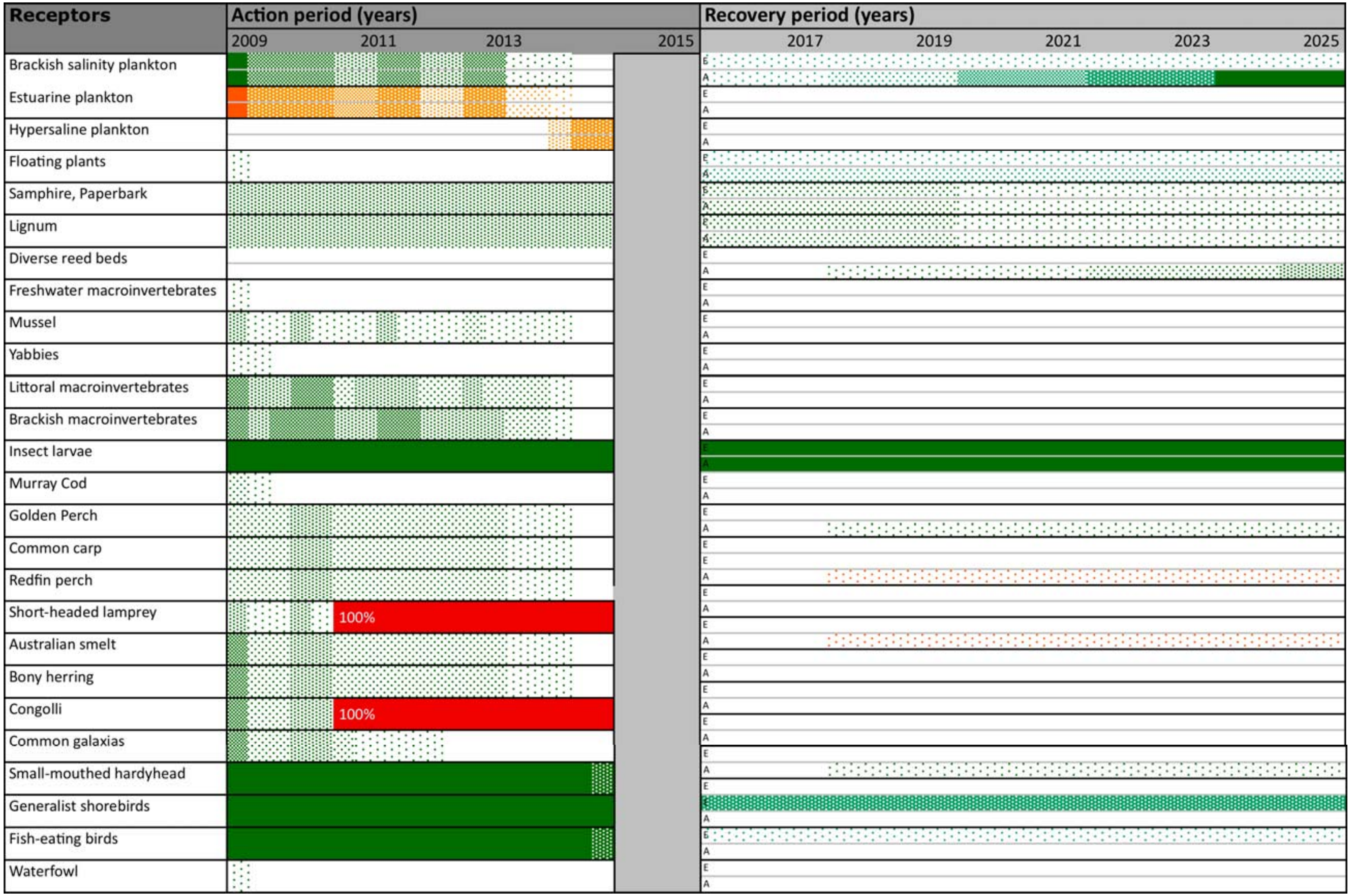


Figure 7.12: Consolidated effects on receptors during the action and recovery periods for Do-Nothing Pumping in Lake Albert.

E = Entitlement recovery flows. A = Average recovery flows.

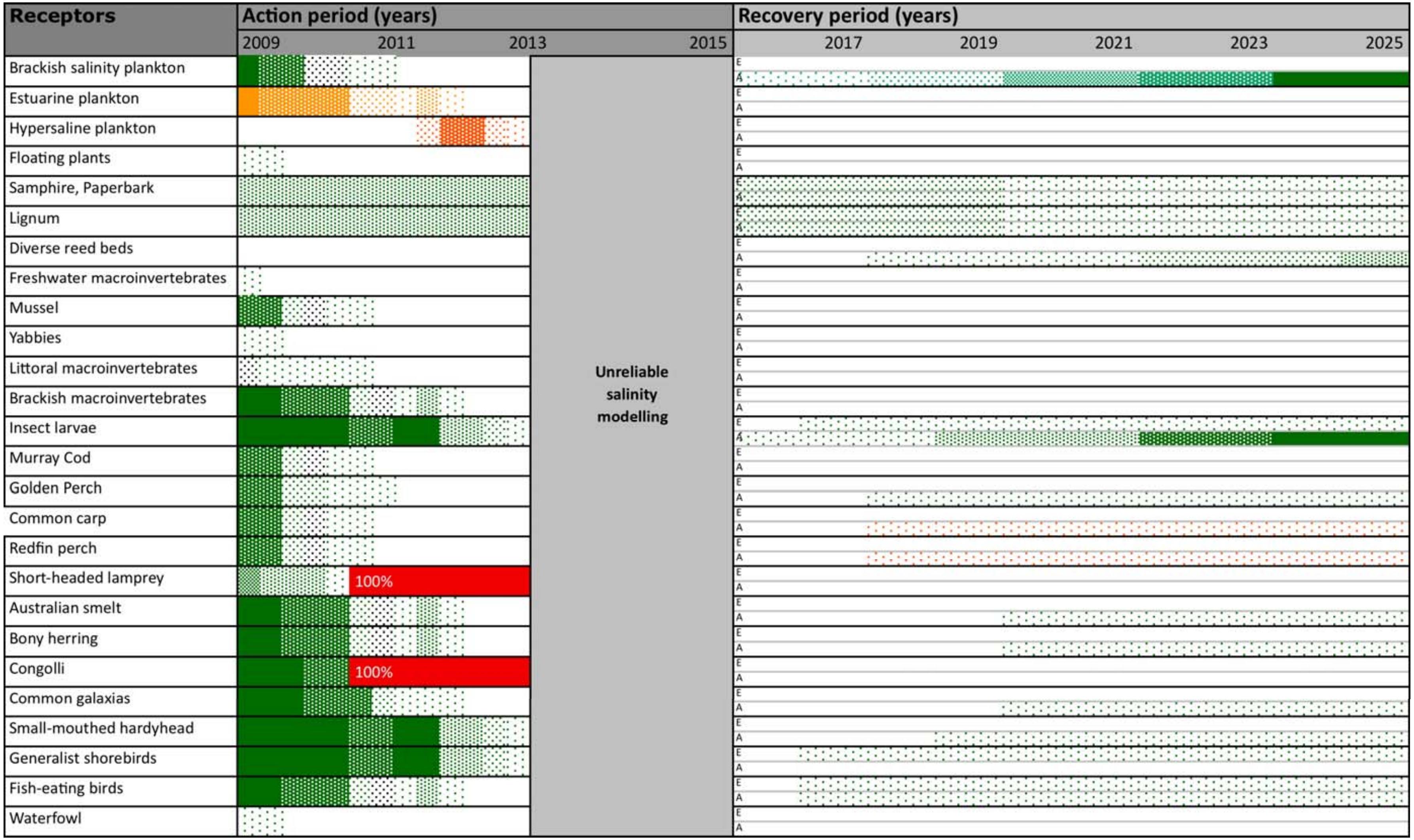


Figure 7.13: Consolidated effects on receptors during the action and recovery periods for Seawater Pumping in Lake Albert.

E = Entitlement recovery flows. A = Average recovery flows.

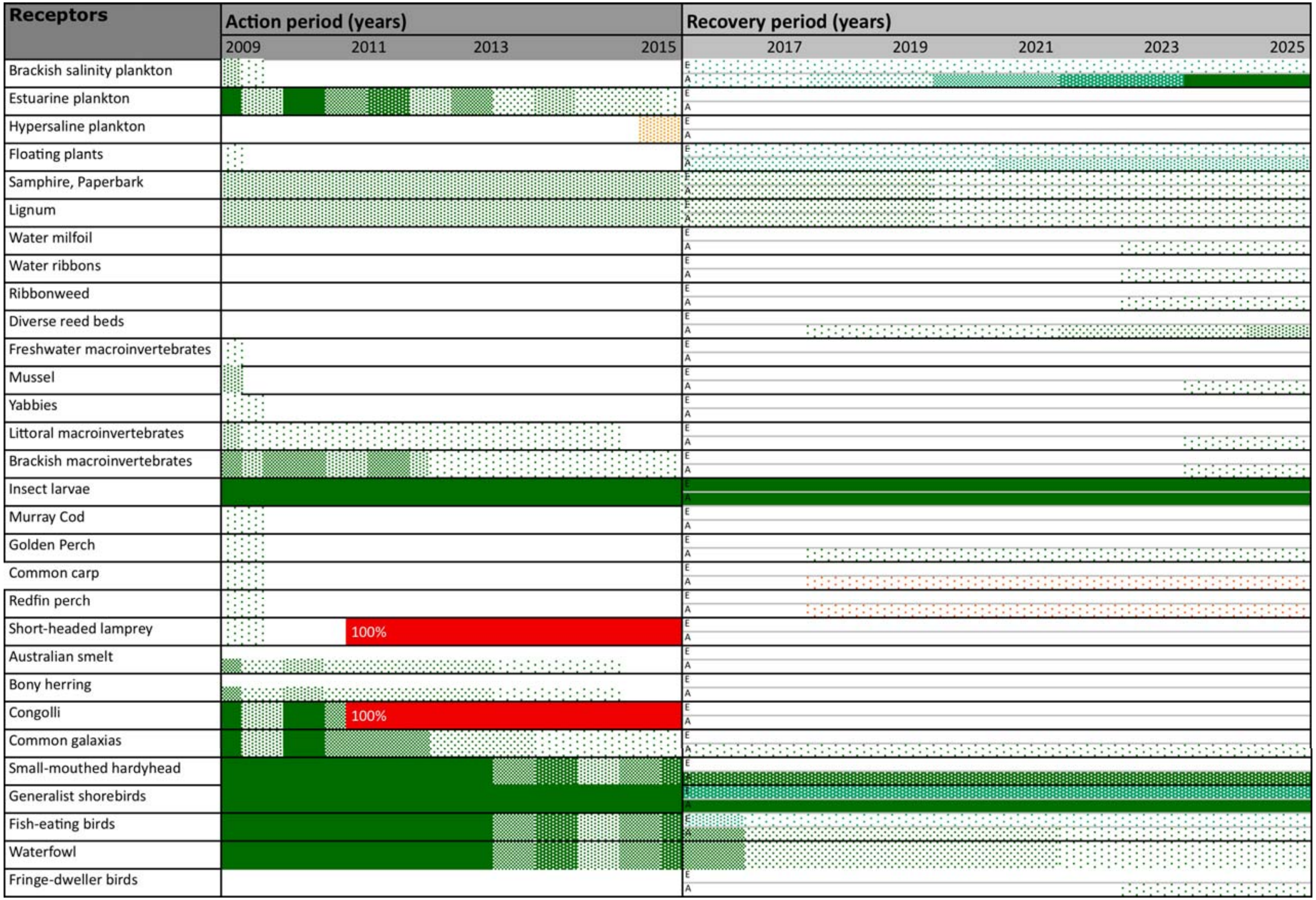


Figure 7.14: Consolidated effects on receptors during the action and recovery periods for Freshwater Pumping in Lake Albert.
E = Entitlement recovery flows. A = Average recovery flows.

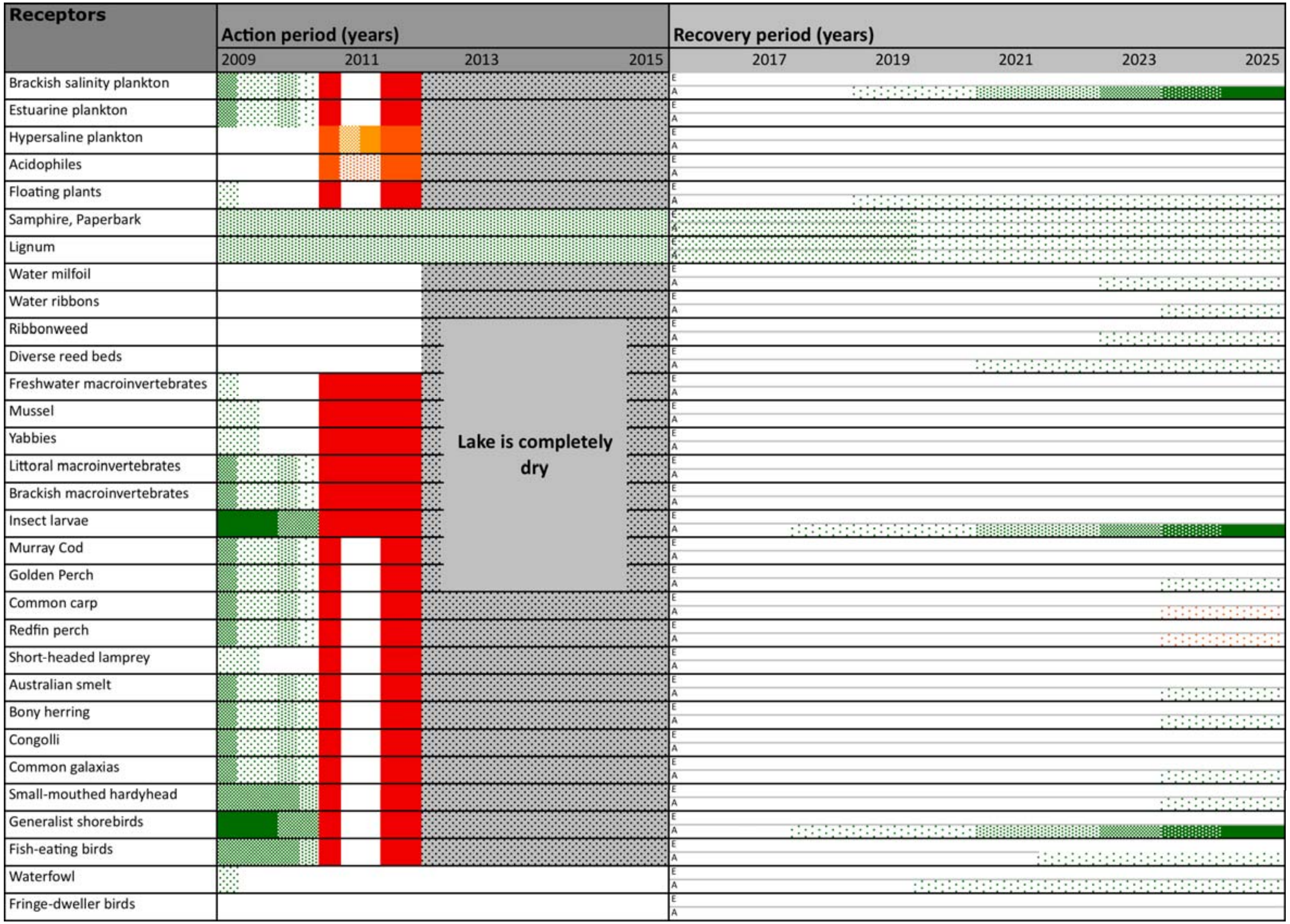


Figure 7.15: Consolidated effects on receptors during the action and recovery periods for Cease Pumping for all scenarios in Lake Albert.

E = Entitlement recovery flows. A = Average recovery flows.

Average flows

Within the first eighteen months of Average recovery flows, water levels will increase to around +0.6 mAHD, inundating the former riparian zone and allowing Narrung Narrows to be open from late 2017 (one year into the ten-year recovery period). Salinities will remain significantly higher than the Ramsar target (<0.84 g/L) even at the end of the ten-year recovery period in 2025 (6 g/L in Do-Nothing, around 10 g/L in Seawater and 3.5-4 g/L in Freshwater), which will limit recovery.

Receptor recovery will be poor under Average flows particularly in the Seawater scenario (Figures 7.12 to 7.14). The aquatic plant seedbank is likely to have been severely damaged by desiccation, soil acidification and then inundation with relatively saline water when lake levels returned to near +0.6 mAHD. Therefore it is unlikely that Water milfoil, Water ribbons or Ribbonweed will return to the main Lake Albert littoral zone during the recovery period, particularly in the more-saline Seawater scenario. Their chances of recovery are greatest in the Freshwater scenario because salinities will be lower earlier and they are also likely to re-establish in Lake Alexandrina in the Freshwater scenario, which will provide a neighbouring population from which dispersal may occur. Over time reed beds will re-form but they will be ecologically simple, taking until at least the early 2020's to form semi-continuous bands around the lakeshore. Recovery of other floral and many faunal receptors (e.g. Lacustrine macroinvertebrates) will be delayed until then because of their dependency on littoral and riparian vegetation. The on-going lack of food resources will indirectly limit fish and bird recovery.

Recovery in the Seawater scenarios will be the lowest, (compared to the Do-Nothing and Freshwater scenarios) because the combined impacts of extreme salinisation during the action period and the longer duration of high salinities during the recovery period.

In the scenarios where pumping to Lake Albert ceases, Average recovery flows lead to physico-chemical recovery of Lake Albert (lake levels +0.6 mAHD; fresh to saline salinities and reconnection with Lake Alexandrina) but not ecological recovery. The re-establishment of receptor populations in Lake Albert following the cease-pumping action periods will be much more difficult than following the pumping action periods because by the time water re-enters Lake Albert it will have been a dry, acidic basin with a few isolated pools of acidic, hypersaline water for six years. During that time any propagule banks will perish. Although some terrestrial and/or invasive biota may establish in less-acidic patches on the dry lakebed, large areas of the lakebed will most likely be sterile, acidic, bare soil prior to inundation during the recovery period.

As for the pumping scenarios, Brackish plankton will enter and may re-establish when the lake refills. It is likely that Hypersaline and Estuarine plankton will come and go as the salinities change over time being regularly re-introduced with inflows. Reedbeds dominated by P. australis, T. domingensis and the introduced Spiny rush will re-establish over time. However, it is likely that it will take longer for reed beds to establish following cease-pumping than pumping given the longer and more extreme drawdown that occurs in the cease-pumping and possible soil chemistry changes that will have induced lasting chemical changes (Attachment F).

No other plants are expected to recover thus Lacustrine macroinvertebrates will not re-establish for many years. Some fish may enter the lake but are unlikely to establish resident populations due to the lack of food and habitat resources. The extremely tolerant Small-mouthed hardyhead are a possible exception but even they will not be able to recruit because of the lack of littoral vegetation and population size will be strongly limited by the paucity of prey. Because of this, fish that do enter are likely to be easy prey for Fish-eating birds and thus these birds may increase in abundance sporadically following fish numbers and catchability. Insect larvae and the Generalist shorebirds that feed on them will recover, thus the ecosystem will be very simple.

This assessment is based on the three primary stressors: water levels, pH and salinity. It may be that toxicity from heavy metals, metalloids or other pollutants in Lake Albert is so great that even less recovery occurs than outlined above. Lake Albert may remain devoid of any complex assemblages for many decades if pumping ceases during the action period and it is left to dry out.

7.6. Conclusions

This consequence assessment shows that it is possible to have complete recovery of key physico-chemical attributes (e.g. water levels, salinity and pH) but not have significant or complete ecological recovery. The disconnection and desiccation of the lakes' littoral and riparian vegetation from 2006 mean that in any of the recovery scenarios the littoral and riparian vegetation will have to recover before significant recovery will be initiated in the higher trophic levels. Recovery for most receptors will, thus, be sequential if it occurs, requiring recovery of aquatic vegetation then macroinvertebrates, fish and birds.

Successful recovery is defined as a return to the Ramsar state (Section 8; Attachment A), as indicated by the probable viability of the 33 Ramsar receptors chosen for Lake Alexandrina and the 29 Ramsar receptors chosen for Lake Albert for the capacity to recovery assessment (Table 7.4). Tables 7.5 and 7.6 summarise the impacts of the primary stressors (salinity, water level and acidification) during the action and recovery periods for each management scenario in Lakes Alexandrina and Albert, respectively. Salinity concentration bands are shown ranging from fresh to hypersaline as defined in Section 8.2. Water levels are shown in approximate mAHD and acidification is qualitatively described as widespread or localised (Section 7). The numbers of Ramsar and invasive receptors are taken from Figures 7.6 to 7.15. Those receptors considered unlikely to establish (~) were not included. It should be noted that the simple summing of numbers of Ramsar and invasive receptors likely to be present does not convey the same understanding of recovery (for example, which receptors had strong populations compared to those that were in relatively poor condition) as shown in Figures 7.6 to 7.15.

Lake Alexandrina (Table 7.5)

- Salinities in Lake Alexandrina will not return to the Ramsar target (< 0.64 g/L) under any recovery scenario;
- Do-Nothing and Freshwater scenarios will have fresh salinities (< 10 g/L) within two years of either Entitlement or Average recovery flows commencing;
- Salinities in the Seawater scenarios will be higher for longer and across larger areas of Lake Alexandrina than Do-Nothing and Freshwater but will ultimately recover to fresh salinities during the recovery period;
- Recovery targets will not be met for water levels under Entitlement flows but will be under Average flows. This will have significant ramifications for ecological recovery primarily because the lower water levels under Entitlement flows will not reconnect the littoral and riparian vegetation upon which most other receptors depend;
- Acidification will not be a stressor in any recovery scenario;

Table 7.5: Summary of the ecological effects of salinity, acidification and water levels for the action and recovery periods under each scenario in Lake Alexandrina.

The two recovery scenarios are Entitlement (1850 GL.y over SA border) and Average (4,000 to 5,000 GL/y) flows. Numbers of receptors are out of a possible 33 Ramsar receptors and 4 invasive receptors.

Scenario	End of action period	End of Entitlement Recovery period	End of Average Recovery period
Do-Nothing			
Pumping	Fresh to Brackish Widespread acidification Very low water level (-1.5 mAHD) 13 Ramsar receptors 3 Invasive receptors	Fresh No acidification Low water level (-0.75 mAHD) 8 Ramsar receptors 4 Invasive receptors	Fresh No acidification Typical water level (+0.6 mAHD) 21 Ramsar receptors 3 Invasive receptors
Cease-pumping	Brackish to Saline (2015) Localised acidification Low water levels (-0.8 mAHD) 22 Ramsar receptors 6 Invasive receptors	Fresh No acidification Low water level (0.0 mAHD) 12 Ramsar receptors 4 Invasive receptors	Fresh No acidification Typical water level (+0.6 mAHD) 24 Ramsar receptors 4 Invasive receptors
Seawater			
Pumping	Saline to Hypersaline Localised acidification Water levels maintained (-1.3 mAHD) 4 Ramsar receptors 2 Invasive receptors	Saline to Fresh No acidification Low water level (-0.75 mAHD) 4 Ramsar receptors 1 Invasive receptors	Brackish to Fresh No acidification Typical water level (+0.6 mAHD) 19 Ramsar receptors 4 Invasive receptors
Cease-pumping	Saline to Hypersaline Localised acidification Water levels maintained (-1.3 mAHD) 4 Ramsar receptors 2 Invasive receptors	Marine to Fresh No acidification Low water level (0.0 mAHD) 4 Ramsar receptors 1 Invasive receptors	Brackish to Fresh No acidification Typical water level (+0.6 mAHD) 19 Ramsar receptors 4 Invasive receptors
Freshwater			
Pumping	Fresh Negligible acidification Water levels maintained (-1.3 mAHD) 23 Ramsar receptors 1 Invasive receptors	Fresh No acidification Low water level (-0.75 mAHD) 12 Ramsar receptors 4 Invasive receptors	Fresh No acidification Typical water level (+0.6 mAHD) 24 Ramsar receptors 4 Invasive receptors
Cease-pumping	Fresh Negligible acidification Water levels maintained (-1.3 mAHD) 23 Ramsar receptors 1 Invasive receptors	Fresh No acidification Low water level (0.0 mAHD) 12 Ramsar receptors 4 Invasive receptors	Fresh No acidification Typical water level (+0.6 mAHD) 24 Ramsar receptors 4 Invasive receptors

- Littoral and riparian vegetation will re-establish in the Average flow scenarios because water levels will return to typical pre-2006 levels and salinities will be low enough. Strong populations of submerged plants are much less likely to re-establish;
- The greatest number of Ramsar receptors (receptors present in the Ramsar state; Attachment A) persist under the Freshwater scenarios, having 12 and 24 receptors out of a possible 33 Lake Alexandrina Ramsar receptors under the Entitlement and Average flow recovery flows, respectively;
- The Do-nothing pumping scenarios will support recovery of three to four less Ramsar receptors than their respective Freshwater scenarios due to the catastrophic impacts of widespread acidification and higher salinities during the Do-nothing pumping action period;
- The Do-Nothing cease-pumping scenarios will have the same Ramsar receptors present as in their respective Freshwater scenarios but recovery capacity will be generally lower in the Do-nothing cease-pumping than the Freshwater scenarios;
- The lowest number of Ramsar receptors within the Entitlement and Average recovery flows will be in the Seawater scenarios, having 4 and 19 out of a possible 33 receptors, respectively;
- All four invasive receptors will be present in the Do-nothing cease-pumping and the Seawater scenarios under Average recovery flows;
- Three out of four invasive receptors will be present in the Freshwater and Do-nothing pumping Average recovery scenarios. The fourth invasive receptor, Tube worms, will perish due to freshening of lake water and return of typical water levels. Tube worms will persist under Entitlement recovery flows provided they can find suitable substrate at a suitable water depth.
- The Seawater Entitlement recovery flow scenarios will have the lowest overall number of receptors having only five receptors (four Ramsar and one invasive).
- Freshwater retains the highest number of Ramsar receptors but they will decline over time, more so under Entitlement than Average recovery flows.

Lake Albert (Table 7.65)

- Salinities in Lake Albert will not return to the Ramsar target (< 0.84 g/L) under any recovery scenario;
- Salinities will be significantly higher for longer than in the respective Lake Alexandrina scenarios presumably because salt is exported from Lake Alexandrina to Lake Albert;
- Salinities in the Do-Nothing and Freshwater scenarios will become fresh over time (< 10 g/L) even in the cease-pumping scenarios but salinities in the Seawater scenarios will not freshen to less than brackish concentrations (10 to 15 g/L);
- Like Lake Alexandrina, recovery targets in Lake Albert will not be met for water levels under Entitlement flows but will be under Average flows. This will have similar ramifications for littoral vegetation and thus ecological recovery as in Lake Alexandrina;
- Acidification will not be a stressor in any recovery scenario after 2017 when the Narrung Narrows regulator will be removed and Lake Albert will be rapidly filled with water from Lake Alexandrina ;
- Simple reedbeds will re-establish in the average recovery scenarios because water levels will return to typical pre-2006 levels and salinities will be low enough

but not in the Entitlement recovery scenarios where these pre-conditions will not be met;

Table 7.6: Summary of the ecological effects of salinity, acidification and water levels for the action and recovery periods under each scenario in Lake Albert.

The two recovery scenarios are Entitlement (1850 GL.y over SA border) and Average (4,000 to 5,000 GL/y) flows. Numbers of receptors are out of a possible 29 Ramsar receptors and 3 invasive receptors.

Scenario	End of action period	End of Entitlement Recovery period	End of Average Recovery period
Do-Nothing			
Pumping	Saline to Hypersaline No acidification Water levels maintained (-1.3 mAHD) 6 Ramsar receptors 1 Invasive receptors	Marine No acidification Low lake levels (-0.75 mAHD) 4 Ramsar receptors 1 Invasive receptors	Saline to Fresh No acidification Typical lake levels (+0.6 mAHD) 14 Ramsar receptors 3 Invasive receptors
Cease-pumping	Hypersaline Widespread acidification Complete drying 0 Ramsar receptors 0 Invasive receptors	Hypersaline Acidified pools Complete drying 2 Ramsar receptors 1 Invasive receptors	Marine to Fresh No acidification Typical lake levels (+0.6 mAHD) 9 Ramsar receptors 1 Invasive receptors
Seawater			
Pumping	Saline to Hypersaline No acidification Water levels maintained (-1.3 mAHD) 4 Ramsar receptors 1 Invasive receptors	Hypersaline No acidification Low lake levels (-0.75 mAHD) 2 Ramsar receptors 1 Invasive receptors	Hypersaline to Brackish No acidification Typical lake levels (+0.6 mAHD) 8 Ramsar receptors 3 Invasive receptors
Cease-pumping	Hypersaline Widespread acidification Complete drying 0 Ramsar receptors 0 Invasive receptors	Hypersaline Acidified pools Complete drying 2 Ramsar receptors 1 Invasive receptors	Saline to Brackish No acidification Typical lake levels (+0.6 mAHD) 5 Ramsar receptors 1 Invasive receptors
Freshwater			
Pumping	Saline to Hypersaline No acidification Water levels maintained (-1.3 mAHD) 10 Ramsar receptors 1 Invasive receptors	Marine No acidification Low lake levels (-0.75 mAHD) 4 Ramsar receptors 1 Invasive receptors	Saline to Fresh No acidification Typical lake levels (+0.6 mAHD) 20 Ramsar receptors 3 Invasive receptors
Cease-pumping	Hypersaline Widespread acidification Complete drying 0 Ramsar receptors 0 Invasive receptors	Hypersaline Acidified pools Complete drying 2 Ramsar receptors 1 Invasive receptors	Marine to Fresh No acidification Typical lake levels (+0.6 mAHD) 10 Ramsar receptors 1 Invasive receptors

- The only invasive receptor will be Spiny rush in the Entitlement recovery flows;
- The greatest number of Ramsar receptors will be in the Freshwater pumping scenario, having 20 receptors out of a possible 29 Lake Albert Ramsar receptors (Attachment A);
- The Do-Nothing pumping scenario will have a moderate number of Ramsar receptors present (14) but the other scenarios will have ten or less with Seawater cease-pumping having the lowest number (5);
- Recovery will be very poor in all the scenarios under Entitlement recovery flows with only four Ramsar receptors in the Do-Nothing and Freshwater pumping scenarios and two in the Seawater scenarios and the Do-Nothing and Freshwater cease-pumping scenarios;
- Based upon presence and not abundance, it would appear that the Ramsar receptors will significantly improve under average recovery flows in Freshwater and Do-Nothing pumping scenarios but most will be in poor and/or declining condition.
- The introduction of Seawater will have significant adverse impacts on the capacity for all but the most hardy Ramsar receptors to recover;
- Ceasing to pump water to Lake Albert will lead to catastrophic loss of receptors during the action period and the adverse impacts appear to persist through both the Entitlement and Average recovery flow periods (as evidenced by the lower number of Ramsar receptors that will occur in the cease-pumping scenarios compared to their respective pumping scenarios);
- The two Ramsar receptors that will remain in Lake Albert under Entitlement flows when pumping ceases will be samphire and paperbark woodlands that are high on the floodplain and will be degrading further during the recovery period due to lack of inundation since probably the late 1990s (approximately 35 years before the end of the recovery period).

The very long period of drawdown that will occur under even the average recovery flows (at least 12 years) will mean that the recovery predicted here after the various management actions, will be less than that observed in Goolwa Channel and in the lakes since they refilled in 2010/11. Goolwa Channel recovery was initiated in 2007 when the Clayton regulator was installed, only a year after partial drying and strong populations of submerged vegetation developed. Lakes Alexandrina and Albert refilled during 2010/11, which was after only four years of drawdown. These drawdown periods are much less than the twelve years under the Average recovery periods and greater than 19 years in the Entitlement recovery scenarios predicted in the modelling outputs. Furthermore, flows through Lake Alexandrina in 2010/11 were in the order of 10,000 GL (twice that of the modelled Average flows). Salinities were very fresh dropping to 400EC (0.25 g/L), which is well within the Ramsar target (1000 EC, 0.64 g/L) and much lower than seen in any of the modelled scenarios even the freshest one, Freshwater pumping Average recovery flows. Together, these factors suggest recovery following any of the management scenarios will be much less than that seen to date in the lakes.

The use of revegetation to control acidification (as suggested in Section 7) would likely benefit the recovery in both lakes, particularly if a diverse array of emergent aquatic plants were planted. Any vegetation present on the lake bed prior to inundation in the Average recovery flows, including Spiny rush and any terrestrial invaders, will provide beneficial organic matter to fuel sulfate reduction and other detrital pathways. The decaying plant material may also provide substrate for macroinvertebrates and help stabilise the lakeshore, further increasing the success of riparian and littoral plant re-establishment.

8. Ecosystem states and transitions during the action and recovery periods compared with the Ramsar and baseline states.

The fourth objective of this consequence assessment is to describe the ecological effects of each scenario in terms of transitions to alternate ecosystem states through time, including capacity to return to the Ramsar state (as described by Phillips and Muller 2006). Ecosystem states are: recognisable, resistant and resilient abiotic/biotic complexes (Stringham *et al.* 2003; Suding *et al.* 2004; Spooner and Allcock 2006; Souter and Stead 2010). Each ecosystem state encompasses a certain amount of spatio-temporal variation in key parameters (e.g. salinity, water level, pH and biotic assemblages) beyond which transitions in ecosystem states occur. That is, the system changes away from the current state towards an alternate state.

Souter and Stead (2010) identified at least thirteen possible ecosystem states for Lake Alexandrina, primarily based upon salinity and pH thresholds, which were alternatives to the Ramsar state. These alternate states were in two broad groups based on whether they were derived from evapo-concentration of freshwater inflows or seawater leakage through the barrages (seawater intrusion was assumed to occur adjacent to the barrages caused by infiltration when Lake Alexandrina water levels are lower than those in the Coorong). One of these thirteen alternate states was the Baseline state that occurred at the beginning of the action period (October 2009).

This section builds on the work by Souter (2009) and Souter and Stead (2010) by describing the ecosystem states based upon detailed assessment of Ramsar and invasive receptor effects in Lakes Alexandrina and Albert during the action and recovery periods (Sections 4 to 7).

The following terms are used to describe the alternate ecosystem states:

- Connected: functional connectivity will exist across the whole site, that is, no regulators nor the Wellington weir will be in place, the barrages will be open and lake water levels will be high enough to connect to the riparian zone and at least allow operation of the barrages fishways, if not allowing opening of multiple barrage gates (typically > 0.4 mAHD);
- Disconnected: functional connectivity missing across part or all of the site (e.g. regulators in place, barrages closed and/or water levels < 0.4 mAHD);
- Freshwater-derived: surface water inflows to the lakes are sourced from the River Murray and the Eastern Mount Lofty Ranges (EMLR) tributaries; and
- Seawater-derived: surface water inflows to the lakes are sourced from the sea via the barrages. Surface water may still flow in from the River Murray and the Eastern Mount Lofty Ranges tributaries.

The predicted ecosystem states are also categorised according to the salinity and pH thresholds that define their transitional boundaries (Table 8.1).

Table 8.1: Ecosystem states in the freshwater- and seawater-derived groups and their salinity and pH thresholds.

State	Thresholds	
	Salinity (g/L)	pH
Freshwater-derived states		
Ramsar state	< 1	> 5.5
Freshwater derived: Fresh (Baseline)	1 - 10	> 5.5
Freshwater derived: Brackish	10 - 15	> 5.5
Freshwater derived: Saline	15 – 25	> 5.5
Freshwater derived: Marine	25 - 50	> 5.5
Freshwater derived: Hypersaline	50 - 150	> 5.5
Freshwater derived: Ultrasaline	> 150	> 5.5
Freshwater derived: Acidified	various	< 5.5, > 3.5
Freshwater derived: Highly acidified	various	< 3.5
Freshwater derived: Post-Hypersaline	< 150	> 5.5
Freshwater derived: Post-Acidified	various	> 5.5
Seawater-derived states		
Seawater derived: Brackish	10 - 15	> 5.5
Seawater derived: Saline	15 – 25	> 5.5
Seawater derived: Marine	25 - 50	> 5.5
Seawater derived: Hypersaline	50 - 150	> 5.5
Seawater derived: Ultrasaline	> 150	> 5.5
Seawater derived: Acidified	various	< 5.5, > 3.5
Seawater derived: Highly acidified	various	< 3.5
Seawater derived: Post-Hypersaline	< 150	> 5.5
Seawater derived: Post-Acidified	various	> 5.5

Not all the receptors found in the Ramsar state (Attachment A; Figure 8.1) will persist under all alternate states, or perhaps any. Persistence will depend on the physico-chemical characteristics such as salinity tolerances of the different receptors as well as the receptors' ecological attributes (described in Sections 3 and 7). To reflect this variance in ecological viability, a five-point descriptor that can be applied to any scenario was developed to further refine the ecosystem state descriptions, as follows:

- Complete: All receptors expected in that ecosystem state will exist in self-sustaining populations without stress.
- Compromised: All receptors expected in that ecosystem state will exist but not all will be living in self-sustaining populations without stress.
- Degraded: Some receptors expected in that ecosystem state will exist in self-sustaining populations without stress. Most will be stressed and the least tolerant will have been lost.
- Depauperate: No receptors expected in that ecosystem state will exist in self-sustaining populations without stress. Most will have been lost and the most tolerant will be stressed.
- Extinct: All the receptors expected in that state will have been lost with the exception of highly tolerant, opportunistic receptors that have dispersive agents available at all times and in all places (e.g. Insect larvae, Generalist shorebirds, Plankton). Small-mouthed hardyhead may also persist in some connected extinct states.

The conceptual diagrams presented below are based on the receptor keys in Attachment A. The number of each receptor icon in the diagrams denotes relative ecological viability compared to other ecosystem state diagrams.

8.1. The Ramsar and Baseline ecosystem states

All the water management scenarios begin in the same Baseline ecosystem state in October 2009. This Baseline state (Figure 8.1) represents a lakes' ecosystem that is significantly degraded compared to the Ramsar state described by Phillips and Muller (2006; Attachment A), which itself was degraded compared to the ecological condition in 1984 at the time of Ramsar nomination (Phillips and Muller 2006) and the pre-European ecosystem (Sim and Muller 2004; *Aldridge et al.* in prep.).

The key differences between the Ramsar 2006 state (Connected Freshwater-derived: Ramsar) and the Baseline state (Disconnected Freshwater-derived: Fresh) are disconnection (from the riparian zone and across the barrages, Narrung Narrows regulator and Goolwa Channel regulator), increased number of invasive receptors and the evapo-concentration of salts to greater than 1 g/L. Sustained disconnection leads to a suite of ecological stressors, such as desiccation of the vegetated riparian and littoral zones present in the Ramsar state and increased disruption of biotic movement across the site. The invasive Common carp and Redfin perch were present in the Ramsar state but as the ecosystem transitioned to the Baseline state, more invaders colonised the lakes: Spiny rush began to colonise the exposed lakebed (apparently able to establish on exposed, acidic sediments), Estuarine birds followed prey to the lake-side of the barrages and Tubeworms began expanding their range from the Murray Mouth and North Lagoon to the Goolwa Channel and into the southern parts of Lake Alexandrina.

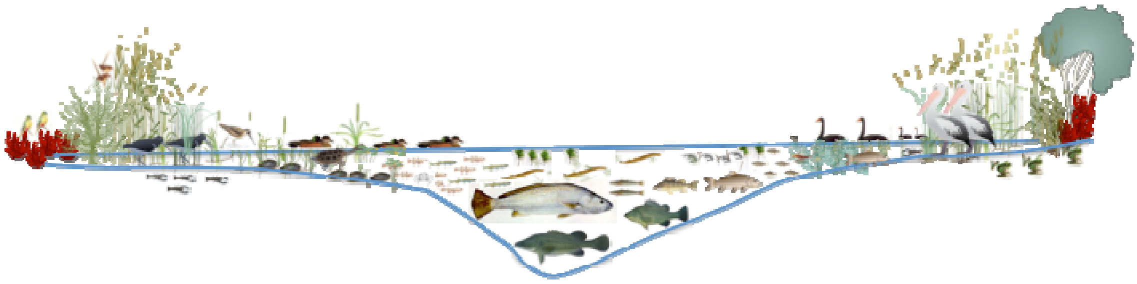
If disconnection persists for more than 3 to 5 years, then the following Ramsar receptors are likely to be lost in all Disconnected Freshwater-derived (DFW) states regardless of salinity levels because of the dependence of these receptors on littoral/riparian vegetation or on free movement across the site (particularly the barrages):

- Diverse reed beds, Water milfoils, Water ribbons, Ribbonweed;
- Freshwater, Littoral and Brackish macroinvertebrates, Yabbies;
- Southern bell frog;
- Short-headed lamprey, Congolli, Common galaxias and Yarra pygmy perch; and
- Australian smelt, Bony herring and Murray Hardyhead.

All Ramsar receptors will be lost if disconnection is infinite, expect perhaps Small-mouthed hardyhead, some phytoplankton, some Insect larvae and Generalist shorebirds that feed upon them. The change from the Ramsar state to the DFW state is a result of freshwater inflows being insufficient to replace evaporative losses and thus water levels (< +0.3 mAHD) decline and salinity increases (1 – 10 g/L). The higher the salinities above 2 g/L, the higher the stress and the less Ramsar receptors supported. Salinity stress for the following Ramsar receptors will increase over time, becoming fatal as salinities increase within the Fresh salinity range (Section 3):

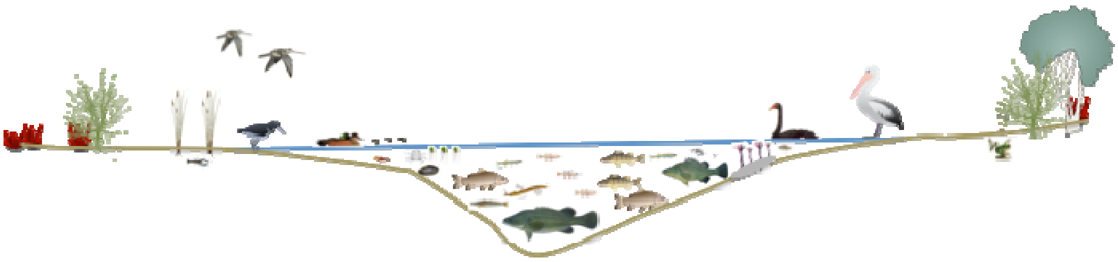
- River-sourced plankton and Low salinity plankton;
- Freshwater macroinvertebrates, Yabbies and Freshwater mussel;
- Floating plants, Water milfoils, Diverse reed beds;
- Waterfowl, Southern bell frog, Short-headed lamprey and Yarra pygmy perch.

(a)



The **Ramsar state (2006)** has a total of thirty-six (36) Ramsar receptors: River-sourced (Lake Alexandrina only), Low salinity and Brackish plankton (Lake Albert only), Floating plants, Samphire, Paperbark, Lignum, Gahnia sedgelands, Diverse reed beds, Water ribbons, Ribbon weed, Water milfoils, Freshwater macroinvertebrates, Lacustrine macroinvertebrates, Brackish macroinvertebrates, Yabbies, Freshwater mussels, Insect larvae, Murray cod, Golden perch, Yarra pygmy perch, Diadromous fish (Short-headed lampreys, Common galaxias, Congolli), Australian smelt, Murray hardyhead, Small-mouthed hardyhead, Bony herring, Mulloway, Black bream, Southern bell frog, Waterfowl, Fish-eating birds, Generalist shorebirds, Terrestrial birds and Fringe-dwelling birds.
There are two (2) invasive receptors: Common carp and Redfin perch.

(b)



The **Baseline state (Disconnected Freshwater derived: Fresh Compromised)** has a possible twenty-seven (27) Ramsar receptors, if salinities remain < 2 g/L: River-sourced (Lake Alexandrina only), Low and Brackish salinity plankton (Lake Albert only), Floating plants, Disconnected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), few Lacustrine macroinvertebrates, Yabbies, Freshwater mussels, Brackish macroinvertebrates, Yarra pygmy perch (probably absent, Lake Alexandrina only), Murray cod, Golden perch, Diadromous fish (Short-headed lampreys, Common galaxias, Congolli), Australian smelt, Murray hardyhead, Small-mouthed hardyhead, Bony herring, Southern bell frog (one location in Lake Alexandrina), Insect larvae, Waterfowl, Fish-eating birds and Generalist shorebirds. There are also six (6) invasive receptors: Brackish macroinvertebrates (Lake Alexandrina), Tube worms (Lake Alexandrina only), Spiny rush (disconnected), Common carp, Redfin perch and Estuarine birds (Lake Alexandrina only).

Figure 8.1: A schematic comparison of the Ramsar state as described by Phillips and Muller (2006; a) and the Baseline ecosystem state, the Disconnected Freshwater-derived: Fresh Compromised state (October 2009; b), which all the scenarios started in.
The key to the receptor images used appears in Attachment A.

Many of the Ramsar receptors will have been experiencing significant stress or will have been lost by October 2009 (Section 3), thus, the lakes will be in ecologically Compromised versions of the Disconnected Freshwater-derived: Fresh state (DFW: Fresh Compromised) at the beginning of the action period. It is against this Baseline state (DFW: Fresh Compromised) that the alternate ecosystem states and their transitions under the Do-nothing, Seawater and Freshwater delivery scenarios are described below.

8.2. Descriptions of the predicted alternate ecosystem states

In total, fourteen alternate ecosystem states are predicted to occur for significant periods (at least 3 months) in Lakes Alexandrina and Albert during the various action and recovery periods based upon the ecological effects detailed in Sections 4 to 7.

8.2.1. Disconnected Freshwater-derived: Brackish

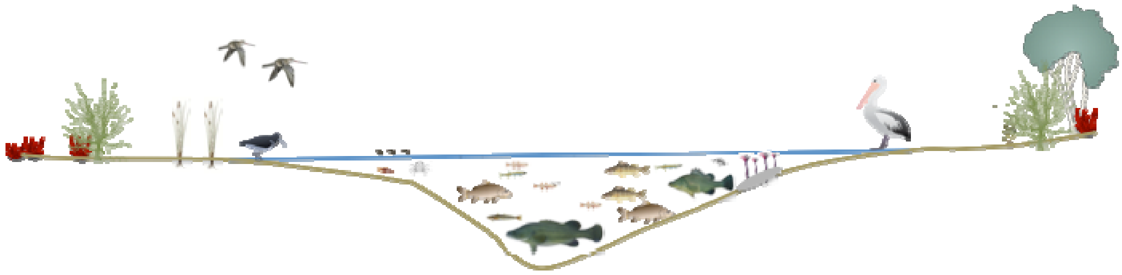


Figure 8.2: A conceptual diagram of the Disconnected Freshwater-derived: Brackish Complete state which has seventeen (17) Ramsar receptors: Brackish salinity plankton (Lake Albert), Disconnected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Littoral macroinvertebrates, Brackish macroinvertebrates, Murray cod, Golden perch, adult Diadromous fish (Common galaxias, Congolli), Australian smelt, Murray hardyhead, Small-mouthed hardyhead, Bony herring, Insect larvae, Fish-eating birds and Generalist shorebirds. Murray cod, Golden perch, Red fin perch and Common carp will be lost at the upper end of the brackish salinity range (15 g/L). There are also five (5) invasive receptors: Tube worms (Lake Alexandrina only), Spiny rush (disconnected), Common carp, Redfin perch and Estuarine birds (Lake Alexandrina only). The key to the receptor images used appears in Attachment A.

If the lakes remain disconnected and salinities increase to greater than 10 g/L, then the Baseline state will transition to the DFW: Brackish state. Such a transition is most likely to be driven by decreasing freshwater inflows leading to decreasing water levels and increasing salinity levels caused by evapo-concentration of the lake water. The lakes will only transition into this state if widespread acidification (caused by declining water levels) does not occur prior to the salinity increasing above the 10 g/L threshold. The following Ramsar receptors will be lost under these brackish conditions:

- River-sourced and Low-salinity plankton, Freshwater macroinvertebrates, Floating plants, Waterfowl, Yabbies, Southern bell frog, Freshwater mussel,
- Short-headed lamprey and Yarra pygmy perch.

The higher the salinities above 10 g/L, the higher the stress and the less Ramsar receptors supported. Salinity stress for:

- Murray cod, Golden perch, Common carp, Redfin perch and Brackish plankton (Ramsar receptor in Lake Albert) will increase over time and they will be lost at the upper end of the Brackish salinity range (15 g/L). If disconnection continues for more than 3 to 5 years, Congolli and Common galaxias will perish and the floodplain vegetation (especially Samphire and Lignum) will decline.

8.2.2. Disconnected Freshwater-derived: Saline

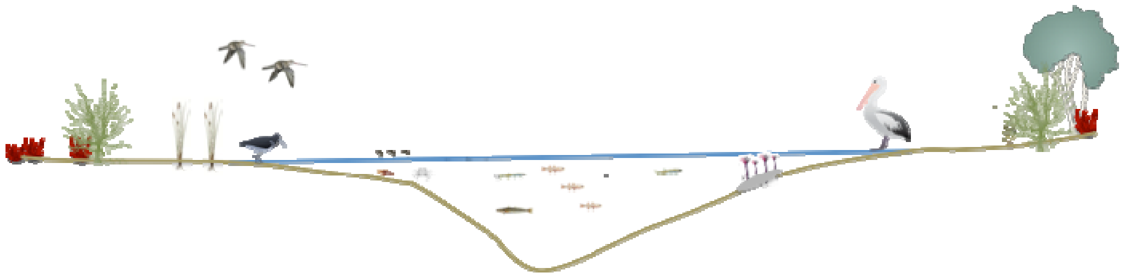


Figure 8.3: A conceptual diagram of the Disconnected Freshwater-derived: Saline Complete state which has fifteen (15) Ramsar receptors: Brackish salinity plankton (Lake Albert), Disconnected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Brackish macroinvertebrates, adult Diadromous fish (Common galaxias, Congolli), Australian smelt, Murray hardyhead, Small-mouthed hardyhead, Bony herring, Insect larvae, Fish-eating birds and Generalist shorebirds. There are also four (4) invasive receptors: Marine plankton, Tube worms (Lake Alexandrina only), Spiny rush (disconnected) and Estuarine birds (Lake Alexandrina only). The key to the receptor images used appears in Attachment A.

If disconnection continues and salinities rise from brackish (10 to 15 g/L) to saline (15 to 25 g/L) the lakes will transition into the DFW: Saline state. Once again, the lakes will only transition into this state if widespread acidification (caused by declining water levels) does not occur prior to the salinity increasing above the 15 g/L threshold. This increase in salinity will drive further loss of Ramsar receptors, namely:

- The remaining Littoral macroinvertebrates.

If disconnection persists for more than 3 to 5 years, then Common galaxias and Congolli will also perish even though they can tolerate salinities up to 30 g/L and the floodplain vegetation (especially Samphire and Lignum) will decline.

8.2.3. Disconnected Freshwater-derived: Marine

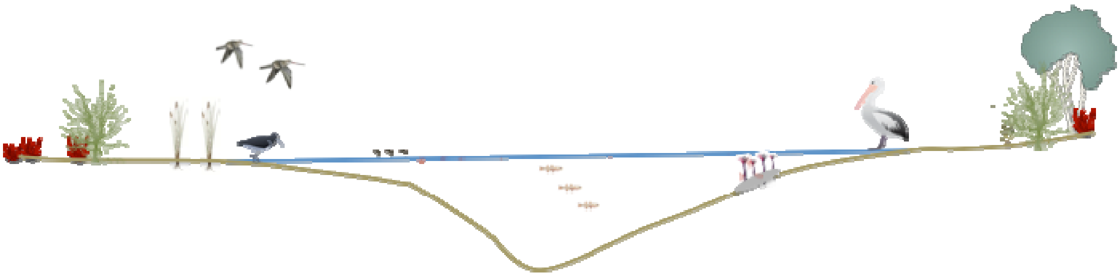


Figure 8.4: A conceptual diagram of the Disconnected Freshwater-derived: Marine Complete state which has nine (9) Ramsar receptors: Brackish salinity plankton (Lake Albert), Disconnected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Small-mouthed hardyhead, Insect larvae, Fish-eating birds and Generalist shorebirds. There are also four (4) invasive receptors: Marine plankton, Tube worms (Lake Alexandrina only), Spiny rush (disconnected) and Estuarine birds (Lake Alexandrina only). The key to the receptor images used appears in Attachment A.

If salinities increase further from the saline to the marine band (25 to 50 g/L) and disconnection persists, the lakes will transition to the DFW: Marine state, provided that widespread acidification does not occur. In this state, salinities will be near seawater concentration. At the lower end of the marine band there will be no further losses of Ramsar receptors, however, increases in salinity to greater than 30 g/L will lead to further losses of Ramsar receptors, including:

- Australian smelt, Bony herring, Murray hardyhead and Brackish macroinvertebrates.

Congolli and Common galaxias will also be lost towards the upper limit of the Marine band, unless disconnection has persisted for more than 3 to 5 years, in which case they will have already been lost. On-going disconnection will also degrade the floodplain vegetation.

8.2.4. Disconnected Freshwater-derived: Hypersaline

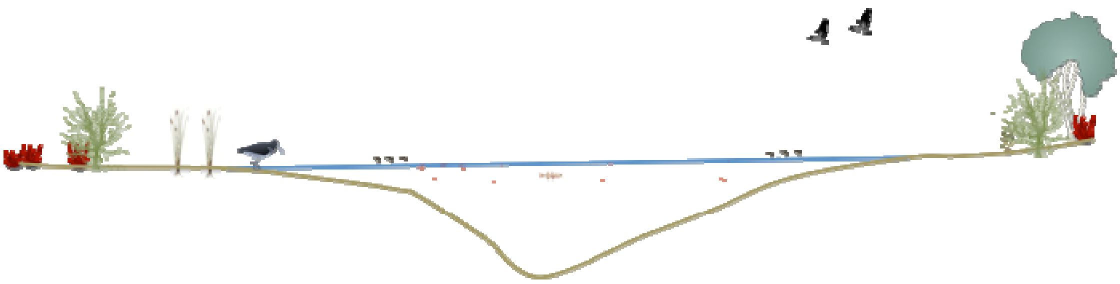


Figure 8.5: A conceptual diagram of the Disconnected Freshwater-derived: Hypersaline Complete state which has a maximum of eight (8) Ramsar receptors: Disconnected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Small-mouthed hardyhead (if < 80 g/L), a few Insect larvae, Fish-eating birds (likely to leave) and Generalist shorebirds. There will also be two (2) invasive receptors: Hypersaline plankton and Spiny rush (disconnected). The key to the receptor images used appears in Attachment A.

If salinities continue to increase beyond the DFW: Marine state to between 50 g/L and 150 g/L the lakes will transition into the DFW: Hypersaline state, that is, salinities will be greater than seawater concentrations. This will see further loss of almost all the remaining Ramsar receptors. Any marine and estuarine receptors that are able to overcome the disconnection and occur in the lakes in this state (e.g. Marine plankton, Estuarine macroinvertebrates, Estuarine shorebirds, Yellow-eyed mullet, Black bream and Mulloway) will also perish.

The invasive Tubeworms will begin to die out at around 60 g/L. Small-mouthed hardyhead will persist to around 80 g/L as will the Fish-eating birds beyond which the only receptors likely to survive are hypersaline plankton, a few Insect larvae and perhaps some Generalist shorebirds feeding on the Insect larvae. Spiny rush is likely to persist on the exposed lakebed where it will not be in contact with the hypersaline lake water. If disconnection persists for greater than 3 to 5 years, the disconnected floodplain vegetation will decline and may be lost, regardless of the salinity in the water.

8.2.5. Disconnected Freshwater-derived or Seawater-derived: Ultrasaline

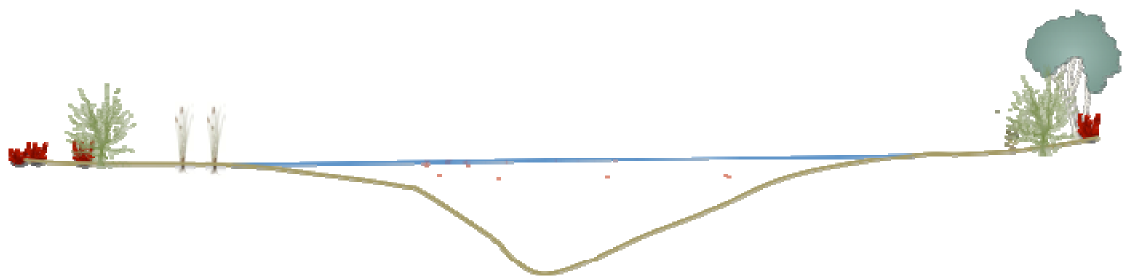


Figure 8.6: A conceptual diagram of the Disconnected Freshwater-derived: Ultrasaline Complete

which state has a maximum of four (4) Ramsar receptors that are disconnected from the water column: Samphire, Paperbark, Lignum and Gahnia sedgelands. There will be two (2) invasive receptors: extreme halophillic plankton and Spiny rush (disconnected). The key to the receptor images used appears in Attachment A.

It is likely that the DFW: Ultrasaline state would have been predicted for some of the Freshwater-derived Do-nothing and Seawater-derived scenarios if the hydrological modelling was reliable at very high salinities (> 150 g/L). If the lakes did transition to the DFW: Ultrasaline state, without widespread acidification occurring, then only extreme halophilic plankton will survive. Spiny rush may continue to occupy the exposed lakebed, depending on soil chemistry. All other Ramsar and invasive receptors will be lost in transition through the less saline ecosystem states described above.

8.2.6. Disconnected Freshwater-derived: Acidified and Highly acidified

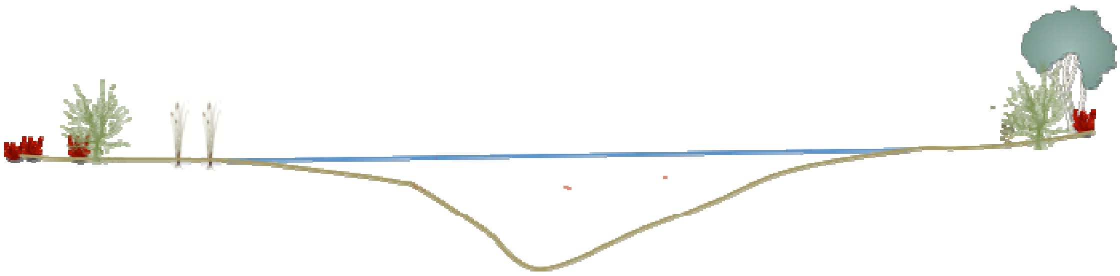


Figure 8.7: A conceptual diagram of the Disconnected Freshwater-derived: Acidified or Highly Acidified Complete state

which has a maximum of four (4) Ramsar receptors that are disconnected from the water column: Samphire, Paperbark, Lignum and Gahnia sedgelands. There will be two (2) invasive receptors: extreme acidophillic plankton and Spiny rush (disconnected). The key to the receptor images used appears in Attachment A.

Declining water levels in the lakes will expose increasingly large areas of acid sulfate soils, thereby producing sulfuric acid (Section 1). For the lake water to become acidic, the acid in the soil needs to be transported into the lake in sufficient quantities that the lakes buffering capacity is exceeded. This is predicted to occur at -1.5 mAHD and -0.5 mAHD for Lakes Alexandrina and Albert, respectively. A transition to the acidified state requires a drop in pH to between 5.5 and 3.5. If pH is < 3.5, then the acidified state will transition to the highly acidified state. The speed of these transitions may be rapid once the buffering capacity of the lake is exceeded.

A transition from the Baseline state to the DFW: Acidified state will lead to mass mortality given that very few species can tolerate pH of less than 5.5, the exceptions being Acidophillic plankton and other microbes. Further transition to the DFW: Highly acidified state will presumably have little further effect other than to reduce the diversity and change the composition of acidophilic communities. The invasive Spiny rush may expand its cover on the exposed lakebed (depending on soil chemistry) but all aquatic invaders will be lost. Birds being mobile are unlikely to be directly affected by water acidification but ultimately all birds will leave due to lack of resources. In this state the lakes will be effectively devoid of aquatic life.

8.2.7. Disconnected Freshwater-derived: Post-Hypersaline

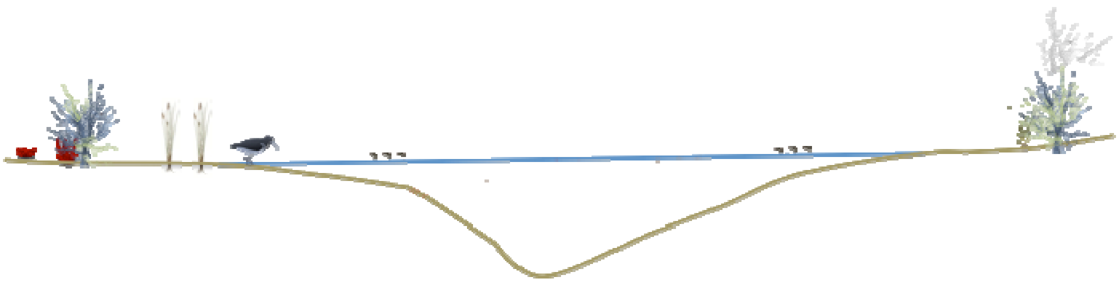


Figure 8.8: A conceptual diagram of the Disconnected Freshwater-derived: Post-Hypersaline state

which has a maximum of four (4) Ramsar receptors: disconnected and stressed floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Insect larvae and Generalist birds. There will be two (2) invasive receptors: various plankton and Spiny rush (disconnected). This diagram is based on ecological effects in the Lake Albert Freshwater pumping Entitlement recovery flows scenario. The key to the receptor images used appears in Attachment A.

In order to transition into this post-hypersaline state, lake salinities will have to drop to less than 150 g/L. It is likely that salinities will remain high (i.e. marine) for many years in this state given that water levels are too low to facilitate reconnection and thus too low to re-establish through-flow that could flush out the salts. Little or no ecological recovery will occur. Even the most salt-tolerant Ramsar receptors will be strongly limited by the riparian zone not being re-established and, thus, not providing the pre-conditions for recovery of other flora and fauna. Spiny rush may continue to grow on the lakebed, depending on the soil salinity regime. Depending on the period that disconnection has persisted, the floodplain vegetation will most likely be declining, particularly Lignum and Samphires that require inundation at least every 3 to 5 years to maintain healthy populations (Section 7). Paperbarks are more tolerant requiring inundation at least once every 10 years. Little is known about the inundation requirements of *Gahnia spp*. (Doeg *et al.* 2011).

It is highly unlikely that estuarine or marine species will colonise the impounded water body, due to extensive dispersal barriers (e.g. closed barrages, Wellington weir, dry lakebed) and poor ecological conditions (Section 7.5.1). Any fauna that might persist through the preceding hypersaline conditions, perhaps by finding refuge in less saline habitats, will have extremely limited food and habitat resources and are not likely to form strong populations in this DFW: Post-hypersaline state. Figure 8.8 is based upon the receptors in Lake Albert under the Freshwater pumping with Entitlement recovery flows scenario (Section 7.5.1).

8.2.8. Disconnected Freshwater-derived: Post-Acidified or Post-Highly-acidified

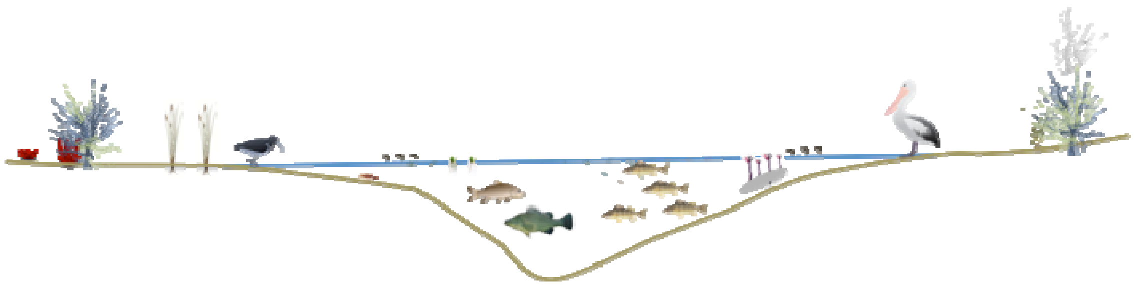


Figure 8.9: A conceptual diagram of Disconnected Freshwater-derived: Post-Acidified or Post-Highly acidified state

which has a maximum of eleven (11) Ramsar receptors: River-sourced plankton (Lake Alexandrina only), Low salinity plankton (Lake Alexandrina only), Floating plants, disconnected and stressed floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Insect larvae, Golden perch, Fish-eating birds and Generalist birds. There will be five (5) invasive receptors: various plankton, Tube worms (Lake Alexandrina only), Common carp, Redfin perch and Spiny rush (disconnected). This diagram is based on ecological effects in the Lake Albert Freshwater pumping Entitlement recovery flows scenario. The key to the receptor images used appears in Attachment A.

The initial transition to the DFW: Highly Acidified state will lead to loss of all biota except acidophiles (see above). To then enter the DFW: Post-Highly acidified state there will need to be a return to circum-neutral pH values without hydrological reconnection across the site. This is most likely to occur if River Murray and/or EMLR tributary inflows are sufficient to inundate most of the exposed acid sulfate soils and neutralise the mobilised acid but insufficient to refill the lakes to > +0.4 mAHD (e.g. as seen under Entitlement recovery flows; Section 7).

The only Ramsar receptors expected to recolonise the DFW: post-acidified state in significant numbers are highly dispersive and tolerant receptors such as Floating plants, common reeds, a few birds and Insect larvae. The on-going lack of connectivity will prevent most receptors dispersing into the lakes once the acidification event passes. Golden perch may re-establish over time given that they are likely to enter the lakes with River Murray flows and are relatively adaptable. The invasive Redfin perch, Common carp and Tubeworms are also likely to recolonise and will most likely dominate their niches over time. The floodplain vegetation is likely to be highly stressed from on-going disconnection (Sections 7 and 8.2.7). Recovery is likely to be better following acidic rather than hypersaline conditions because salinities stay higher for a longer in the post-hypersalinity states than pH stays low in the post-acidic states. Figure 8.9 is based upon the receptor effects predicted for Lake Alexandrina under the Do-Nothing pumping with Entitlement recovery flows scenario (Section 7.5.1).

8.2.9. Connected Freshwater-derived: Post-Hypersaline

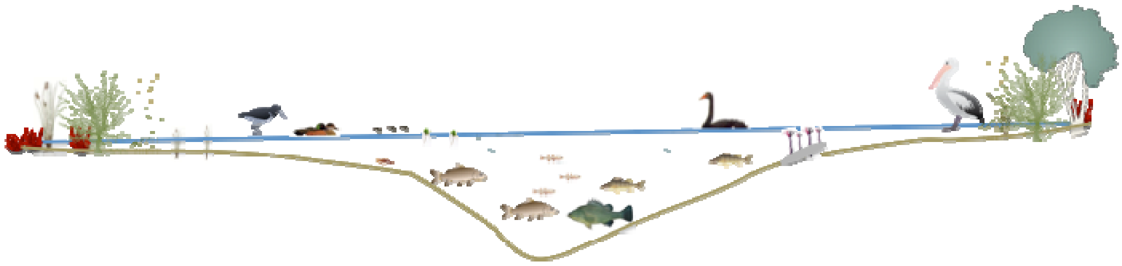


Figure 8.10: A conceptual diagram of the Connected Freshwater-derived: Post-Hypersaline state which has a maximum of thirteen (13) Ramsar receptors: Brackish plankton (< 15 g/L), Floating plants (< 6.8 g/L), re-connected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Simple reed beds, Insect larvae, Golden perch, Small-mouthed hardyhead, Fish-eating birds, Waterfowl and Generalist birds. There will be five (5) invasive receptors: various plankton, Tube worms (Lake Alexandrina only), Common carp, Redfin perch and Spiny rush (inundated). This diagram is based on ecological effects in the Lake Albert Freshwater-pumping scenario after five years of Average recovery flows. The key to the receptor images used appears in Attachment A.

Water levels need to reach at least > 0.4 mAHD to allow removal of regulators, opening of the barrages or operation of the fishways and reconnection to the riparian zone. Salinities also need to drop to less than 50 g/L to enter this state. Reconnection of the riparian zone may stimulate growth of emergent plants, which in turn, may provide the pre-conditions for re-establishment and recovery of other receptors (Section 7). The extent of this recovery will depend on the period of time that the hypersaline conditions have persisted, the rate at which salinity decreases and the absolute salinity values. In turn, the extent of the vegetation recovery (diversity and abundance) will greatly determine the capacity for faunal receptors to persist or re-establish. The more saline, the greater the rate of change or the longer the period that hypersaline conditions persist, the lower the post-hypersaline recovery potential will be in terms of number of Ramsar receptors, likely abundance and capacity to sustain their populations.

Figure 8.10 is based upon the receptor effects predicted in Lake Albert Freshwater-pumping scenario after five years of Average recovery flows (Section 7.5.1). In that CFW: Post-hypersaline state, very few Ramsar receptors will re-establish and the relative abundance of invasive receptors will increase, rendering it a Degraded ecosystem (Section 8.5). In the longer-term (depending on salinity regime, pre-conditions and availability of dispersal mechanisms), other Ramsar receptors such as Brackish macroinvertebrates, Water ribbons, Water milfoils, Australian smelt, Bony herring, Mulloway or Yabbies, may re-establish.

8.2.10. Connected Freshwater-derived: Post-Acidified or Post-Highly acidified

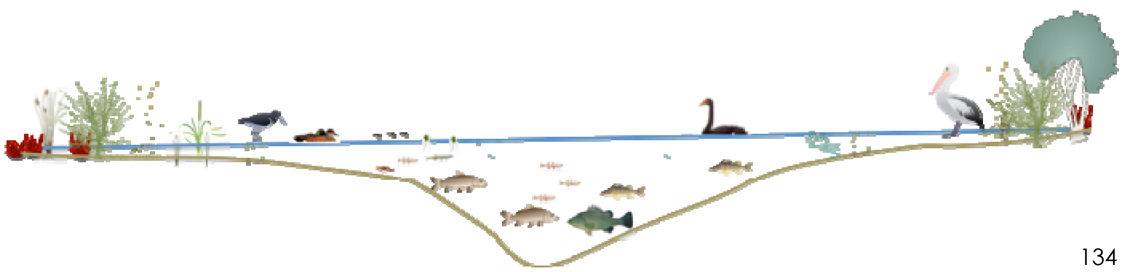


Figure 8.11: A conceptual diagram of the Connected Freshwater-derived: Post-Acidified or Post-Highly acidified state

which could have a maximum of twenty-two (22) Ramsar receptors: River-sourced (Lake Alexandrina only), Low salinity (Lake Alexandrina only) and Brackish plankton (< 15 g/L), Floating plants (< 6.8 g/L), re-connected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Water milfoil, Water ribbons, Ribbonweed, Simple reed beds, Insect larvae, Golden perch, Australian smelt, Bony herring, Murray hardyhead, Common galaxias, Small-mouthed hardyhead, Fish-eating birds, Waterfowl and Generalist birds. There will be four (4) invasive receptors: various plankton, Common carp, Redfin perch and Spiny rush (inundated). This diagram is based on ecological effects in the Lake Alexandrina Do-nothing pumping scenario after ten years of Average recovery flows. The key to the receptor images used appears in Attachment A.

To enter this state, water levels and flow through the lakes will be high enough to reconnect the former littoral and riparian zones to the open water, allow for any regulators to be removed and keep the barrages (or fishways) open. It is therefore likely that flows through the system will be high enough to keep Lake Alexandrina fresh but may not be high enough to reduce or maintain Lake Albert salinities. Simple reed beds dominated by Phragmites australis will re-establish but full recovery of diverse reed beds typical of the CFW: Fresh state will be highly unlikely due to loss of propagules during the Acidified state and high levels of competition later in the vegetation succession (Section 7). The floodplain vegetation will be regularly connected and/or inundated leading to steady recovery if disconnection does not persist for so long that the floodplain vegetation communities are lost or highly degraded.

Re-establishment of riparian vegetation will provide pre-conditions for macroinvertebrates, fish and birds to re-establish over time. Any fauna that survived the Acidified or Highly acidified state (by seeking refuge in less acidic habitats) will have very poor food and habitat resources. The full diversity and abundance characteristic of the CFW: Fresh Complete state will not be recovered due to the complete loss that will have occurred in the acidified states.

Ramsar receptors that do not occur in the River Murray or the EMLR tributaries are at the highest risk of extinction because local populations from which dispersal may occur do not exist. Bird numbers may increase (particularly Generalist shorebirds that feed on insect larvae) but birds would be highly responsive to food availability at this and other sites and thus may fluctuate in terms of diversity and abundance over time. It is highly likely that invasive fish (Common carp and Redfin perch) will increase in relative abundance and dominance compared to native fish. Estuarine fish (e.g. Mulloway and Black bream) may visit the lakes.

If this ecologically degraded CFW: Post acidified state becomes strongly established it is unlikely that it could transition back to the Ramsar-state without extensive intervention (e.g. captive breeding, habitat rehabilitation, translocations). Figure 8.12 is based upon the receptor effects predicted for Lake Alexandrina under the Do-nothing pumping scenario following ten years of Average recovery flows (Section 7.5.1).

8.2.11. Disconnected Seawater-derived: Hypersaline

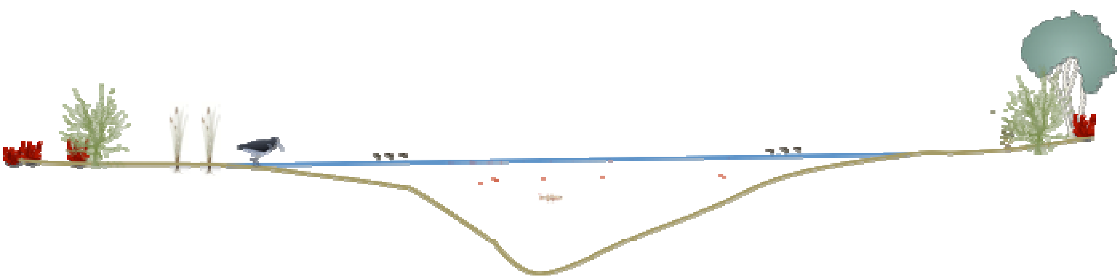


Figure 8.12: A conceptual diagram of the Disconnected Seawater-derived: Hypersaline state

which has seven (7) Ramsar receptors: Disconnected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Small-mouthed hardyhead (< 80 g/L), few Insect larvae and possibly Generalist shorebirds. There will also be five (5) invasive receptors: Hypersaline plankton, the most tolerant Estuarine ostracods and macroinvertebrates, Spiny rush (disconnected) and possibly a few Tubeworms (Lake Alexandrina only). This is based on the results of in Lake Alexandrina under the Seawater pumping scenario. The key to the receptor images used appears in Attachment A.

This state results from the annual opening of the barrages to let seawater (~35 g/L) into Lake Alexandrina in the Seawater scenarios. Salinity is projected to rise above 90 g/L (Section 5), which will see widespread mortality and the lake transition to a simplified halotolerant aquatic community. In the intermediate phases, between the Baseline state and this Hypersaline state, there may be periods when incoming estuarine and marine species could survive but ultimately salinities will become fatally high.

Only the seven most-salt tolerant Ramsar receptors are expected to survive transition into this hypersaline state. Small-mouthed hardyhead will only persist until salinities reach 80g/L. A few Insect larvae will tolerate close to the highest hypersaline salinities (138 g/L; Section 3) but diversity and abundance will be low and it is unknown whether Generalist shorebirds will find the remaining larvae palatable. The four floodplain vegetation receptors will be disconnected and increasingly stressed by lack of freshwater inundation. It is highly unlikely that estuarine plants (e.g. seagrasses) will establish considering their poor recruitment capacity and the highly dynamic physico-chemical conditions (Section 3). This state will be highly resilient to change and will trend unilaterally towards extinction of all biota except hypersaline plankton.

8.2.12. Disconnected Seawater-derived: Post-Hypersaline

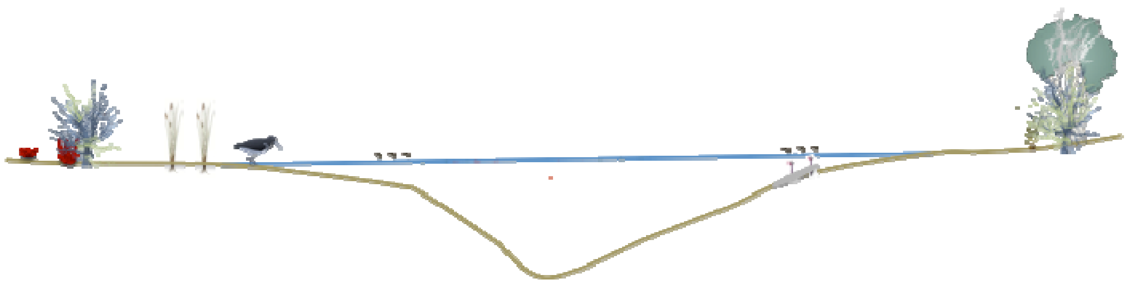


Figure 8.13: A conceptual diagram of the Disconnected Seawater-derived: Post-hypersaline state

which has nine (9) Ramsar receptors: River-sourced and Low salinity plankton (Lake Alexandrina only), rackish plankton, disconnected and stressed floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Insect larvae and possibly Generalist shorebirds. There will also be two (2) invasive receptors: Spiny rush (disconnected) and possibly a few Tubeworms (Lake Alexandrina only). This is based on the results of in Lake Alexandrina under the Seawater pumping scenario after five years of Entitlement recovery flows. The key to the receptor images used appears in Attachment A.

It is likely that salinities in the lake following hypersalinity induced by Seawater introduction will be higher for longer than following hypersalinity induced by evapo-concentration of freshwater in the Do-Nothing and Freshwater scenarios. Therefore, even less ecological recovery is expected to occur in the DSW: Post-Hypersaline state than in the DFW: Post-Hypersaline state. Introduction of Seawater during the action period may facilitate greater dispersal of estuarine and marine biota than in the Freshwater-derived states but salinities will be so high during the DSW: Hypersaline state that they will perish. Any fauna that might persist through the hypersaline conditions, perhaps by finding refuge in less saline habitats, will have extremely limited food and habitat resources and are not likely to form strong populations. Figure 8.13 is based upon the receptor effects predicted for Lake Alexandrina under the Seawater pumping scenario after five years of Entitlement recovery flows (Section 7.5.1).

8.2.13. Connected Seawater-derived: Post-Hypersaline

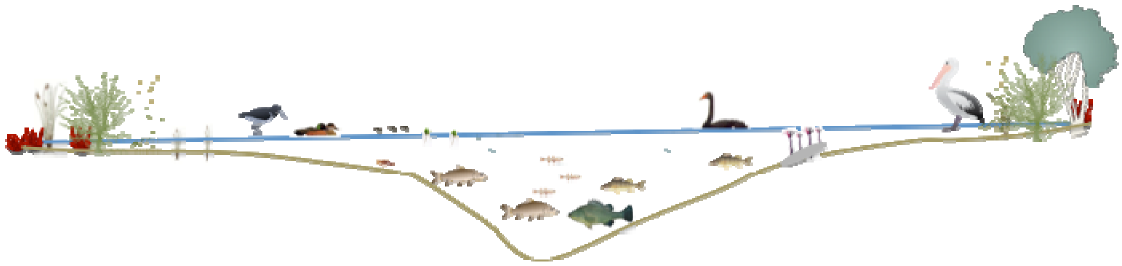


Figure 8.14: A conceptual diagram of the Connected Seawater-derived: Post-hypersaline state which has thirteen (13) Ramsar receptors: River-sourced and Low salinity plankton (Lake Alexandrina only), Brackish plankton, re-connected floodplain vegetation (Samphire, Paperbark, Lignum and Gahnia sedgelands), Floating plants, Simple reed beds, Golden perch, Small-mouthed hardyhead, Insect larvae and possibly Generalist shorebirds. There will also be four (4) invasive receptors: Common carp, Redfin perch, Spiny rush (inundated) and Tubeworms (Lake Alexandrina only). This is based on the results of in Lake Alexandrina under the Seawater pumping scenario after five years of Average recovery flows. The key to the receptor images used appears in Attachment A.

Salinity needs to drop to less than 50 g/L to enter this state. The riparian zone also needs to be reconnected, the barrages (or fishways) open and the regulators removed. It is likely that the capacity of the freshwater vegetation characteristic of the Ramsar state to re-establish will be much lower in this state than in the CFW: Post-Hypersaline due to Seawater causing greater adverse salinity impact for longer than evapo-concentration of freshwater. The extent of this recovery will depend on the period of time that the hypersaline conditions have persisted, the rate at which salinity decreases and the absolute salinity values. The more saline, the greater the rate of change or the longer the period that hypersaline conditions persist, the lower the post-hypersaline recovery potential will be. Figure 8.14 is based upon the receptor effects predicted for Lake Alexandrina under the Seawater pumping scenario after five years of Average recovery flows (Section 7.5.1). Other receptors such as Water milfoils, Australian smelt, Bony herring, Common galaxias may return later in the recovery period. Estuarine fish (e.g. Mulloway and Black bream) may also visit the lakes in latter years.

8.2.14. Connected Freshwater-derived: Fresh

The Connected Freshwater-derived: Fresh state is characterised by water levels within the typical operating range that allows for connection via the fish passages (> +0.4 mAHD). In this state, the lake water bodies will be connected to: each other (Narrung Narrows regulator removed); the Murray Mouth, Coorong and the Southern Ocean (open barrages); complex shorelines of diverse riparian and submerged vegetation; fringing wetland complexes (e.g. Waltowa Swamp) and the EMLR tributaries (Clayton regulator removed).

All 36 Ramsar receptors could survive in the CFW: Fresh state if salinities were < 2 g/L, except for the most salt-sensitive of the Insect larvae, but they may not all having self-sustaining and healthy populations (Figure 8.1; Attachment A). As salinities increase to 10 g/L, the stress experienced by the following Ramsar receptors will increase over time and may be fatal at the upper end of the Fresh salinity range:

River-sourced plankton and Low salinity plankton;

Freshwater macroinvertebrates, Yabbies and Freshwater mussel;

Floating plants, Water milfoils, Diverse reed beds;

Waterfowl;

Southern bell frog,

Short-headed lamprey and Yarra pygmy perch;

Transition from the Ramsar state to the CFW: Fresh is a result of freshwater inflows being insufficient to replace evaporative losses, which cause an increase in salinity to greater than the Ramsar targets (0.64 and 0.84 g/L for Lake Alexandrina and Albert, respectively) but less than 10 g/L. However, transition may come also from any of the alternate ecosystem states, including the Baseline state, although this is highly unlikely to occur (without intervention) in any of the management scenarios assessed here because of the significant losses between the Ramsar state and the Baseline state prior to October 2009 (Section 7). If any of the alternate states do transition to an ecologically Complete version of this CFW: Fresh state, that is one containing all Ramsar receptors and life history stages that tolerate salinities of 1-2 g/L, then it is highly likely that successful transition to the Ramsar state, and thus full ecological recovery, could be made if salinities dropped to Ramsar target levels. If a given alternate ecosystem state makes a transitions to an ecologically Degraded version of this CFW: Fresh state, key receptors such as Freshwater macroinvertebrates, Yabbies, Murray cod, Southern bell frog, Yarra pygmy perch, the diadromous fish and Freshwater mussels (Sections 8.3 to 8.5), will be missing and transition to the Ramsar state will not occur without intervention.

8.3. Do-Nothing ecosystem states and transitions

8.3.1. Lake Alexandrina

Pumping to Lake Albert

Pumping water from Lake Alexandrina to Lake Albert will lead to a decline in water levels in Lake Alexandrina over the action period. Consequently, there will be a rapid progression from the Baseline (DFW: Fresh Compromised) to the DFW: Brackish state (Figure 8.15). Water levels will continue to decline, leading to widespread acidification of the water body and a shift to the DFW: Acidified and then DFW: Highly acidified states. This transition is in effect a loss of all biota living in the water, thus the ecological viability degraded to Extinct.

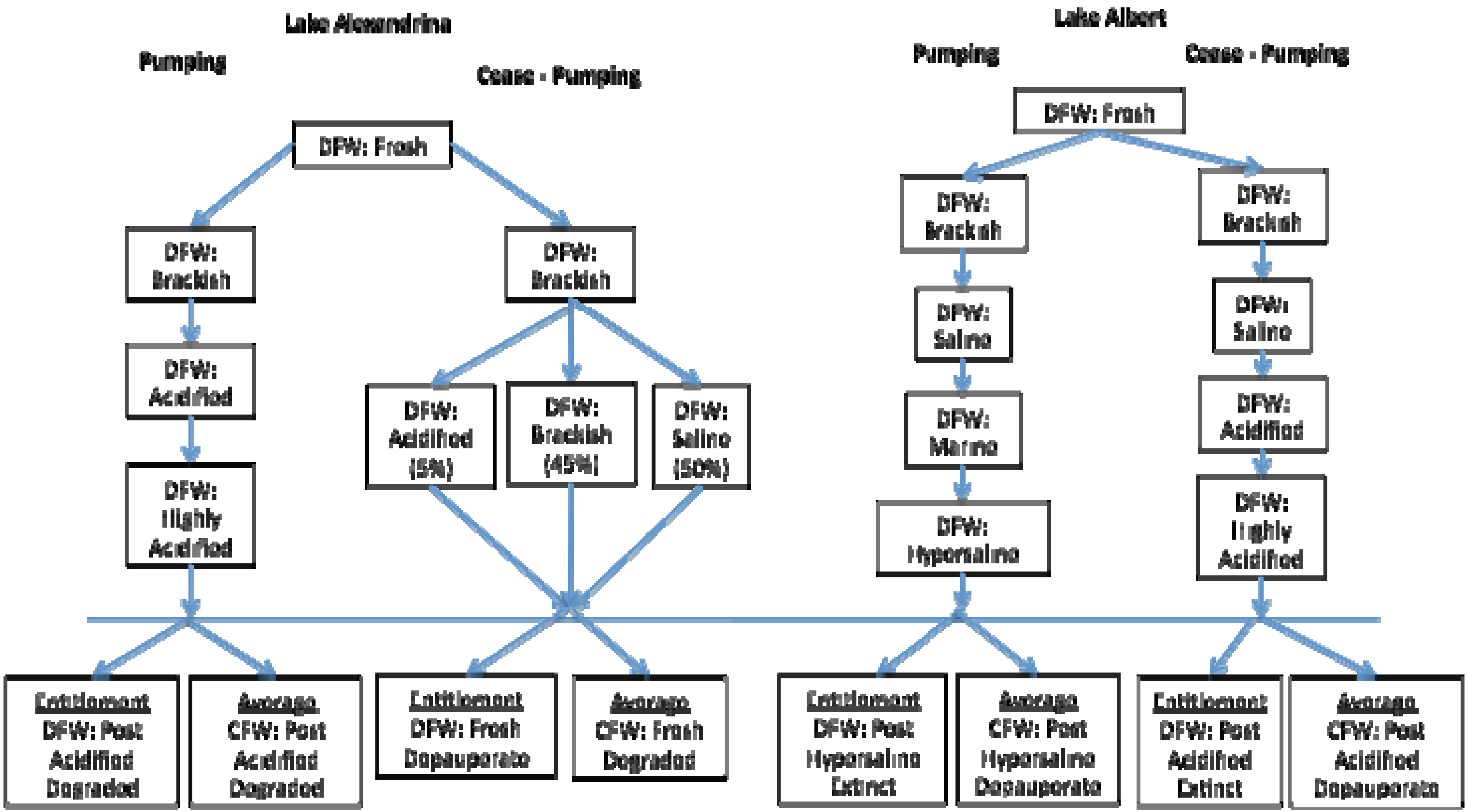


Figure 8.15: Probable transitions in ecosystems states in Lakes Alexandrina and Albert under the Do-Nothing scenario.
DFW: Disconnected Freshwater derived; CFW: Connected Freshwater derived. Entitlement refers to Entitlement recovery flows; Average refers to Average recovery flows. Refer to Attachment A for ecosystem state descriptions.

Under this scenario, Lake Alexandrina would be effectively devoid of aquatic life at the end of the five-year action period (2015), DFW: Highly acidified Extinct. This catastrophic impact means it will not transition towards the CFW: Fresh or Ramsar states under either Entitlement or Average recovery flows (Figure 8.15). Instead the Lake Alexandrina ecosystem will transition to alternate Post-acidified states, even though salinities return to fresh concentrations and pH will be circum-neutral in both recovery scenarios, which are the physico-chemical conditions indicative of a freshwater state (Section 7). Under Entitlement recovery flows, diverse aquatic flora will not re-establish, thus, the pre-conditions for recovery of other biota will not be met. This will result in a Depauperate ecosystem compared to the complete set of biota that may occur in the DFW: Post acidified state.

Average recovery flows result in slightly better recovery with a transition towards a Connected post-acidified state that was ecologically Degraded (CFW: Post acidified Degraded). If this alternate ecosystem state, DFW: Post acidified Degraded, becomes strongly established it is unlikely that there could be a transition back to the Ramsar-state without intervention. Thus although recovery under Average flows was better than under Entitlement flows, stabilisation of the resultant DFW: Post-acidified Degraded state may necessitate comprehensive intervention to even partially transition towards the CFW: Fresh state (i.e. partially restore the Ramsar-state). The ecosystem state transitions that will occur during the five-year Do-nothing action (due to salinisation and acidification) will, therefore, not be reversed even after ten years of Average recovery flows.

Cease pumping to Lake Albert

If pumping to Lake Albert ceases, water will not be taken from Lake Alexandrina. Consequently, water levels in Lake Alexandrina will remain higher than in the pumping scenario and, importantly, will remain above the tipping point for widespread acidification. Localised acidification events will occur around the lake margins but these will be relatively brief and minor. Therefore the DFW: Acidified state will only occur around 5% of the lake margins when pumping ceases compared to the DFW: Highly Acidified Extinct state occurring across the whole lake when pumping to Lake Albert continues (see above).

Increasing salinity will drive a transition from the DFW: Fresh Degraded Baseline state to the DFW: Brackish state in the northern half of the lake and to the DFW: Saline state in the southern half (Figure 8.15). Vegetation will not re-establish under Entitlement flows because of on-going disconnection and hostile conditions around the new shoreline (Section 7). Therefore, even though physico-chemical conditions in the lake improve from the DFW: Saline/Brackish states to the DFW: Fresh state, ecological recovery will not occur. The ecological condition will be Depauperate (DFW: Fresh Depauperate). If recovery flows are Average, ecological recovery will be improved, primarily because the water levels will be high enough to facilitate connectivity (CFW: Fresh Degraded). However, ecological recovery will still be poor and will not restore the Baseline state, remaining in the CFW: Fresh Degraded state, that is, lacking the diversity and abundance of the CFW: Fresh Complete or Ramsar ecosystem states (see above).

The resultant ecosystem state in Lake Alexandrina when pumping to Lake Albert ceases (CFW: Fresh Degraded) will be more connected and complex than if the pumping continues (DFW: Fresh Depauperate). However even under the best Do-nothing case, when pumping to Lake Albert ceases and recovery flows are Average, there will be little chance of recovery to the CFW: Fresh Complete state.

8.3.2. Lake Albert

Pumping

Under the Do-nothing pumping scenario, Lake Albert will be steadily salinised. Increasing salinities result in several ecosystem state transitions from the Baseline state (DFW: Fresh Compromised) through the DFW: Brackish, DFW: Saline, DFW: Marine states to the DFW: Hypersaline state (Figure 8.15).

Improvement in the physico-chemical environment of Lake Albert will occur under Entitlement recovery flows, however, the ecological viability will decline further to a previously unseen DFW: Post Hypersaline Extinct ecosystem state (see above). Under Average recovery flows, ecological response will be greater. The system may transition to the CFW: Fresh Degraded state over time but it is more likely to transition to a new ecologically Depauperate CFW: Post Hypersaline state, with significantly different ecological functionality.

Cease pumping

Ceasing to pump water into Lake Albert, results in a cascade of catastrophic events: high salinities, low pH and near complete drying that will cause complete ecological loss. At first a major simplification of the lake ecosystem occurs due to increasing salinity (DFW: Brackish to DFW: Saline; Figure 8.15). As water levels continue to drop, widespread acidification occurs before the lake dries to a few, very small isolated pools.

The result is total loss of all aquatic biota and habitat during the action period. No recovery is expected under Entitlement flows (dFW: Post-acidified Extinct) and very little under Average flows (CFW: Post-acidified Depauperate).

8.4. Seawater ecosystem states and transitions

8.4.1. Lake Alexandrina

Widespread acidification will be avoided in the seawater-pumping scenarios but salinities will increase from fresh concentrations in the Baseline state (DFW: Fresh Compromised) rapidly through Disconnected Seawater-Derived (DSW): Brackish, DSW: Saline, DSW: Marine to DSW: Hypersaline state (Figure 8.16). Salinity will be the dominant stressor; however, the ecological effects will be different to the salinity-induced changes from evapo-concentration in Do-nothing scenario, primarily because of periodic barrage opening and increased availability of marine dispersal mechanisms. The ecosystem state transitions will be so rapid that critical life stages of receptors with suitable salinity tolerances will be unable to be completed, thus the receptors will be unlikely to form self-sustaining populations (Lester *et al.* 2011).

These seawater-driven ecosystem transitions will be similar whether pumping to Lake Albert ceases or not. The key difference between the pumping and cease-pumping scenarios will be that any given receptor in Lake Alexandrina might persist for a few months longer in the cease-pumping scenario than in the pumping scenario. The pathway from the Baseline DFW: Fresh Compromised state was, thus, unilaterally towards extinction (DSW: Hypersaline Extinct) in Lake Alexandrina under the Seawater scenarios.

Recovery after seawater will be extremely poor under both Entitlement and Average recovery flows (DSW: Post-Hypersaline Extinct and CSW: Post-Hypersaline Extinct, respectively; Figure 8.16). There will be no transition to the CFW: Fresh or the Ramsar state.

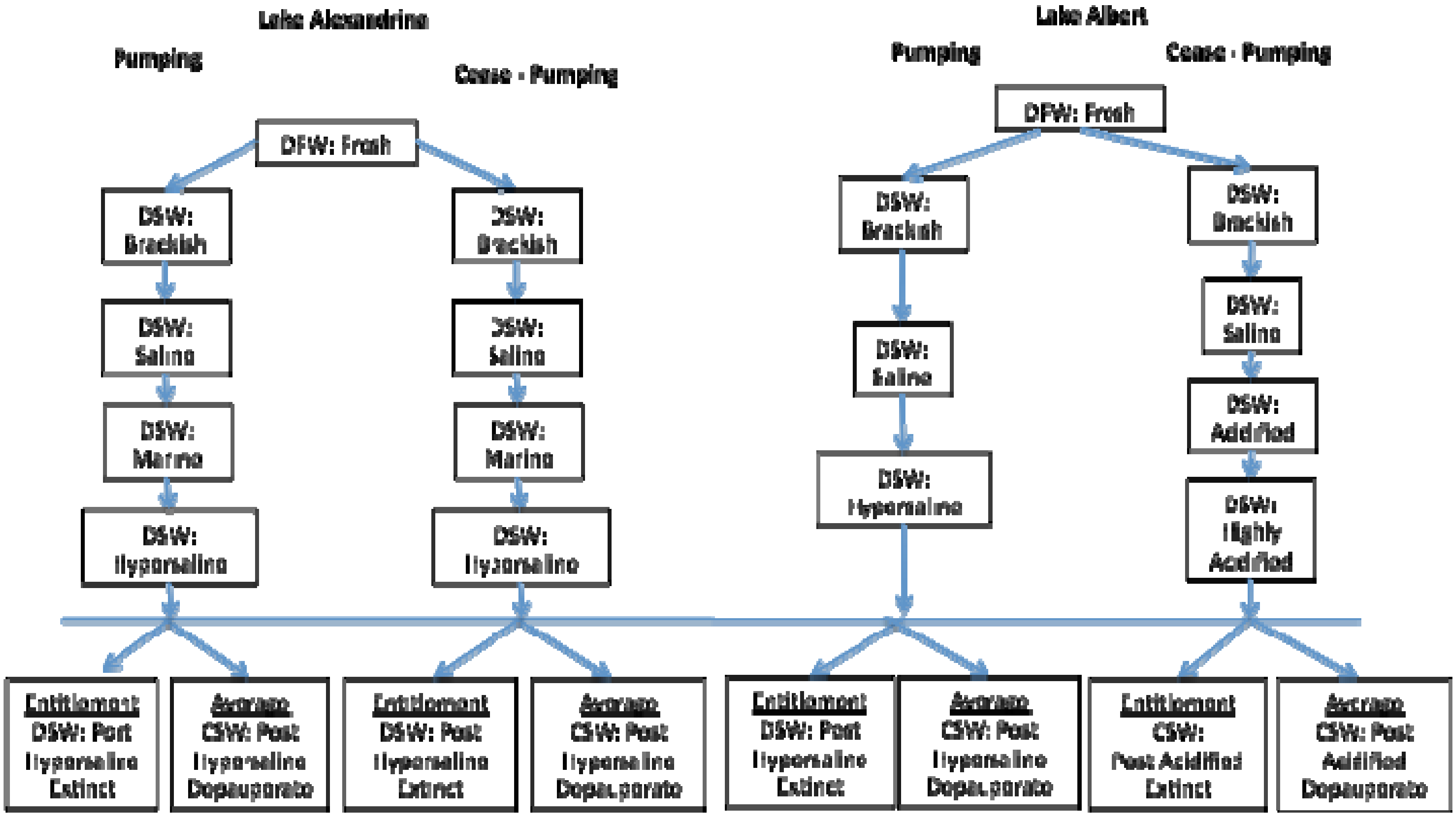


Figure 8.16: Probable transitions in ecosystems states in Lakes Alexandrina and Albert under the Seawater scenario.
DFW: Disconnected Freshwater derived; CFW: Connected Freshwater derived. Entitlement refers to Entitlement recovery flows; Average refers to Average recovery flows. Refer to Attachment A for ecosystem state descriptions

8.4.2. Lake Albert

When pumping continues, salinities in Lake Albert rapidly increase through DSW: Brackish to DSW: Saline then to DSW: Hypersaline (Figure 8.16). No Ramsar receptors will re-establish under Entitlement recovery flows except for extremely hardy Insect larvae and any birds that may feed upon them, thus, the system will end up in the DSW: Post Hypersaline Extinct state. Under Average recovery flows, the ecological response will be better but still extremely poor (CSW: Post Hypersaline Depauperate).

As in the Do-nothing cease-pumping scenario, if pumping ceases Lake Albert will transition to the DSW: Highly acidified state (Figure 8.16). There will be no recovery under Entitlement flows (DSW: Post-acidified Extinct) and only a very simple ecosystem with low resilience will establish under Average flows (CSW: Post Acidified Depauperate).

8.4.3. Murray Mouth and Coorong

Introducing seawater to the lakes will not induce salinity driven changes in the ecology of the Murray Mouth and Coorong given that increases in salinities will be ecologically insignificant compared to the very high baseline. However, long-term risks exist for the Coorong ecosystem, such as less frequent opportunities to release freshwater from Lake Alexandrina into the Coorong and the consequential increases in the salt load contained in water discharging from Lake Alexandrina. Inside the Murray Mouth there will be a risk of rapid drying of sediments on the seaward side of the barrages when seawater is introduced. This drying will probably be significant for Estuarine macroinvertebrates living in the sediments as well as for any remaining Ruppia spp. plants. Although introducing seawater will not induce a transition in ecosystem state in the Murray Mouth and Coorong, ecological viability will continue to decline and not recover even though seawater will "freshen" some areas.

8.5. Freshwater ecosystem states and transitions

8.5.1. Lake Alexandrina

Widespread acidification will be avoided, thus, salinity and water regime will be the primary drivers of community composition (Section 6). Salinities remain within the Fresh band (1-10 g/L) throughout the action and recovery periods. However, ecological viability will reduce over time.

There will be a transition from the Baseline DFW: Fresh Compromised state to the DFW: Fresh Degraded state during the action period (Figure 8.17), whether pumping to Lake Albert ceases or not.

Differences in ecological viability between the Entitlement (DFW: Fresh Depauperate) and Average (CFW: Fresh Degraded) recovery flows are due to on-going disconnection under Entitlement flows compared with reconnection under Average flows. Under Average recovery flows,the former riparian zone will be re-connected and simple vegetation communities will form. This has strong positive effects on ecological recovery. The lack of reconnection is a strong driver for the transition to a Depauperate ecosystem under Entitlement flows compared to the transition to a Degraded one under Average flows.

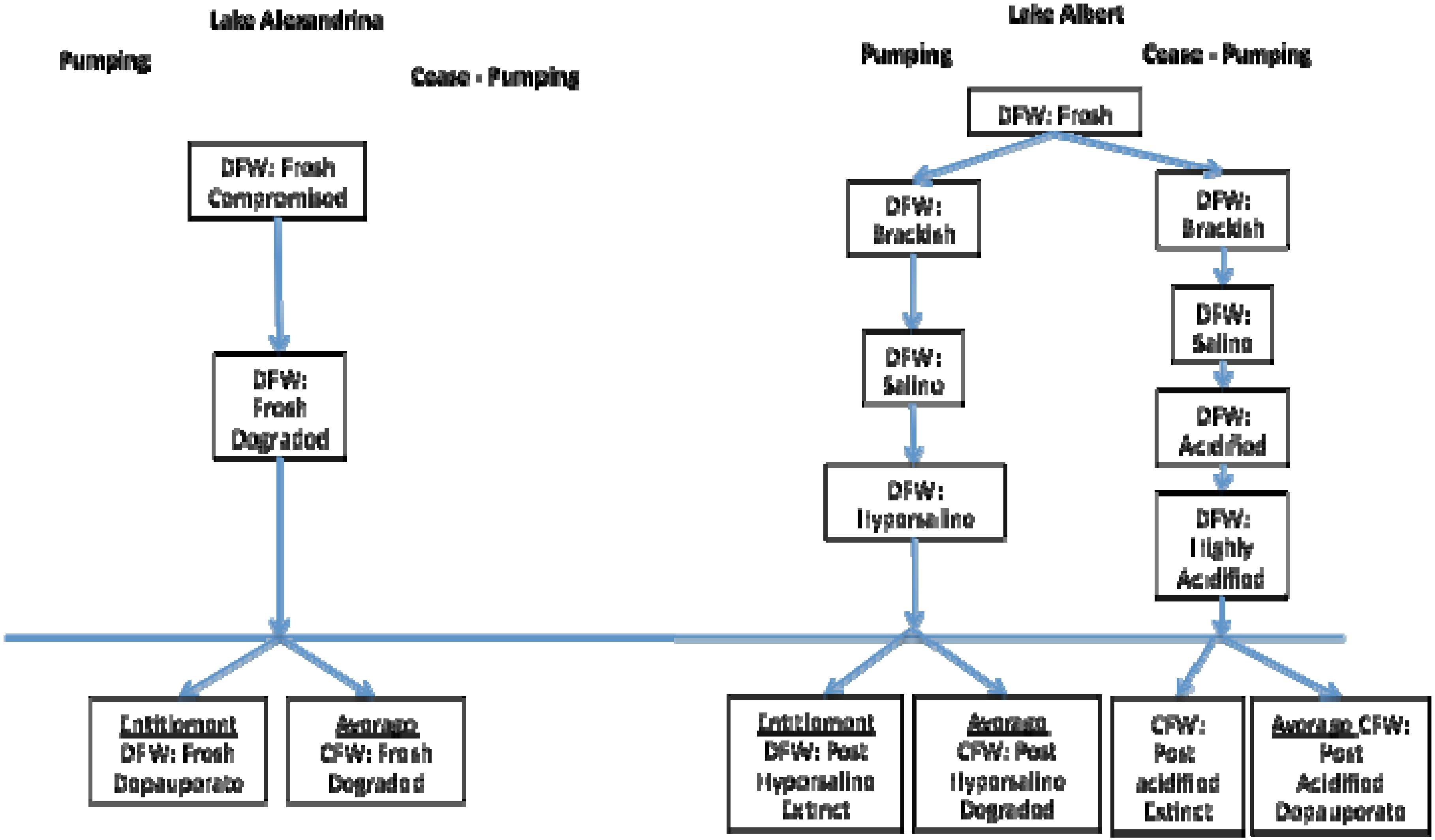


Figure 8.17: Probable transitions in ecosystems states in Lakes Alexandrina and Albert under the Freshwater scenario.
DFW: Disconnected Freshwater derived; CFW: Connected Freshwater derived. Entitlement refers to Entitlement recovery flows; Average refers to Average recovery flows. Refer to Attachment A for ecosystem state descriptions.

8.5.2. Lake Albert

Pumping to Lake Albert will prevent widespread acidification, however, salinities will increase rapidly. This will transition the ecosystem from the Baseline state (DFW: Fresh) through the DFW: Brackish state to the DFW: Saline state (Figure 8.17). Salinities will stay within the DFW: Saline band (15-25 g/L) until the last few months of the action period when a transition to the DFW: Hypersaline state will occur.

Under Entitlement recovery flows, only Insect larvae that persist through the action period and the Generalist shorebirds that feed upon them, will respond positively to the enhanced physico-chemical conditions. The low water levels will drive the ecological viability within the DFW: Post Hypersaline state to the Extinct class. If recovery flows were Average, then connectivity will be re-established. However, the ecological response will not transition the lake to the recovery state (CFW: Fresh Complete), but rather to a CFW: Post Hypersaline Degraded state.

Catastrophic loss of all receptors occurred in Lake Albert, as for the Do-Nothing and Seawater cease-pumping scenarios, resulting in transitions to the DSW: Post Acidified Extinct and CSW: Post Acidified states under Entitlement and Average recovery flows, respectively.

8.6. Conclusions

All the regional management options start in the same ecosystem state (Baseline state, DFW: Fresh Compromised) but the specific ecosystem states they will transition through and to differ markedly. No two management scenarios will have the same chain of ecosystem states and transitions. The transitions will be driven primarily by changes in the physico-chemical conditions (salinity, pH and water levels), although ecological interactions and processes will also strongly affect the ecological outcomes. All transitions that will occur during the action periods will be negative, that is, trend away from both the Baseline and Ramsar states. This is partly due to the very poor baseline condition of the lakes' ecosystems but is mostly due the adverse effects of high salinities, low water levels and/or low pH that the receptors will experience during the action periods.

Transition to an ecologically complete Connected Freshwater-derived: Fresh state (the pre-cursor to recover to the Ramsar state) will not occur even under those scenarios where the lakes become reconnected and fresh. The closest ecosystem states will be CFW: Fresh Degraded in Lake Alexandrina and CFW: Post Hypersaline Degraded in Lake Albert under the Freshwater pumping followed by Average recovery flows scenarios.

Some of the predicted alternate ecosystem states (e.g. DFW: Post Hypersaline Extinct) will be highly resistant to restorative transitions towards the recovery state (CFW: Fresh Complete) or the Ramsar state, regardless of River Murray flow regimes or scale of the intervention strategies. That is, the ecological effects will be essentially irreversible and probably unmanageable. Other alternate ecosystem states that seem less negatively affected relative to the Ramsar state (e.g. CFW: Fresh Degraded) will still take decades of average or greater River Murray inflows and smart interventions (e.g. captive breeding, revegetation) to transition towards the recovery state and may never return to the Ramsar-state.

9. Conclusions and Future works recommendations

Introducing seawater or delivering sufficient fresh River Murray water to the site to maintain target water levels will effectively prevent widespread acidification and the subsequent extinction of the Lakes' ecosystems. Localised and brief water acidification events will occur in Lake Alexandrina in the Seawater and Freshwater scenarios when pumping to Lake Albert continues but these will be ecologically significant for only a subset of receptors that depend on the littoral zones (e.g. macroinvertebrates).

Widespread acidification occurs when water levels in Lake Alexandrina drop under the Do-nothing scenario and in Lake Albert under all the scenarios in which pumping ceases. When this occurs, all biota in contact with the acidic water will perish. Lake Albert will then dry to a few isolated pools that will be highly acidic and near-saturation with salt. The only aquatic life will be extremely acid-tolerant halophilic microbes (extremophiles).

None of the alternative acidification control measures (e.g. planting, mulching or neutralising with limestone) will be capable of preventing either widespread or localised water acidification (Attachment F). However revegetation of the exposed acid sulfate soils around the lakes where water acidification will occur will be likely to improve recovery from that assessed here. Therefore whichever regional water management option is chosen, revegetating the exposed lakebed with a range of plants will provide multiple ecological benefits even though it will be unlikely to provide acidification control.

Salinity will be a key driver of ecosystem composition in all scenarios, regardless of whether acidification occurs or not. Salinities in the Do-nothing scenarios increase during the action period to levels that will cause many of the freshwater receptors to be lost or adversely affected before acidification occurs. Seawater introduction will lead to extreme increases in salinity and the subsequent rapid and complete loss of all receptors typical of the Ramsar state. Estuarine and marine communities will not establish in the lakes in either the Do-nothing or the Seawater scenarios. Thus, the overall result will be the loss of diverse and productive ecosystems in the lakes not a transition to different, more salt-tolerant ones under the Do-Nothing and Seawater scenarios.

Even under the least-adverse scenario (Freshwater pumping to Lake Albert with Average recovery flows) the receptor populations are not likely to be very healthy or resilient and are likely to be highly susceptible to further impacts. Simple reed beds will form over time in all the Average flow recovery scenarios but not in the Entitlement flow scenarios. Less common emergent plants and the submerged plants will be unlikely to re-establish for many years. Given that it will be necessary for diverse and wide littoral and riparian vegetation to establish before there can be significant recovery of macroinvertebrates, fish, frogs and birds, it is highly unlikely that complex, diverse food webs typical of the Ramsar state will re-establish across one or both lakes under any scenario by 2025.

In all paired scenarios, recovery will be significantly higher in Lake Alexandrina than in Lake Albert. Recovery in Lake Alexandrina will assist recovery in Lake Albert in terms of providing recruits that may disperse into Lake Albert but recovery in Lake Alexandrina will limit recovery in Lake Albert in terms of exporting salt and keeping salinity levels in Lake Albert higher for longer. Overall, the Lake Albert ecosystem will be far more degraded and further from the Ramsar state than the Lake Alexandrina ecosystem under any given scenario.

Invasive receptors (Redfin perch, Tubeworms, Spiny rush and Common carp) will be the only receptors to increase in abundance and diversity during the action period. They will continue to increase during the recovery period for all but the Do-nothing cease-pumping and Freshwater Average recovery flow scenarios. If these invasive receptors form strong populations then it is likely to be more difficult or even impossible to return to the Ramsar state, regardless of the recovery flow regime.

No receptors found in the Ramsar state will increase in abundance during the action period under any of the scenarios. Their capacity to subsequently increase during the recovery periods will be highly dependent on the magnitude of the consequences that occur during the action period, the duration of stressful periods and the magnitude of the recovery flows. That is, recovery potential under Entitlement recovery flows will be far less than under Average recovery flows in all scenarios. Furthermore, recovery following Seawater introduction or the drying of Lake Albert under the cease pumping scenarios will be significantly less than for the other scenarios.

It is likely that some of the new ecosystem states that will form in the lakes will be resilient to restorative transitions (Zelder 2000, Bakker and Berendse 1999). Souter and Stead (2010) describe this as a type of inertia that prevents restorative change, in this case, transition towards a healthy, freshwater ecosystem reminiscent of the Ramsar state. The shifts from saline and/or acidic conditions to fresh will occur so quickly in the recovery periods that they are likely to effectively be another disturbance in already damaged populations rather than initiating recovery.

If the need to implement one of the management options arises, it is likely that River Murray will have been low for several years and thus 'recovery' flows may be even less than Entitlement or Average flows. Lower inflow volumes from the River Murray or more intermittent River Murray flows during recovery will lead to less strong recovery, lower diversity of Ramsar receptors and greater dominance of invasive receptors.

The disconnection, desiccation and soil acidification that will occur in key fringing wetland areas such as Boggy and Dog Lakes and Dunn's Lagoon in Lake Alexandrina and Waltowa Swamp in Lake Albert may also mean that recovery will not be as great as predicted here (these areas are significant drought refugia and contained the greatest diversity and abundance prior to 2006).

Furthermore, the effects of secondary stressors such as heavy metals, metalloids and nutrients were not evaluated. It may be if they were considered that the predictions for recovery, particularly in the scenarios where widespread acidification occurs and large quantities of these pollutants may have been mobilised, would be even less. Other factors that have not been considered are the flow-on effects on ecosystem services. For example, there may be increased human health risk from increased dominance of insects (including mosquitos) and lower abundance of predators (e.g. fish) predicted in many of these scenarios.

Of all the management options, Freshwater delivery was the only option that showed any trend towards the Ramsar-state. However even under this option, with Average recovery flows, there will still be a significant decline in ecological viability with an increase in dominance by invasive taxa. The Do-nothing and Seawater management options will trend away from the baseline state towards a range of, as yet unseen, alternate ecosystem states that will most likely resist transition to the Ramsar state under any future flow regime.

Recovery is likely to be better following acidic rather than hypersaline conditions because salinities stay higher for a longer in the post-hypersalinity states than pH stays low in the post-acidic states. The ecological viability that will result from any management decision will depend on a multiplicity of ecological interactions and pre-conditions that are highly unlikely to be reversible if catastrophic ecological impacts occur. These results show that recovery of the Lakes' ecosystems will not simply be a matter of recovering abiotic conditions (e.g. water regime, salinity and pH) to target levels.

Considering the probable ecological responses during both the action and recovery periods, the management scenarios for Lake Alexandrina scenarios ranked in order of increasing negative ecological effects are:

- Freshwater pumping
- Freshwater cease-pumping
- Do-nothing cease-pumping
- Do-nothing pumping

- Seawater cease-pumping
- Seawater pumping

For Lake Albert, the management scenarios ranked in order of increasing negative ecological effects are:

- Freshwater pumping
- Do-nothing pumping
- Seawater pumping
- Freshwater, Do-Nothing and Seawater cease-pumping

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Attachments

Attachment A: Description of the Ramsar and baseline ecosystem states for Lakes Alexandrina and Albert, including the key to the receptor icons used in the conceptual diagrams.

Ecosystem states are: recognisable, stable, resistant and resilient abiotic/biotic complexes (Stringham *et al.* 2003; Suding *et al.* 2004; Spooner and Allcock 2006; Souter and Stead 2010). Each ecosystem state encompasses a certain amount of variation in space and time but these authors recognise transitions in ecosystem states, which are trajectorys of change away from the current stable state towards an alternative stable state triggered by natural and/or managed events.

Thirteen observed and predicted alternative ecosystem states for Lakes Alexandrina and Albert were identified by Souter and Stead (2010) as part of the ECA process, which were defined based upon salinity and pH thresholds. Two broad groups were identified based on whether they were derived from freshwater inflows and evaporation (i.e. Do-nothing and Freshwater scenarios) or from seawater introduction through the barrages (i.e. Seawater scenarios). These ecosystem state determinants formed the basis of the descriptions of ecosystem states provided below but consideration was also given to whether connectivity across the site was functional (Connected) or not (Disconnected) and which receptors were expected to be present if the ecosystem state was biologically complete. Also the salinity thresholds between states are marginally different here (Section A.2) to those used in Souter and Stead (2010). These threshold refinements were based upon the outcomes of the ECA workshops, expert literature reviews (Section 3) and the outcomes of the ecological consequence assessments (Sections 3-7). Thresholds for pH (< 5.5 and < 3.5) were the same as in Souter and Stead (2010).

The descriptions of the alternate ecosystem states provided below are based upon the predictions in Souter and Stead (2010), iterating with the results of the ecological consequences assessment undertaken here (Sections 4-7). In order to satisfy the aims of ECA (Section 1.1), the Ramsar state was defined as the ecosystem state the lakes were in when described by Phillips and Muller (2006; Section A.1). The baseline state at the beginning of the action period was different to this. The lakes had transitioned from the Ramsar state to an alternate baseline state that was Freshwater-derived and fresh in salinity (< 10 g/L) but disconnected and ecologically degraded (Section A.2). Under each management scenario, transitions to one or more of the ecosystem states described below occurred during the action period. A range of alternate post-action states that have not yet been seen in the lakes (e.g. Alternate post-freshwater derived acidified) were also predicted during the ‘recovery’ period. These are also described below.

A.1. The Ramsar state

The Ramsar-state for the lakes is that described in Phillips and Muller (2006; Figure A.1). In this state, the lakes are vast open water body with sandy beaches and diverse stands of reeds and semi-emergent plants. The ecology of the main open water body is not well known but is thought to be dominated by plankton, large-bodied fish and possibly floating plants (ECA workshops). Most of the diversity and production is thought to occur in the littoral and riparian zones as well as the fringing wetland complexes that adjoin the open water. The most ecologically diverse areas occur near the confluences: Pomanda Island where the River Murray enters Lake Alexandrina, between Lake Alexandrina and Lake Albert, where the Eastern Mount Lofty Ranges tributaries meet Lake Alexandrina and around the island streams. Sheltered bays and the fringing wetlands, such as Dunn’s Lagoon and Waltowa Swamp also provide diverse and abundant wetland habitats.

Submerged littoral plants in the lake are restricted to the near-shore, wetland and channel areas. In 2006, the littoral zone extended approximately 25 m into the lake water body limited by light penetration, wind action and lakeshore instability (Gehrig and Nicol 2009). Fringing lakeshore habitats are important for a range of fauna, but Phillips and Muller (2006) concluded they were depauperate in species that rely on variable water regimes for growth and reproduction. Such species are mostly confined to the tributary influenced areas (i.e. Baumea spp.). Submerged aquatic plants provide critical habitat and food resources for a range of small- and large- bodied native fish, macroinvertebrates and birds. Overall, these observations suggest that in 2006, the lakes were in a Compromised Ramsar-state compared to the Complete Ramsar-state which occurred at the time of listing (1985).

The salinity thresholds for the Ramsar-state are < 0.64 g/L in Lake Alexandrina and < 0.84 g/L in Lake Albert based upon the requirements of a comprehensive suite of indicators developed by Lester *et al.* (2011). Although for the purposes of this assessment the salinity threshold for the Ramsar-state can be rounded up to less than 1 g/L for both lakes given that no receptors indicative of the Ramsar-state would experience significant salinity-induced stress at that level (Section 3; Attachments B and C). In the Ramsar-state, an estuarine salinity regime occurs downstream of the barrages with an ecologically suitable gradient across the Coorong (Lester *et al.* 2011). The water regime in the lakes is not static but varies in a manner that mimics the natural pattern of rise and fall. Water levels range +0.35 mAHD to +0.95 mAHD or greater (as described by Muller 2011) and never drop below +0.3 mAHD. Such a water regime meets the environmental water requirements of the littoral, riparian and floodplain habitats (Lester *et al.* 2011).

Acidification events do not occur in the Ramsar-state because the water regime inundates the bulk of the lake bed and allows for 'burning-off' of peripheral acid sulfate soils (Attachment F), thus, pH is circum-neutral. Full functional connectivity exists between the: river, lakes, tributaries, fringing wetlands, floodplain, Murray Mouth, Coorong and the Southern Ocean. The barrages and fishways are operated such that there are no periods of disconnection (Bice and Zampatti 2010; Muller 2011). The ECA experts selected a subset of these depicted taxa, known to have occurred in the Ramsar-state, as receptors for the ecological consequences assessment (Section 3; Table A.1). Under Ramsar-state abiotic conditions, none of the Ramsar receptors in Table A.1 are under stress. The conceptual diagram of the Ramsar-state in Figure A.1 shows the Ramsar and invasive receptors that were present in the Ramsar-state as illustrations and a receptor list below the caption. The number of each receptor in the diagrams denotes relative ecological viability compared to the conceptual diagrams for alternate ecosystem states. It should be interpreted with the aid of the receptor keys in Tables A.2 and A.3.

The Ramsar-state differs significantly from the pre-European ecosystem state (Muller *et al.* in prep.) in that the water regime was altered, the littoral zone had severely contracted, some taxa were lost or had extremely low ecological viability (e.g. Purple-spotted gudgeon, Yarra pygmy perch, sensitive submerged and emergent aquatic plants, freshwater macroinvertebrates), hydrological barriers had been constructed (e.g. barrages) and key processes had been modified or interrupted (e.g. terrestrial-aquatic connectivity).

Receptors tolerate less than the stressor value where the < symbol is used and greater than the stressor value where the > symbol is used. Thresholds are adult mortality unless stated. Where known, optimal values are shown after the range in parentheses. *phytoplankton: tolerate pH of 5; zooplankton: tolerate pH of 4. Lx = Lake Alexandrina, Lb = Lake Albert. Where the receptor is a mixed group, the lowset threshold for a group member is given.

Table A.1: Ramsar receptors for Lakes Alexandrina and Albert showing their tolerance ranges or thresholds for the three primary stressors: salinity, water level and pH.

Receptor	Salinity range or threshold (g/L)	pH range or threshold	Water level range or threshold
Plankton			
River-sourced plankton (Lx)	0 - 3	> 5 (> 4)*	Changing areas for growth; mortality if dry.
Low salinity plankton (Lx, Lb)	3 - 10	> 5 (> 4)*	
Brackish plankton (Lb)	5 - 15	> 4	
Vegetation			
Floating plants	< 6.8	> 4	Changing areas for growth; mortality if dry.
Samphires	> 50	> 4	Optimal regular inundation >+0.6 mAHD
Paperbark woodlands	> 50	> 4	
Lignum	< 50	> 4	
Gahnia sedgelands	> 50	> 4	
Water milfoils	< 10	> 5	Optimal > +0.3 m AHD
Water ribbons	< 20	> 5	Optimal > +0.3 m AHD
Ribbonweed	< 15	> 5	Optimal > +0.3 m AHD
Diverse reed beds	< 10	> 4	Optimal regular inundation >+0.6 mAHD
Lacustrine Macroinvertebrates			
Freshwater macroinvertebrates	< 3.4	> 6.5	Optimal > +0.3 m AHD
Mussel (reproduction failure)	< 3.5	> 6.5	Optimal > +0.3 m AHD
Mussel (adult mortality)	< 10	> 6.5	Optimal > +0.3 m AHD; Can use open water
Yabbies	< 8.16	> 6.5	Optimal > +0.3 m AHD; May use open water
Littoral macroinvertebrates	< 20	> 6.5	Optimal > +0.3 m AHD
Brackish macroinvertebrates	< 30	> 6.5	Optimal > +0.3 m AHD
Insect larvae	1 - 138	< 6	Optimal > +0.3 m AHD; sediments; pelagic
Fish			
Murray cod	< 13.2	> 5	Open water (> 1m deep); -1.5 m AHD
Golden perch	< 14.4	> 5	Open water; -1.5 m AHD
Common carp	< 13	> 5	Open water; -1.5 m AHD; spawn in littoral zones
Short-headed lamprey ammocoetes	< 10	> 5	Optimal > +0.1 m AHD;

			connectivity
Australian smelt	< 30	> 5	Littoral; Optimal > +0.3 m AHD
Bony herring	< 30	> 5	Open water; -1.5 m AHD
Murray hardyhead	< 30	> 5	Littoral; Optimal > +0.3 m AHD
Yarra pygmy perch	< 10	> 5	Littoral; Optimal > +0.3 m AHD
Congolli (preferred habitat)	< 2	> 5	Connectivity and littoral optimal >+0.3 m AHD; -1.5 mAHD
Congolli (adult mortality)	< 40	> 5	
Common galaxias (females & juveniles)	< 2	> 5	Connectivity and littoral optimal >+0.3 m AHD; can use open water; -1.5 mAHD
Common galaxias (adult mortality)	< 40	> 5	
Small-mouthed hardyhead	3 - 80	> 5	Open water; -1.5 m AHD
Yellow-eyed mullet (visitor)	< 60	< 5	Open water; -1.5 m AHD
Black bream	< 60 (20-35)	< 5	Open water; -1.5 m AHD
Mulloway (visitor)	< 35	< 5	Open water; -1.5 m AHD
Frogs			
Southern bell frog	< 9	unknown	Optimal > +0.1 m AHD; lake connections
Birds			
Generalist shorebirds	No specific tolerance bands; will follow Insect larvae		
Fish-eating birds	No specific tolerance bands; will follow fish (Small-mouthed hardyhead typically last remaining fish as salinity increases from Coorong observations and published tolerances)		
Waterfowl	No specific tolerance bands; will follow Floating plants and zooplankton		
Terrestrial birds	No specific tolerance bands; Require fringing wetlands to be connected and well-vegetated with Ramsar state flora.		
Fringe-dwelling birds			

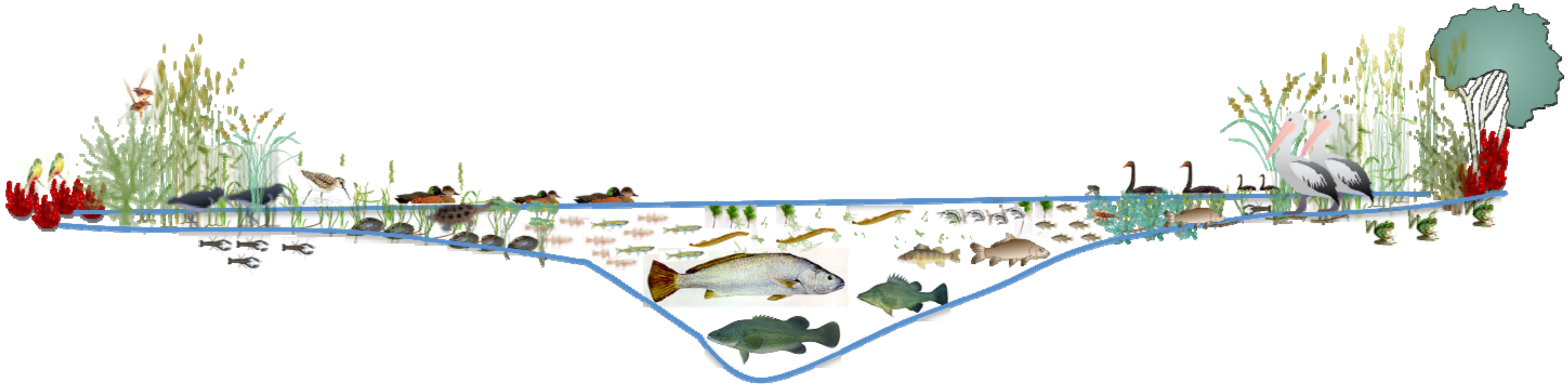

Figure A.1: A schematic diagram of the Ramsar state: Degraded that occurred in 2006 when lake water levels began to drawdown

Ramsar-State: Degraded has: River-sourced and Low salinity plankton, Floating plants, Samphire, Paperbark, Lignum, Gahnia sedgelands, Diverse reed beds, Water ribbons, Ribbon weed, Water milfoils, Lacustrine macroinvertebrates (Yabbies, Freshwater mussels), Insect larvae, Murray cod, Golden perch, Yarra pygmy perch, Catfish, Diadromous fish (Short-headed lampreys, Common galaxias, Congolli), Australian smelt, Murray hardyhead, Small-mouthed hardyhead, Bony herring, Southern bell frog, Terrestrial birds, Fringe-dwelling birds, Waterfowl, Fish-eating birds, Generalist shorebirds (healthy turtles, mammals and snakes). Invaders: Common carp and Redfin perch

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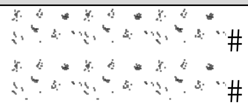
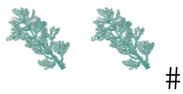
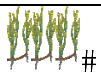
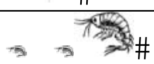
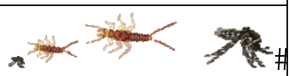
Table A.2: Key to the illustrations for Ramsar receptors used in the conceptual diagrams for Lakes Alexandrina and Albert.

Lx = Lake Alexandrina, Lb = Lake Albert. Note: not all Ramsar receptors used in ECA were individually depicted but all were represented by an illustration.

Ramsar Receptor	Indicator for	Illustration used
Plankton		
River sourced plankton*	River-influence	
Low salinity plankton	Typical Lx taxa	
Brackish salinity plankton	Typical Lb taxa	
Vegetation		
Floating plants	Open water	
Samphires	Floodplain	
Paperbark woodlands	Floodplain	
Lignum	Floodplain	
Gahnia sedgelands	Fringing wetlands	
Water milfoil	Littoral zone	
Water ribbons *(Triglochin procerum)*	Riparian and Littoral zones	
Ribbonweed *(Vallisneria spiralis)*	Littoral water	
Diverse reed beds	Riparian and Littoral zones	
Lacustrine macroinvertebrates		
Freshwater macroinvertebrates*	Littoral zone	
Mussel *(Velesunio ambiguus)*	Littoral zone (can use open water)	
Yabbies (*Cherax destructor*)	Littoral zone	
Littoral macroinvertebrates	Littoral zone	
Insect larvae	Highly tolerant as a group, Flying adults	
Fish		

Ramsar Receptor	Indicator for	Illustration used
Murray Cod	Open water, predator	 #
Golden Perch	Open water, predator	 #
Short-headed lamprey, Congolli and Common galaxias	Diadromous, Connectivity	 #
Yarra pygmy perch	Littoral zone, Fringing wetlands	 #
Australian smelt (Murray Hardyhead)	Mid-salinity tolerant small-bodied fish	 #
Small-mouthed hardyhead	Highly tolerant fish	 #
Mulloway (Black bream)	Estuarine fish that visit the lakes, Connectivity	 #
Frogs		
Southern bell frog	Littoral, streams Lx, Lb, GC	 #
Birds		
Generalist shorebirds	Follow Insect larvae, Opportunistic	 #
Fish-eating birds	Follow fish, Opportunistic	 #
Waterfowl	Follow aquatic plants, Opportunistic	 #
Terrestrial birds (Southern emu wren, Orange bellied parrot)	Fringing wetlands, Connectivity	 #
Fringe dwelling birds (Latham's snipe)	Fringing wetlands, Connectivity	 #

Table A.3: Key to the illustrations used to depict invasive receptors in the conceptual diagrams for Lakes Alexandrina and Albert that were present in the Ramsar state.

The number of each receptor in the diagrams denotes relative ecological viability compared to the conceptual diagrams for alternate ecosystem states.

Invasive Receptor	Indicator for	Illustration used
Fish		
Common carp	Invasive littoral zone	 #
Redfin perch	Invasive predator	 #

A.2 Alternate ecosystem states for the lakes

As described above, there is a range of possible ecosystem states alternate to the Ramsar-state that the lakes' ecosystems could be in. They are broadly categorised as Freshwater- or Seawater- derived and the salinity and pH thresholds that define their boundaries are shown below in Table A.2. The ecosystem states are also described in terms of functional connectedness: if the open water body is connected to the riparian zone, the barrages are open and no regulators are in place then it is in a connected state. If this connectivity is not present, that is, lake water levels are too low to connect to the Ramsar riparian zone (< 0.3 mAHD, regulators are in place and the barrages are closed, then it is a Disconnected state.

Table A.2: Ecosystem states in the freshwater- and seawater-derived groups and their salinity and pH thresholds.

State	Thresholds	
	Salinity (g/L)	pH
Freshwater-derived states		
Ramsar state	< 1	> 5.5
Freshwater derived: Fresh	1 - 10	> 5.5
Freshwater derived: Brackish	10 - 15	> 5.5
Freshwater derived: Saline	15 – 25	> 5.5
Freshwater derived: Marine	25 - 50	> 5.5
Freshwater derived: Hypersaline	50 - 150	> 5.5
Freshwater derived: Ultrasaline	> 150	> 5.5
Freshwater derived: Acidified	various	< 5.5, > 3.5
Freshwater derived: highly acidified	various	< 3.5
Alternate post-freshwater derived acidified	various	> 5.5
Seawater-derived states		
Seawater derived: Fresh	1 - 10	> 5.5
Seawater derived: Brackish	10 - 15	> 5.5
Seawater derived: Saline	15 – 25	> 5.5
Seawater derived: Marine	25 - 50	> 5.5
Seawater derived: Hypersaline	50 - 150	> 5.5
Seawater derived: Ultrasaline	> 150	> 5.5
Seawater derived: Acidified	various	< 5.5, > 3.5
Seawater derived: highly acidified	various	< 3.5
Alternate post-seawater derived acidified	various	> 5.5

Not all the receptors in the Ramsar state will persist under these alternate states. Persistence will depend on the physico-chemical characteristics such as salinity tolerances of the different receptors (Table A.1 and Figure A.2) as well as the receptors' ecological attributes described in Sections 3 and 7. To reflect this variance in ecological viability, a five-point health descriptor was developed to further refine the ecosystem state descriptions, as follows:

Complete: All receptors expected in that ecosystem state exist in self-sustaining populations without stress.

Compromised: All receptors expected in that ecosystem state exist but not all are in self-sustaining populations without stress.

Degraded: Some receptors expected in that ecosystem state exist in self-sustaining populations without stress. Most are stressed and the least tolerant have been lost.

Depauperate: No receptors expected in that ecosystem state exist in self-sustaining populations without stress. Most have been lost and the most tolerant are stressed.

Extinct: All the receptors expected in that state have been lost with the exception of highly tolerant, opportunistic receptors that have dispersive agents available at all times and in all places (e.g. Insect larvae, Generalist shorebirds, Plankton). Small-mouthed hardyhead may also persist in some connected states.

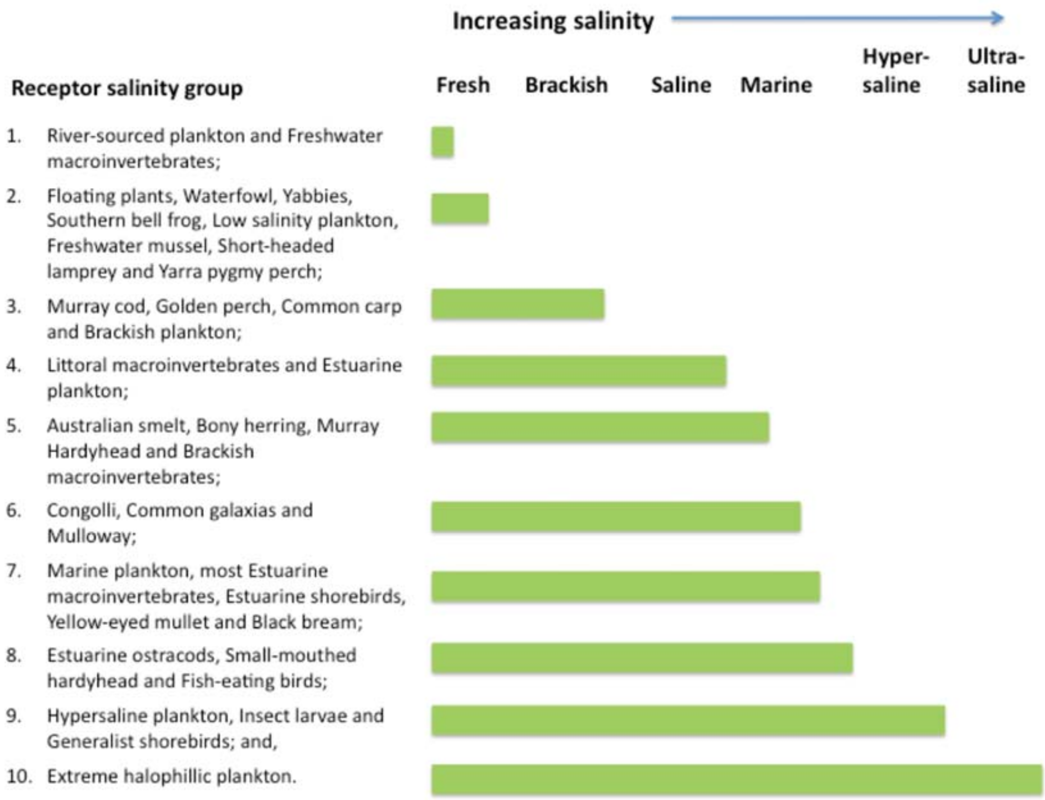


Figure A.2: Schema of receptor persistence through the salinity categories for defining the ecosystem states.

The following subsections provide brief descriptions of the alternate ecosystem states and the receptors likely to occur within them based upon the results of the ecological consequences assessment. The conceptual diagrams are based on the receptor keys in Tables A.2, A.3 and A.4. The number of each receptor in the diagrams denotes relative ecological viability compared to other ecosystem state diagrams. It should be noted that Connected Freshwater derived states with salinities greater than 10 g/L are not described. They are unlikely to occur because if there is sufficient freshwater being delivered to the site that there is functional connectivity then lake salinities will be higher than 10 g/L (Heneker 2010).

Table A.4: Key to the illustrations used in the conceptual diagrams to depict change in Ramsar receptors and the invasive receptors that occurred during the predicted transitions to alternate ecosystem states in Lakes Alexandrina and Albert.

Invasive Receptor	Indicates	Illustration used
Plankton		
Estuarine, Marine or Hypersaline plankton	Shift in salinity conditions	 #
Acidophillic plankton	Acidic conditions	 #
Vegetation		
Spiny rush	Floodplain	
Simple reed beds (dominated by *Phragmites australis)*	Simplified riparian zone	
Dead Paperbark trees and Lignum bushes	Degraded floodplain vegetation, on-going disconnection	
Estuarine macroinvertebrates		
Tube worms *(Ficcopomatus enigmaticus)*	Invasion, Estuarine shift in Lx, require hard substrate (depicted as rock)	 #
Fish		
Yellow-eyed mullet	Estuarine shift, Connectivity (partial)	 #
Birds		
Estuarine shorebirds	Invasion, Estuarine shift, Opportunistic (shown flying in)	 #
Pelican eating fish on beach	Fish kills	 #
Flying pelican	Abandonment of site by birds	 #

A.2.1. Disconnected freshwater derived: Fresh (DFW:Fresh) – ECA Baseline Condition

The Disconnected Freshwater derived: Fresh state (DFW: Fresh) is characterised by a salinity regime that would be generally considered freshwater (1-10 g/L) but that is significantly higher in salinity than the Ramsar-state threshold of < 1 g/L, in ecological terms. The low water levels in this state lead to loss of functional connectivity. The water level is not so low, however, that the water body has become acidified. Therefore, in the DFW: Fresh state water levels are less than +0.3 m AHD but higher than -1.5 m AHD in Lake Alexandrina and less than +0.3 m AHD but higher than -0.75 mAHD in Lake Albert. The barrages are closed therefore the lakes are disconnected from the Coorong. The complex lake shoreline will be disconnected and the riparian, littoral and fringing wetland vegetation will be desiccated. The fringing wetlands will be dry and most likely containing exposed and acidified acid sulfate soils. Lake Alexandrina and Lake Albert may also be disconnected from each other as well by the Narrung Narrows bund. The Clayton regulator may be in place, further disconnecting the lakes from the EMLR tributaries.

The change from the Ramsar state: Degraded seen in 2006 to the Disconnected freshwater derived: Fresh state (DFW: Fresh) seen in 2009 is a result of insufficient freshwater inflow. Sustained low river inflows do not replace evaporative losses, which leads to an increase in salinity from < 1 g/L (possibly up to 10 g/L) and a reduction in lake water levels to less than +0.3 mAHD. Based on salinity tolerances alone all the Ramsar receptors could persist in the DFW: Fresh state if salinities were < 2 g/L, except for perhaps the most salt-sensitive of the Insect larvae. As salinities increase above 2 g/L towards 10 g/L, the stress experienced by the following Ramsar receptors will increase over time and they are likely to be lost at the upper end of the Fresh salinity range:

River-sourced plankton and Low salinity plankton;

Freshwater macroinvertebrates, Yabbies and Freshwater mussel;

Floating plants, Water milfoils, Diverse reed beds;

Waterfowl;

Southern bell frog,

Short-headed lamprey and Yarra pygmy perch.

As well as salinity stress, disconnection from the riparian zone will lead to desiccation of the riparian and littoral vegetation (Diverse reed beds, Water ribbons, Water milfoil, Ribbonweed) seen in the Ramsar-state and reduced ecological viability of the floodplain vegetation (Samphires, Paperbark, Lignum and Gahnia). The loss of littoral and riparian vegetation pre-determines the loss or reduction in Ramsar receptors dependent upon that vegetation (Sections 3 and 7). All but the most tolerant Ramsar receptors will be lost if disconnection is infinite. If disconnection persists for more than 3 to 5 years, then the following Ramsar receptors are likely to be lost in all disconnected freshwater derived states regardless of salinity levels because of their dependence on littoral or riparian vegetation or on free movement across the barrages:

Diverse reed beds, Water milfoils, Water ribbons, Ribbonweed;

Freshwater, Littoral and Brackish macroinvertebrates, Yabbies;

Southern bell frog;

Short-headed lamprey, Congolli, Common galaxias and Yarra pygmy perch; and

Australian smelt, Bony herring and Murray Hardyhead.

At the baseline (October 2009), disconnection had persisted for almost 3 years and salinities were 2.5-5 g/L in Lake Alexandrina and 4–9 g/L in Lake Albert. Many Ramsar receptors were in poor or degraded condition (Section 3), so the ecological viability was compromised.

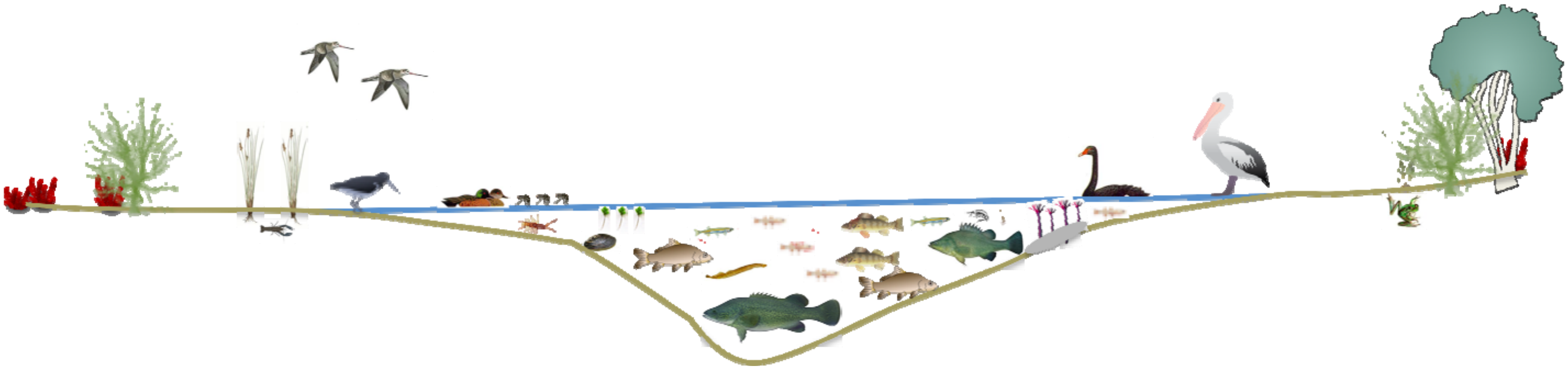


Figure A.3: A schematic diagram of the Baseline state - Disconnected Freshwater-derived: Fresh Compromised showing remaining Ramsar receptors and receptors that have invaded the lakes.

Disconnected Freshwater derived: Fresh State Compromised has: River-sourced, Low and Brackish salinity plankton, Floating plants, Disconnected Samphire, Paperbark, Lignum and Gahnia sedgelands, few Lacustrine macroinvertebrates (Yabbies, Freshwater mussels), Murray cod, Golden perch, adult Diadromous fish (Short-headed lampreys, Common galaxias, Congolli), Australian smelt, Murray hardyhead, Small-mouthed hardyhead, Bony herring, Southern bell frog (one location), Insect larvae, Waterfowl, Fish-eating birds, Generalist shorebirds.

Invaders: Tube worms (Lake Alexandrina only), Spiny rush, Common carp, Redfin perch and Estuarine birds (Lake Alexandrina only).

Attachment B: Baseline condition of receptors in October 2009.

The assessors completed these Baseline condition sheets independently (outside of workshops) in the early stages of the ECA process. Therefore some of the receptors, groupings and group names are different to the final receptor list and groupings used in this report. The assessor who completed each template is named at the top of the sheet.

Phytoplankton (no baseline template completed for zooplankton)

Vegetation

Ruppia tuberosa (provided separately to other vegetation)

Freshwater macroinvertebrates (later renamed as Lacustrine macroinvertebrates)

Marine invertebrates (later renamed Estuarine macroinvertebrates)

Fish

Southern bell frog

Birds

Baseline condition template: Phytoplankton

Completed by: Rod Oliver

Date: 14/06/2010

Phytoplankton Receptor	Present (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
River sourced phytoplankton (Mainly occur in area of upper Lake Alexandrina under river influence, also receiving waters depending on flow)				
Aulacoseira granulata *Ankistrodesmus spp* *Anabaena spp.* *Planktothrix peronata* *Cylindrospermopsis raciborskii* *Microcystis aeruginosa*	*Open water Lx, connected to Lb, and intermittently to GC,MM, NL*	*Common, but varies across sites generally decreasing from upstream Lx to MM and infrequent in NL.* *Anabaena spp. - Regular blooms in Lakes* *Cylindrospermopsis raciborskii has only been observed on one occasion in Lx to date* *Microcystis aeruginosa – are common but minor*	*SA Water Surveys, Geddes 1984; 1987; 1988; 2005; 2005b; Geddes and Tanner 2007; Geddes and Francis 2008;Baker 2000; Aldridge et al 2010*	*Extrapolation of the limited available data set based on expert opinion.* *Phytoplankton population dynamics are rapid and influenced by many environmental characteristics. Consequently communities may show long term (eg. 7-10 year) cycles depending on environmental drivers. A snapshot of a baseline is not appropriate. The attempt here is to derive a broad environmental response framework driven essentially by flows and salinity. Hence the five water types: River sourced, Lake, Estuarine, Marine and Hypersaline.*
Low and mid salinity phytoplankton (Lake Alexandrina, Lake Albert and receiving waters)				
Planctonema lauterbornii *Ankistrodesmus spp.* *Chlorella spp.* *Anabaena spp.* *Aphanizomenon spp.* *Aphanocapsa spp.* *Planktolyngbya spp* *Pseudanabaena spp.* *Nodularia spumigenia* *Cylindrospermopsis raciborskii*	*Mainly open water Lx, Lb and intermittently washed into GC,MM, NL.* *Nodularia spumigenia intermittently grows in GC, MM and NL* *Cylindrospermopsis raciborskii - Open water Lx*	*Frequent dominant but varies across sites generally decreasing from Lx to MM and infrequent in NL.* *Anabaena spp., Aphanizomenon spp. and Aphanocapsa spp. – all regular occurrence at bloom concentrations* *Nodularia spumigenia - Occasional occurrence at bloom concentrations in Lakes.* *Cylindrospermopsis raciborskii - Observed on one occasion so far in Lx*	*SA Water Surveys, Geddes 1984; 1987; 1988; 2005; 2005b; Geddes and Tanner 2007; Geddes and Francis 2008;Baker 2000; Aldridge et al 2010*	
Estuarine phytoplankton (North Coorong, Goolwa Channel, Murray Mouth)				
Cyclotella spp. *Synechococcus spp.* *Synechocystis spp.*	*Nodularia spumigenia - Intermittently observed in GC,MM, NL*	*Nodularia spumigenia - Occasional occurrence at bloom concentrations.*		

Nodularia spumigenia *Chlorella spp.* *Prorocentrum*				
Marine phytoplankton (Murray Mouth, North Coorong)				
Chaetoceros spp. *Asterionella spp.* *Nitzchia spp.* *Asterionella spp.* *Gymnodinium spp* *Nannochloris sp*	*Open water MM, NL* *Nannochloris sp. - Southern end of NL occasionally washed into MM*	*Nannochloris sp. - Regular blooms in southern end of NL and washed in from SL*		
Hypersaline phytoplankton (Southern Coorong)				
Nannochloris sp. *Gymnodinium spp.* *Chlamydomonas spp.* *Palmellaceae spp.*	*Open water of SL*	*Regular blooms in SL* *Gymnodinium spp. - Common in SL*		

#

Baseline condition template: Vegetation

Completed by: Jason Nicol

Date: 27/5/2010

#

Vegetation Receptor	Present (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Samphire communities *(Halosarcia pergranulata ssp. pergrannulata, Suaeda australis, Sarcocornia quinqueflora and Parapholis incurva)*	Lx, Lb, GC, MM, NL, SL	All samphire communities except in the Coorong and Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Paperbark woodlands *(Melaleuca halmatuorum)*	Lx, Lb, GC, MM, NL, SL	All paperbark woodlands except in the Coorong and Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Lignum *(Meuhlenbeckia florulenta)*	Lx, Lb, GC,	All lignum shrublands except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Gahnia sedgelands *(Gahnia filum and G. trifida)*	Lx	Small stand in the edge of Dunn's Lagoon but is disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Spiny rush *(Juncus acutus)*	Lx, Lb	Common around both lakes but is disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Large-fruited and Tuberous sea tassels *(Ruppia megacarpa and R. tuberosa)*	GC, NL, SL	R. *megacarpa* present in Goolwa Channel, R. tuberosa present in North and South Lagoons of Coorong. Also present in Loveday Bay Wetland (spring 2008 and 2009 but wetland was disconnected and water was from local runoff) and Narrung Wetland after it was watered in 2009-10	Yes TLM condition monitoring and Dave Paton's monitoring	

Vegetation Receptor	Present (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion

Vegetation Receptor	Present (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Water milfoil *(Myriophyllum salsugineum and M. caput-medusae)*	GC	Only present in Goolwa Channel (M. salsugineum only), will not be assessed except for recovery	Yes TLM condition monitoring	
Ribonweed *(Vallisneria spiralis)*	GC	Only present in Goolwa Channel will not be assessed except for recovery	Yes TLM condition monitoring	
Water ribbons *(Triglochin procerum)*	Lx, GC	Uncommon in Lake Alexandrina (couple of plants in Dunn's Lagoon) and Goolwa Channel (a couple of plants in the Finniss near Wally's Landing	Yes TLM condition monitoring	
Diverse reed beds *(Phragmites australis and Typha domingensis)*	Lx, Lb, GC	All diverse reed beds except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Terrestrial dry (High salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel.	Yes TLM condition monitoring	
Terrestrial dry (Moderate salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel.	Yes TLM condition monitoring	
Terrestrial dry (Low salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel.	Yes TLM condition monitoring	
Terrestrial damp (High salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel (although not usually present in autumn because most species are winter annuals).	Yes TLM condition monitoring	
Terrestrial damp (Moderate salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel (although not usually present in autumn because most species are winter annuals).	Yes TLM condition monitoring	
Terrestrial damp (Low salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel (although not usually present in autumn because most species are winter annuals).	Yes TLM condition monitoring	
Floodplain (High salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel.	Yes TLM condition monitoring	
Floodplain (Moderate salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel.	Yes TLM condition monitoring	
Floodplain (Low salinity)	Lx, Lb, GC	Common on exposed lakebed of both lakes and at high elevations in Goolwa Channel.	Yes TLM condition monitoring	

Vegetation Receptor	Present (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Amphibious non-woody (High salinity)	Lx, Lb, GC	All amphibious non-woody species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Amphibious non-woody (Moderate salinity)	Lx, Lb, GC	All amphibious non-woody species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Amphibious non-woody (Low salinity)	Lx, Lb, GC	All amphibious non-woody species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Amphibious woody (High salinity)	Lx, Lb, GC	All amphibious woody species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Amphibious woody (Moderate salinity)	Lx, Lb, GC	All amphibious woody species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Amphibious woody (Low salinity)	Lx, Lb, GC	All amphibious woody species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Floating (only low salinity species present)	Lx	Probably present in northern section of Lake Alexandrina		Speculation but there is plenty in the main channel; therefore are probably in low salinity areas of Lake Alexandrina.
Submergent r-selected (only high salinity tolerant species present)	Lx, GC, NL, SL	Present in Goolwa Channel and both Coorong Lagoons. Also in Loveday Bay Wetland (spring 2008 and 2009 but wetland was disconnected and water was from local runoff) and Narrung Wetland after it was watered in 2009/10.	Yes TLM condition monitoring and Dave Paton's monitoring.	
Emergent (High salinity)	Lx, Lb, GC	All emergent species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Emergent (Moderate salinity)	Lx, Lb, GC	All emergent species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Emergent (Low salinity)	Lx, Lb, GC	All emergent species except in Goolwa Channel are disconnected and will not be assessed except for recovery	Yes TLM condition monitoring	
Submergent k-selected (High salinity)	GC	Only present in Goolwa Channel and will not be assessed except for recovery	Yes TLM condition monitoring	
Submergent k-selected (Moderate salinity)	Lx, Lb, GC	Only present in Goolwa Channel and will not be assessed except for recovery	Yes TLM condition monitoring	
Submergent k-selected (Low salinity)	Lx, Lb, GC	Only present in Goolwa Channel and will not be assessed except for recovery	Yes TLM condition monitoring	

Baseline condition template: Ruppia tuberosa

Completed by: Dan Rogers

Date: 08/06/10

Ruppia tuberosa	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Ruppia tuberosa	NL, SL	Mudflats, NL Shallow saline wetlands, Lx, La	Not recorded in SL July 2009 SL (Paton and Bailey 2010)	Almost complete loss (incl. propagules) from SL. Small but increasing populations in central NL. Status in Lx, La fringing wetlands requires confirmation	University of Adelaide Jan 2010	

Baseline condition template: Freshwater macroinvertebrates

Completed by: Paul McEvoy

Date: 31/5/10

Freshwater macroinvertebrate Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Velesunio ambiguus	Lx, Lb, GC	Littoral zone and open water, Lx, Lb, GC		Unknown		Assumed; no reports of mass deaths.
Cherax destructor	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Unknown; existing habitat is of lower quality and productivity than that found among fringing vegetation		Assumed
Baetidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Caenidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Mesoveliidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Hebridae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Veliidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Corixidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Naucoridae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Notonectidae	Lx, Lb, GC, fringing vegetation/littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed

Freshwater macroinvertebrate Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Pleidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Pyralidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Coenagrionidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Hydroptilidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Ecnomidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Leptoceridae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Ceinidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Eusiridae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Corophiidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Atyidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Palaemonidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Hymenosomatidae	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Unknown; may inhabit bare sediment		Assumed

Freshwater macroinvertebrate Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Halicaridae	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Unknown; may inhabit bare sediment		Assumed
Mesostigmata	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Unknown; may inhabit bare sediment		Assumed
Oribatida	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Oligochaeta	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Present	EPA 2010	extrapolated from Currency Creek sites
Syllidae "Polychaeta sp.2"	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Present	EPA 2010	extrapolated from Currency Creek sites
Glossiphoniidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Hydra	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Likely		
Nematoda	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Present	EPA 2010	extrapolated from Currency Creek sites
Ancylidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Hydrobiidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Lymnaeidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Planorbidae	Lx, Lb, GC, fringing vegetation and littoral zone		>0.3 m AHD Littoral zone	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed
Corbiculidae	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Unknown; may inhabit bare sediment		Assumed
Scirtidae	Lx, Lb, GC, fringing vegetation and littoral		>0.3 m AHD	Lost in 2007 as habitat was lost	inferred from vegetation patterns (Gehrig & Nicol 2010)	Assumed

Freshwater macroinvertebrate Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
	zone		Littoral zone			
Tipulidae	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Present	EPA 2010	extrapolated from Currency Creek sites
Ceratopogonidae	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Present	EPA 2010	extrapolated from Currency Creek sites
Empididae	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Present	EPA 2010	extrapolated from Currency Creek sites
Chironomidae	Lx, Lb, GC	Littoral zone, Lx, Lb, GC		Present	EPA 2010	extrapolated from Currency Creek sites

Baseline condition template: Marine invertebrates

Completed by: Sabine Dittmann

Date: 30 May 2010

Marine Macroinvertebrate Receptors	Ramsar Component^	Present (Oct 2009)*	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Ficopomatus enigmaticus (Polychaeta, Serpulidae)	No colonised lake as salinity increased	Older reefs in MM and NL. Established in GC and NL.		Well established throughout GC, new reef growth. Expanding into Lx, current to Point Sturt. MM and NL reefs with few live tubeworms	Maps of distribution based on field surveys and experiments. ([1) 7)] and ongoing research)	Sabine Dittmann, based on recent field surveys (Benger and Brown) and research student work (Goldschmidt, Kirkpatrick)
Nephyts australiensis (Polychaeta, Nephtyidae)	No prominent in mudflat sediments	Frequent in sediments of MM, present also in GC and NL		Present in mudflats and subtidal sediments of the MM and NL, and recently in GC; important predator within the benthic community	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Simplisetia aequisetis (Polychaeta, Nereididae)	No prominent in mudflat sediments	Frequent in sediments of MM, NL, and GC		Present in mudflats and subtidal sediments of the MM, NL and GC, important bioturbator and prey for waders	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Australonereis ehlersi (Polychaeta, Nereididae)	No prominent in mudflat sediments	Present in sediments of MM and NL		Present in mudflats and subtidal sediments of the MM and, NL, important bioturbator and prey for waders, deep dwelling and high biomass	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Capitella spp. (Polychaeta, Capitellidae)	No prominent in mudflat sediments	Frequent in sediments of MM, NL, and GC, some found in Lx sediments		Present in mudflat sediments of the MM, NL and GC, some in Lx, dominating some sites in MM and NL; deposit feeder and important indicator for eutrophication and pollution. Complex of several morphologically indistinct species.	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Oligochaeta	*No prominent in*	*Frequent in sediments of MM, NL, GC, and Lx*		*Present in mudflat sediments of the MM, NL, GC, and Lx; may be*	*Based on field surveys ([2), 3), 5), 8), 9), 10),]*	*Sabine Dittmann, Alec Rolston*

Marine Macroinvertebrate Receptors	Ramsar Component^	Present (Oct 2009)*	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
	mudflat sediments			*a mix of several morphologically similar species. Deposit-feeder*	*11), 12), 13))*	
Amphipoda (Crustacea)	*No prominent in mudflat sediments*	*Frequent in sediments of MM, NL, GC, Lx and Lb*		*Have decreased in numbers in MM and now almost absent at sites with previous high abundance; mix of several morphologically similar species; prey for birds.*	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston*
Arthritica helmsi (Bivalvia)	*No prominent in mudflat sediments*	*Present in sediments of MM*		*Small sized bivalve which has decreased in numbers in recent years*	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston*
Notospisula trigonella (Bivalvia)	*No Present in submerged mudflat sediments*			*Larger sized bivalve recorded in sediment transfer samples at Ewe Island.*	*Based on Sediment Transfer Experiment of 9)*	*Alec Rolston, Sabine Dittmann*
Soletellina alba (Bivalvia)	*No Occasionally present in submerged mudflat sediments*			*Larger sized bivalve recorded in sediment transfer samples at Ewe Island.*	*Based on Sediment Transfer Experiment of 9)*	*Alec Rolston, Sabine Dittmann*
Chironomidae (Insect larvae)	*No prominent in mudflat sediments although pelagic*	*Frequent in sediments of MM, NL, GC, Lx and Lb*		Distribution spread from Coorong into MM, dominant 'benthic' organism at many sites. Also dominant around lakes. Possibly mix of several species, occurring in the different salinities throughout the area.	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston; see also Mike Geddes*
Dolichopodidae (Insect larvae)	*No prominent in mudflat sediments*	*Present in sediments of MM, NL, GC, Lx and Lb*		*Frequently found in sediment samples*	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston*

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Baseline condition template: **Fish**

Completed by: Chris Bice

Date: 28/05/2010

#

Fish Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
*Murray Cod**	*Lx, Lb, GC, MM (during flows only)*	*Open water Lx, Lb, GC*		*Likely present in low abundances. Population likely exhibiting poor recent recruitment similar to fish in river reach below lock 1 (i.e. population dominated by large adults).*	*Ye and Zampatti 2007, Baumgartner et al 2008, SARDI unpublished commercial fishery CPUE data, expert opinion*	*Little recent quantitative data on distribution and abundance of Murray cod in Lx & Lb due to need for targeted sampling and being a non-target spp in the commercial fishery. Nonetheless, the species is potentially present (expert opinion) in deeper areas of Lx.*
Golden perch	*Lx, Lb, GC, MM (during flows only)*	*Open water Lx, Lb, GC*		*Golden perch are present throughout Lx and Lb in moderate numbers. This spp is heavily targeted in the commercial fishery in both lakes*	*SARDI unpublished commercial fishery CPUE data, Bice 2009, Ferguson 2010*	*Present in reasonable numbers throughout Lx and Lb. Over 60 tonne removed in the commercial fishery from the Lakes in 2008-09 (Ferguson 2010)*
Australian smelt	*Lx, Lb, GC, MM (during flows only)*	*Lx, Lb, GC*		*Present and abundant in Lx (including GC) and Lb*	*SARDI unpublished, Bice et al 2009, Wedderburn and Barnes 2009*	*Common species in Lakes. Short-lived spp, recruitment occurring*
Murray hardyhead	*Lx, Lb, GC*	*Lx, GC*		*Present in Lx (including GC) at limited number of sites. Includes sites a site on Hindmarsh Island, 2 in NW Lx (near Milang and Dog Lake) and in Goolwa channel/Finniss arm.*	*SARDI unpublished, Bice et al 2009, Wedderburn and Barnes 2009, Wedderburn unpublished*	*Present in low numbers in Lx. Somewhat scattered distribution. Low numbers spread around GC (random catches and expert opinion). One site with moderate numbers (Boggy Creek, Hindmarsh Island) (Wedderburn unpublished)*
Yarra pygmy perch	*Lx, GC (presence not confirmed till 2002 due to historic mis-identification)*	*Not sampled but may have been present*	*Potentially absent.*	*Not recorded since December 2007, although captive population being held (Hammer 2008)*	*Bice et al 2008, Hammer 2008, Bice et al 2009, Wedderburn and Barnes 2009*	*Whilst fish have not been recorded for ≥2 years there is a chance there are still some individuals left in Lx and the status of this species means inclusion is warranted*

Fish Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Common carp	*Lx, Lb, GC, MM (during flows only)*	*Lx, Lb, GC*		*Abundant in Lower Lakes, high abundance of juveniles in GC.*	*SARDI unpublished, SARDI unpublished commercial fishery CPUE data, Bice 2009*	*Common and abundant spp throughout Lower Lakes. Significant spawning and recruitment event in GC following managed water level rise*
Congolli	*Lx, Lb, GC, MM, NL, SL*	*Lx, GC, MM, NL*		*Likely broadly distributed in Lx (including GC) but in low numbers. Population dominated by large adult fish due to prolonged disconnection of Lakes from Coorong/Ocean. Probably present in low numbers in Lb (expert opinion, limited data). Present and moderately common in MM area and present in low numbers in NL.*	*SARDI unpublished, Jennings et al 2008, Noell et al 2009*	*Prolonged disconnection of Lakes and Coorong has resulted in obstruction of downstream spawning movements of adult females and subsequent significant decreases in abundance of upstream migrating juveniles since 2006/07 (Jennings et al 2008, SARDI unpublished). Adult fish in Lx may be nearing end of life expectancy (predicted ~5 yrs) (expert opinion). Spp presence in Lx is under imminent threat.*
Common galaxias	*Lx, Lb, GC, MM, NL, SL*	*Lx, GC, MM*		*Broad distribution in Lx and probably Lb (expert opinion). Juveniles were detected in MM area in summer 2009/10.*	*Jennings et al 2008, Bice et al 2009, Wedderburn and Barnes 2009, SARDI unpublished, Wedderburn unpublished*	*Naturally catadromous fish but with conditions of disconnection has been shown to adapt life history to recruit within Lx. Nevertheless, recruitment is likely to be of a much lower magnitude than under conditions of connectivity*
Short-headed lamprey	*Lx, GC, MM, NL*	*Lx*		*Adults not collected migrating upstream since 2006/07. Juvenile downstream migrant collected in 2009. Potential for ammocoetes to be present in sediments in lakes and tributaries*	*Jennings et al 2008, SARDI unpublished, expert opinion*	*Short-headed lamprey (and pouched lamprey) likely most heavily impacted by lack of freshwater flows to Coorong/Ocean and subsequent lack of migrational/attraction cues for adults. Furthermore disconnection of Lakes and Coorong inhibits movement between these habitats. Ammocoetes are present below Lock 1 and potentially in Lx and maybe Lb (expert opinion).*
Yellow-eyed mullet	*MM, NL, SL*	*MM, NL*		*Abundant in MM area and moderately abundant in NL. Contributes the greatest proportion of finfish captures in the Lakes and*	*Jennings et al 2008, Noell et al. 2009, Ferguson et al 2010, SARDI unpublished commercial fishery CPUE*	*Common in Coorong. Some individuals likely residing in Lx, particularly GC (Expert opinion). Likely to further colonise Lx under seawater delivery*

Fish Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
				Coorong fishery	*data*	*scenario*
Small-mouthed hardyhead	*Lx, Lb, GC, MM, NL, SL*	*Lx, Lb, GC, MM, NL, SL*		*Abundant throughout Lx (particularly GC), likely Lb, MM, NL and SL*	*Jennings et al 2008, Bice et al 2009, Noell et al 2009, Wedderburn et al 2009, SARDI unpublished*	*Highly abundant species across study region. Euryhaline, completing life cycle across the site in a range of different salinities i.e. ~2 - > 40 g.L-^{1}*
Black bream	*Lx, MM, NL, SL*	*Lx, MM, NL*		*Primarily distributed in MM area where moderately common, uncommon in NL. Commercial captures significantly reduced from 1980's. ~1 tonne taken in 2008/09*	*Noell et al 2009, Ferguson et al 2010, SARDI unpublished commercial fishery CPUE data, SARDI unpublished*	*Recent movement study shows primary habitat area is from Goolwa barrage down to Tauwitchere Barrage with the reach directly below Goolwa, Mundoo channel and Boundary Creek likely the most important areas within the site (unpublished data and expert opinion). Likely impacted by lack of freshwater flows into Coorong over preceding years (expert opinion). A small number of fish were recorded entering the GC and there have also been catches of small numbers in the GC and observation of individuals in Lx (Pers. Obs., SARDI unpublished). Will likely further colonise Lx under seawater delivery scenario*
Mulloway	*MM, NL, SL*	*MM, NL*		*Moderately common in MM area from Goolwa Barrage down to Tauwitchere Barrage. ~30 t total catch in Lakes and Coorong fishery in 2008/09*	*Ferguson et al 2008, Noell et al 2009, Ferguson 2010, SARDI unpublished commercial fishery CPUE data*	*Species likely less abundant than historically. Likely impacted by lack of freshwater flows into Coorong over preceding years (Ferguson et al 2008). Historic records from Lx and will likely further colonise Lx under seawater delivery scenario*

[1)] *^Present in the Ramsar-listed Ecological Character (1985 and/or 2006) for Lake Alexandrina (Lx), Lake Albert (Lx), Goolwa Channel (GC), Murray-Mouth (MM), North Lagoon (NL), South Lagoon (SL) or not (No). * Completed cells are provided as examples only and may well not reflect the real situation.*

Baseline condition template: Southern Bell Frog

Completed by: Nick Souter

Date: 15 June 2010

#

Receptor (complete list Attach. 2)	Ramsar Component^	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Southern Bell Frog	Lx	One adult found at waters edge in Channel 1 on Mundoo Island (26/11/2009).	Tadpoles absent from Channel 1 on Mundoo Island		Draft Southern Bell Frog *(Litoria raniformis)* Inventory of Lake Alexandrina, Lake Albert and Tributaries. SAMDBNRMB	

Baseline condition template: Birds

Completed by: Dan Rogers

Date: 8/07/2010

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Bird Receptor	Ramsar Component	Present (Oct 2009)	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Terrestrial species	GC, MM, Lx, Lb, NL, SL (MLR SEW GC only)	MLR SEW in tributaries above GC; OBP very rare in site		OBP global population ~150 individuals; 3 recorded in Coorong in 2009; not likely to be impacted by action MLR SEW in GC tributaries, well above surface hydrology influence across water level range regarded here. Will not be considered further.	OBP Recovery Program	
Fringing vegetation species	GC, Lx, Lb (MM, NL, SL?)	GC (Latham's Snipe) Jan 2010	La, Lx (all species)	Disconnection of fringing veg. from water → loss of habitat for fringing veg. shorebirds in lakes. GC may still hold small area of habitat downstream of regulator. Regional declines also likely. Common species (e.g. Purple Swamphen) also rare, but still present. Some species possibly found in reedbeds associated with freshwater soaks in Coorong and Salt Creek	University of Adelaide / SA MDB NRM Board Jan 2010	
Generalist shorebirds	GC, MM, Lx, Lb, NL, SL	GC, MM, Lx, Lb, NL, SL		some species still present across site, though some (e.g. Curlew Sandpiper from SL) absent. Typically transequatorial migrants so presence is seasonal	University of Adelaide / SA MDB NRM Board Jan 2010	
Estuarine shorebirds	GC, MM, Lx, Lb, NL	GC, Lb, NL, MM	Lx	Likely to still occur in Lx (Godwits recorded on lakeside of Tauwitcherie Barrage Jan	University of Adelaide / SA MDB NRM Board Jan 2010	

Bird **Receptor**	**Ramsar Component**	**Present** **(Oct 2009)**	**Absent** **(Oct 2009)**	**Current status notes** **(May 2010)**	**Data-derived**	**Assessor/Other Expert opinion**
				2009). Primarily focused in estuary. Wood Sandpiper only recorded in Lb.		
Fish-eating species	GC, MM, Lx, Lb, NL, SL	GC, MM, Lx, La, NL, SL		presence in SL primarily due to Australian Pelican & Caspian Tern, breeding on islands and feeding elsewhere (no food locally)	University of Adelaide / SA MDB NRM Board Jan 2010	
Waterfowl (Ducks & Swans)	NL, SL, MM, Lx, Lb, GC	NL, SL, MM, Lx, Lb, GC		SL support different suite of species (teal, shelduck) to NL/MM. These species were also abundant in Lakes. Black Swan (species most directly tied to aquatic submergent vegetation) most abundant in GC	University of Adelaide / SA MDB NRM Board Jan 2010	

Attachment C: Level of stressor effect on the receptors

These completed Level of stressor effect sheets were provided by the assessors independently and have not been altered in later steps of ECA. Therefore some of the receptors, groupings and group names are different to the final receptor list and groupings used in this report. The assessor who completed each template is named at the top of the sheet. The stressors are separated based on whether their level of effect is primary (i.e. direct effect on the receptor) or secondary (i.e. effect the receptors through one other food web or ecological interaction with the receptor being primarily affected). The bird assessors did not provide a completed template. However, it can be assumed that salinity, water level and pH affect birds indirectly on the whole through other ecological receptors such as vegetation they use as habitat and prey species.

Phytoplankton (no baseline template completed for zooplankton)

Vegetation

Ruppia tuberosa (provided separately to other vegetation)

Freshwater macroinvertebrates (later renamed as Lacustrine macroinvertebrates)

Marine invertebrates (later renamed Estuarine macroinvertebrates)

Fish

Southern bell frog

Level of primary stressor effect template: Phytoplankton

Completed by: Rod Oliver

Date: 14/06/2010

Receptor list (present or MNES)^	Primary Stressors (level of effect)#			
	Salinity	**pH**	**Water levels**	**Dissolved Oxygen**
Impact ranges	0-3k (Fresh); 3-5k (Brackish), 5-15k (Hyper-Brackish), 15-25k (Estuarine), 25-50k (Marine), 50-150k (Hypersaline), >150k (Hypersaline, salt tolerant)	<3.5 (acidophiles), 3.5-5(homogeneous and limited populations), 5-6 (major reductions in diversity), 6-8(no impact)	Presence/Absence or percentage	
River sourced phytoplankton	Primary 0-3000 mg/L Fresh	Primary See range at top of table	Primary Presence/Absence or percentage	Primary
Low and Brackish phytoplankton	Primary 3000-5000 mg/L Brackish 5000-15000 mg/L Hyper-brackish	Primary See range at top of table	Primary Presence/Absence or percentage	Primary
Estuarine phytoplankton	Primary 15000-25000 mg/L Estuarine	Primary See range at top of table	Primary Presence/Absence or percentage	Primary
Marine phytoplankton	Primary 25000-50000 mg/L Marine	Primary See range at top of table	Primary Presence/Absence or percentage	Primary
Hypersaline phytoplankton	Primary 50000-150000 mg/L	Primary See range at top of table	Primary Presence/Absence or percentage	Primary
Hypersaline	Primary >150000 mg/L (salt tolerant)	Primary See range at top of table	Primary Presence/Absence or percentage	Primary

Salt impact scale: 0-3k; 3-5k, 5-15k, 15-25k, 25-50k, 50-150k, >150k

Low pH impact scale: <3.5 (acidophiles), 3.5-5(homogeneous and limited popn), 5-6 (major changes), 6-8(no impact)

No information provided on level of secondary stressor effects

Level of primary stressor effect template: Vegetation

Completed by: Jason Nicol

Date: 2/5/2010

Vegetation Receptor	Primary Stressors (level of effect)#			
	Salinity	pH	Water levels	Dissolved Oxygen
Samphire communities *(Halosarcia pergranulata ssp. pergranulata, Suaeda australis, Sarcocornia quinqueflora and Parapholis incurva)*	Primary >50,000 EC	Primary <4	Primary Shallow water 20 cm to saturated soil 0-1.0 m AHD	NA
Paperbark woodlands *(Melaleuca halmaturorum)*	>50,000 EC	Primary <4	Primary Shallow water 50 cm to quite dry soil. Varying water levels, will not tolerate long-term submergence around trunks or tolerate top flooding 0-1.0 m AHD	NA
Lignum *(Muehlenbeckia florulenta)*	<50,000 EC, absolute values unclear but published values not applicable to Lower Lakes.	Primary <4	Primary Shallow water 50 cm to quite dry soil. Varying water levels, will not tolerate long-term submergence around stems or tolerate top flooding 0-1.0 m AHD	NA
Gahnia sedgelands *(Gahnia filum and G. trifida)*	>50,000 EC	Primary <4	Primary Shallow water 50 cm to quite dry soil. Varying water levels, will not tolerate long-term submergence around stems or tolerate top flooding 0-1.0 m AHD	NA
Spiny rush *(Juncus acutus)*	>50,000 EC	Primary <4	Primary Shallow water 30 cm to quite dry soil. Varying water levels, will not tolerate long-term submergence around stems or tolerate top flooding 0-1.0 m AHD	NA
Large-fruited and Tuberous sea tassels *(Ruppia megacarpa and R. tuberosa)*	>50,000 EC	Primary <5	Primary Permanent water at least 10 cm deep, maximum depth depends on water clarity.	NA

Vegetation Receptor	Primary Stressors (level of effect)#			
	Salinity	pH	Water levels	Dissolved Oxygen
			Minimum water level 0.3 m AHD	
Water milfoil *(Myriophyllum salsugineum and M. Primary caput-medusae)*	*M. salsugineum* at least 20,000 EC *M. caput-medusae* probably around 10,000 EC	Primary <5	Primary Permanent water at least 10 cm deep is ideal but will grow on exposed soil with high soil moisture, maximum depth depends on water clarity. Minimum water level 0.3 m AHD	NA
Ribonweed *(Vallisneria spiralis)*	At least 15,000 EC (it is growing in Clayton Bay)	Primary <5	Primary Permanent water at least 10 cm deep, maximum depth depends on water clarity. Minimum water level 0.3 m AHD	NA
Water ribbons *(Triglochin procerum)*	Absolute values unclear but published values not applicable to Lower Lakes. [probably around 20,000 EC	Primary <5	Primary Permanent water at 10-50 cm deep is ideal but will grow on exposed soil with high soil moisture. Minimum water level 0.3 m AHD	NA
Diverse reed beds *(Phragmites australis and Typha domingensis)*	*Typha and Phragmites* at least 20,000 EC (growing well around Goolwa. *Schoenoplectus validus* at least 15,000 EC (growing in Clayton Bay), *Bolboschoenus caldwellii* probably around 50,000 EC (present in some quite saline areas near Mundoo and Hunter's Creek)	Primary <4	Primary Permanent water at 10-100 cm deep is ideal but will grow on exposed soil with high soil moisture. Minimum water level 0 m AHD	NA
Terrestrial dry (High salinity)	>50,000 EC	Primary <4	Primary Does not tolerate submergence or long-term waterlogging. Well drained moist soil is ideal but will grow under dry conditions. The lower the water level the greater the area open to colonisation. Ideally restricted to above 0.6 m AHD.	NA
Terrestrial dry (Moderate salinity)	<50,000 EC	Primary <4	Primary. Ideally restricted to above 0.6 m AHD. Does not tolerate submergence or long-term waterlogging.	NA

Vegetation Receptor	Primary Stressors (level of effect)#			
	Salinity	pH	Water levels	Dissolved Oxygen
			Well-drained moist soil is ideal but will grow under dry conditions. The lower the water level the greater the area open to colonisation.	
Terrestrial dry (Low salinity)	<10,000 EC	Primary <4	Primary. Ideally > 0.6 m AHD. Does not tolerate submergence or long-term waterlogging. Well drained moist soil is ideal but will grow under dry conditions. The lower the water level the greater the area open to colonisation.	NA
Terrestrial damp (High salinity)	>50,000 EC	Primary <4	Primary. Ideally > 0.6 m AHD. Will tolerate short-term (<2 weeks) submergence, waterlogged to moist soil is ideal. The lower the water level the greater the area open to colonisation.	NA
Terrestrial damp (Moderate salinity)	<50,000 EC	Primary <4	Primary. Ideally > 0.6 m AHD. Will tolerate short-term (<2 weeks) submergence, waterlogged to moist soil is ideal. The lower the water level the greater the area open to colonisation..	NA
Terrestrial damp (Low salinity)		Primary <4	Primary. Ideally > 0.6 m AHD. Will tolerate short-term (<2 weeks) submergence, waterlogged to moist soil is ideal. The lower the water level the greater the area open to colonisation.	NA
Floodplain (High salinity)	>50,000 EC	Primary <4	Primary. Ideally > 0.4 m AHD. Will tolerate short-term (<2 weeks) submergence, waterlogged to moist soil is ideal. The lower the water level the greater the area open to colonisation.	NA
Floodplain (Moderate salinity)	<50,000 EC	Primary <4	Primary. Ideally > 0.4 m AHD. Will tolerate short-term (<2 weeks) submergence, waterlogged to moist soil is ideal. The lower the water level the greater the area open to colonisation.	NA

Vegetation Receptor	Primary Stressors (level of effect)#			
	Salinity	pH	Water levels	Dissolved Oxygen
Floodplain (Low salinity)	<10,000 EC	Primary <4	Primary. Ideally > 0.4 m AHD. Will tolerate short-term (<2 weeks) submergence, waterlogged to moist soil is ideal. The lower the water level the greater the area open to colonisation.	NA
Amphibious non-woody (High salinity)	>50,000 EC	Primary <4	Fluctuating water levels, will tolerate short to medium-term flooding providing (some species will tolerate total submergence). Some species will tolerate desiccation and some species are capable of persisting for extended periods using rainwater. 0.3-1.0 m AHD	NA
Amphibious non-woody (Moderate salinity)	<50,000 EC	Primary <4	Fluctuating water levels, will tolerate short to medium-term flooding providing (some species will tolerate total submergence). Some species will tolerate desiccation and some species are capable of persisting for extended periods using rainwater. 0.3-1.0 m AHD	NA
Amphibious non-woody (Low salinity)	<10,000 EC	Primary <4	Fluctuating water levels, will tolerate short to medium-term flooding providing (some species will tolerate total submergence). Some species will tolerate desiccation and some species are capable of persisting for extended periods using rainwater. 0.3-1.0 m AHD	NA
Amphibious woody (High salinity)	>50,000 EC	Primary <4	Fluctuating water levels, will tolerate short to medium-term flooding providing plants are not totally submerged. Will tolerate desiccation and some species are capable of persisting for extended periods using rainwater. 0-1.0 m AHD	NA
Amphibious woody (Moderate salinity)	<50,000 EC	Primary <4	Fluctuating water levels, will tolerate short to medium-term flooding providing plants are not totally submerged. Will tolerate desiccation and some species are capable of persisting for extended periods using rainwater. 0-1.0 m AHD.	NA
Amphibious woody (Low salinity)	<10,000 EC	Primary <4	Fluctuating water levels, will tolerate short to medium-term flooding providing plants are not totally submerged. Will	NA

Vegetation Receptor	Primary Stressors (level of effect)#			
	Salinity	pH	Water levels	Dissolved Oxygen
			tolerate desiccation and some species are capable of persisting for extended periods using rainwater. 0-1.0 m AHD.	
Floating (only low salinity species present)	<10,000 EC	Primary <4	Permanent water at least 5 cm deep but will persist for short periods on saturated soil. This group is the only group that will persist in open water areas throughout the lakes and is not restricted to the fringes.	NA
Submergent r-selected (only high salinity tolerant species present)	>50,000 EC	Primary <4	Seasonal wetlands with at least 10 cm of water during the growing season (usually late autumn to mid to late spring). Maximum depth depends on water clarity. Minimum water level 0.3 m AHD	NA
Emergent (High salinity)	>50,000 EC	Primary <4	Primary Permanent water at 10-100 cm deep is ideal but will grow on exposed soil with high soil moisture. Minimum water level 0 m AHD	NA
Emergent (Moderate salinity)	<50,000 EC	Primary <4	Primary Permanent water at 10-100 cm deep is ideal but will grow on exposed soil with high soil moisture. Minimum water level 0 m AHD	NA
Emergent (Low salinity)	<10,000 EC	Primary <4	Primary Permanent water at 10-100 cm deep is ideal but will grow on exposed soil with high soil moisture. Minimum water level 0 m AHD	NA
Submergent k-selected (High salinity)	>50,000 EC	Primary <4	Primary Permanent water at least 10 cm deep, maximum depth depends on water clarity. Minimum water level 0.3 m AHD	NA
Submergent k-selected (Moderate salinity)	<50,000 EC	Primary <4	Primary Permanent water at least 10 cm deep, maximum depth depends on water clarity. Minimum water level 0.3 m AHD	NA
Submergent k-selected (Low	<10,000 EC	Primary	Primary	NA

Vegetation Receptor	Primary Stressors (level of effect)#			
	Salinity	pH	Water levels	Dissolved Oxygen
salinity)		<4	Permanent water at least 10 cm deep, maximum depth depends on water clarity. Minimum water level 0.3 m AHD	

Level of primary stressor effect template: Ruppia tuberosa

Completed by: Dan Rogers

Date: 08/06/10

Receptor list (present or MNES)^	**Primary Stressors (level of effect)#**			
	Salinity	**pH**	**Water levels**	**Dissolved Oxygen**
Ruppia tuberosa	Upper limit: Primary - germination limitation > 120 ppt (still some germination at higher salinity) - mortality of young plants > >110-120 ppt (based on Paton and Bailey 2010) - likely to be other sublethal effects (growth rate, which leads to both delay in propagule production, and reduction in propagule abundance) Lower limit: Secondary - in Coorong, suffers 'swamping' by Enteromorpha at < ~55 ppt (not necessarily an issue in ephemeral saline wetlands) – evidence based on Enteromorpha salinity tolerance in field, + literature (Reed and Russell 1979)	Primary - general statement of mortality below pH of 2-3 (but possibly much higher) - no real evidence for acid impacts in CLLMM – work required particularly for lakes wetlands - identified as key knowledge gap for all aquatic plants by Gehrig & Nicol 2010	Primary - mortality as a result of mudflat exposure (relevant if this occurs before propagule production) - interactions with turbidity to create upper depth limit (~30cm-1m – depending on turbidity) based on light availability	

Level of stressor effect: Freshwater Macroinvertebrates

Completed by: Gillian Napier

Date: 8th June 2010

Freshwater Macroinvertebrate Receptors	Primary Stressors (level of effect)#			
	Salinity	**pH**	**Water levels**	**Dissolved Oxygen**
Freshwater Mussel	Primary 2 g/L observed to have sub-lethal effects. Adults withstand 5-10g/L for 2-3 weeks and higher salinities for relatively short periods. > 3.5g/L sustainable populations unlikely (Walker 1981) owing to tolerance of glochidia	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5*	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or secondary effect first	*Primary* *Using ANZECC(2000) Guidelines – 90% saturation (6mg/L)* Can tolerate low DO for a period of time
Yabby *Cherax destructor*	Primary LC50 salinities recorded at >45g/L (Dunlop et al. 2008) Maximum field salinities recorded at 8.16g/L (Horrigan et al. 2007) *Using ANZECC(2000) Guidelines - 3.4g/L*	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5*	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or secondary effect first	*Primary* *Using ANZECC(2000) Guidelines – 90% saturation (6mg/L)*
Gastropoda	Primary Physidae: Maximum field salinities recorded at 3.3g/L Ancylidae: Egg tolerance 6.256 g/L, hatchling survival at 8.16g/L and an older stage tolerance at 7.84g/L *Using ANZECC(2000) Guidelines - 3.4g/L*	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5* *Ferrissia sp.* have been found in pH 4.75 (Fiske 1987)	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or secondary effect first	*Primary* *Using ANZECC(2000) Guidelines– 90% saturation (6mg/L)*
Ephemeroptera	Primary Baetidae: LC50 salinities recorded between 3.74 and 5.4g/L (Kefford et al. 2004) Maximum field salinities recorded at 8g/L (Horrigen et al. 2007) Caenidae: Salinity tolerances approximately 8g/L Horrigen et al. 2007; Dunlop et al. 2008) Leptophlebiidae: LC 50 salinities at > 5.4g/L (Dunlop et al. 2008) Maximum field salinities recorded at 2.7g/L (Horrigen et al. 2007) Note: non-Baetidae LC50 range >8.568 – 10.2g/L	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5*	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or secondary effect first	Primary *Using ANZECC(2000) Guidelines – 90% saturation (6mg/L)*

Freshwater Macroinvertebrate Receptors	Primary Stressors (level of effect)#			
	Salinity	**pH**	**Water levels**	**Dissolved Oxygen**
	Using ANZECC(2000) Guidelines - 3.4g/L			
Hymensomatidae *Amarinus lacustris*	Secondary Known to occur in slightly saline waters, salinity tolerance between 10-58 ppt (Geddes & Bulter 1984; James et al. 2003; Geddes 2005) Salinity range between 47 – 58.5g/L *Using ANZECC(2000) Guideline - 3.4g/L*	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5*	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or secondary effect first	*Primary* *Using ANZECC(2000) Guidelines– 90% saturation (6mg/L)*
Acarina	Primary Maximum field salinities recorded at 9.2g/L (Horrigen et al. 2007) *Using ANZECC(2000) Guidelines - 3.4g/L*	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5* pH may have a direct effect on shredders because of osmotic stress, or indirect effects as a result of heavy metals, especially aluminium, which becomes soluble at low pH (Griffith & Perry 1993)	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or secondary effect first	*Primary* *Using ANZECC(2000) Guidelines– 90% saturation (6mg/L)*
Cnidaria *Hydra sp.*	Primary Salinity LC 50 for *Hydra viridissima* range 2.584 – 4.012g/L (96hr – 24hr) *Using ANZECC(2000) Guidelines - 3.4g/L*	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5* *Has been some suggestion that Hydra have some sensitivity to acidity and heavy metals*	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or secondary effect first	*Primary* *Using ANZECC(2000) Guidelines– 90% saturation (6mg/L)*
Oligochaetes**	Secondary Have highly variable salinity tolerance (Giere 2006) May resuspend/swim in the water column to migrate to more favourable areas ((Nielsson et al. 2000) *Using ANZECC(2000) Guidelines - 3.4g/L*	*Primary* *Using ANZECC(2000) Guidelines - pH 6.5*	Tertiary Loss of habitat and food source. Other environmental factors likely to have a primary or	*Primary* *Using ANZECC(2000) Guidelines– 90% saturation (6mg/L)*

Freshwater Macroinvertebrate Receptors	Primary Stressors (level of effect)#			
	Salinity	pH	Water levels	Dissolved Oxygen
			secondary effect first	

Note: Dissolved oxygen content linked to water temperature.

Exposure time is a factor that needs consideration. Any LC50 data is for short-term exposure (up to 4 days)
Chronic exposure - longer exposure time, may have deleterious effects, and at levels that may be assumed to be at "safer" levels.

Overall there is very little or no toxicity data for the species residing in the Lower Lakes
There is also scarce quantitative data on their distribution, especially in Lake Albert

** Oligochaetes habitat is in the sediments – and exposure to water quality is mainly through interstitial water, which may have differing water quality to the overlying lake waters.

Baseline condition template: Marine invertebrates

Completed by: Sabine Dittmann

Date: 30 May 2010

Marine Macroinvertebrate Receptor	Ramsar Component^	Present (Oct 2009)*	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
Ficopomatus enigmaticus (Polychaeta, Serpulidae)	No colonised lake as salinity increased	Older reefs in MM and NL. Established in GC and NL.		Well established throughout GC, new reef growth. Expanding into Lx, current to Point Sturt. MM and NL reefs with few live tubeworms	Maps of distribution based on field surveys and experiments. ([1) 7)] and ongoing research)	Sabine Dittmann, based on recent field surveys (Benger and Brown) and research student work (Goldschmidt, Kirkpatrick)
Nephyts australiensis (Polychaeta, Nephtyidae)	No prominent in mudflat sediments	Frequent in sediments of MM, present also in GC and NL		Present in mudflats and subtidal sediments of the MM and NL, and recently in GC; important predator within the benthic community	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Simplisetia aequisetis (Polychaeta, Nereididae)	No prominent in mudflat sediments	Frequent in sediments of MM, NL, and GC		Present in mudflats and subtidal sediments of the MM, NL and GC, important bioturbator and prey for waders	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Australonereis ehlersi (Polychaeta, Nereididae)	No prominent in mudflat sediments	Present in sediments of MM and NL		Present in mudflats and subtidal sediments of the MM and, NL, important bioturbator and prey for waders, deep dwelling and high biomass	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Capitella spp. (Polychaeta, Capitellidae)	No prominent in mudflat sediments	Frequent in sediments of MM, NL, and GC, some found in Lx sediments		Present in mudflat sediments of the MM, NL and GC, some in Lx, dominating some sites in MM and NL; deposit feeder and important indicator for eutrophication and pollution. Complex of several morphologically indistinct species.	Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])	Sabine Dittmann, Alec Rolston
Oligochaeta	*No* *prominent in mudflat sediments*	*Frequent in sediments of MM, NL, GC, and Lx*		*Present in mudflat sediments of the MM, NL, GC, and Lx; may be a mix of several morphologically*	*Based on field surveys ([2), 3), 5), 8), 9), 10), 11), 12), 13)])*	*Sabine Dittmann, Alec Rolston*

Marine Macroinvertebrate Receptor	Ramsar Component^	Present (Oct 2009)*	Absent (Oct 2009)	Current status notes (May 2010)	Data-derived	Assessor/Other Expert opinion
				similar species. Deposit-feeder		
Amphipoda (Crustacea)	*No prominent in mudflat sediments*	*Frequent in sediments of MM, NL, GC, Lx and Lb*		*Have decreased in numbers in MM and now almost absent at sites with previous high abundance; mix of several morphologically similar species; prey for birds.*	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston*
Arthritica helmsi (Bivalvia)	*No prominent in mudflat sediments*	*Present in sediments of MM*		*Small sized bivalve which has decreased in numbers in recent years*	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston*
Notospisula trigonella (Bivalvia)	*No Present in submerged mudflat sediments*			*Larger sized bivalve recorded in sediment transfer samples at Ewe Island.*	*Based on Sediment Transfer Experiment of 9)*	*Alec Rolston, Sabine Dittmann*
Soletellina alba (Bivalvia)	*No Occasionally present in submerged mudflat sediments*			*Larger sized bivalve recorded in sediment transfer samples at Ewe Island.*	*Based on Sediment Transfer Experiment of 9)*	*Alec Rolston, Sabine Dittmann*
Chironomidae (Insect larvae)	*No prominent in mudflat sediments although pelagic*	*Frequent in sediments of MM, NL, GC, Lx and Lb*		Distribution spread from Coorong into MM, dominant 'benthic' organism at many sites. Also dominant around lakes. Possibly mix of several species, occurring in the different salinities throughout the area.	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston; see also Mike Geddes*
Dolichopodidae (Insect larvae)	*No prominent in mudflat sediments*	*Present in sediments of MM, NL, GC, Lx and Lb*		*Frequently found in sediment samples*	*Based on field surveys (2), 3), 5), 8), 9), 10), 11), 12), 13))*	*Sabine Dittmann, Alec Rolston*

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Level of stressor effect: Fish

Completed by: Chris Bice

Date: 28/05/2010

Fish receptors	Primary Stressors (level of effect)			
	Salinity	**pH**	**Water levels**	**Dissolved Oxygen**
Murray Cod	*Primary* *>13,200 mg.L-^{1}*	*Primary* *<5*	*Secondary – decreases in productivity – trophic dynamics* *Habitat prefer > 1m depth*	*Primary* *<2 mg.L-^{1}*
Golden perch	*Primary* *>14,400 mg.L^{-1}*	*Primary* *<5*	*Secondary - decreases in productivity – trophic dynamics* *Likely more common in deeper areas of Lx*	*Primary* *<2 mg.L^{-1}*
Australian smelt	*Primary* *>30,000 mg.L-^{1}*	*Primary* *<5*	*Primary* *Major habitat in littoral zones*	*Primary* *<2 mg.L-^{1}*
Murray hardyhead	*Primary* *>35,000 mg.L-^{1}*	*Primary* *<5*	*Primary* *Major habitat in littoral zones*	*Primary* *<2 mg.L^{-1}*
Yarra pygmy perch	*Primary* *>10,000 mg.L-^{1}*	*Primary* *<5*	*Primary* *Major habitat in littoral zones*	*Primary* *<2 mg.L^{-1}*
Common carp	*Primary* *>12,8000 mg.L^{-1}*	*Primary* *<5*	*Primary* *Spawning habitat likely in vegetated littoral zones*	*Primary* *<1 mg.L-^{1}*
Congolli	*Primary* *Highly tolerant, however adult females have preference for lower salinities (fresh-brackish) and thus increased salinity reduces habitat area.* *>50,000 mg/L*	*Primary* *<5*	*Primary* *Using water level as a proxy for connectivity: Low water levels result in continued disconnection of Lakes and Coorong. In seawater delivery scenario connectivity is one-way. Furthermore, littoral zones likely represent preferred habitat in Lx & Lb*	*Primary* *<2 mg.L-^{1}*
Common galaxias	*Primary* *Highly tolerant, however adults have preference for lower salinities (fresh-brackish) and thus increased salinity reduces habitat area.* *>40,000 mg/L*	*Primary* *<5*	*Primary* *Major habitat in littoral zones.* *Using water level as a proxy for connectivity: Low water levels result in continued disconnection of Lakes and Coorong.*	*Primary* *<2 mg.L^{-1}*
Short-headed lamprey	*Primary* *>10,000 mg.L-^{1} (ammocoetes) (Reis-Santos et al*	*Primary* *<5*	*Using water level as a proxy for connectivity: Low water levels result in continued disconnection of Lakes and Coorong. Furthermore, receding water levels may result in exposure of ammocoetes and/or*	*Primary* *<2 mg.L-^{1}*

Fish receptors	Primary Stressors (level of effect)			
	Salinity	**pH**	**Water levels**	**Dissolved Oxygen**
	2008). Ammocoetes reside in freshwater		*their habitat.*	
Yellow-eyed mullet	*Primary* *Highly tolerant. >60,000 mg.L-*^{1} *May be benefited by increased salinity in Lx not negatively impacted*	*Primary* *<5*	*Secondary - decreases in productivity – trophic dynamics*	*Primary* *<2 mg.L-*^{1}
Small-mouthed hardyhead	*Primary* *Extremely tolerant. >80,000 mg.L*$^{-1}$ *May be benefited by increased salinity in Lx not negatively impacted*	*Primary* *<5*	*Primary* *Major habitat in littoral zones.*	*Primary* *<2 mg.L-*^{1}
Black bream	*Primary* *Highly tolerant. >60,000 mg.L*$^{-1}$ *May be benefited by increased salinity in Lx not negatively impacted* *Recruitment may be impacted in MM region if salinities increase. Preferred range likely 20,000-35,000 mg/L*	*Primary* *<5*	*Secondary - decreases in productivity – trophic dynamics*	*Primary* *<2 mg.L-*^{1}
Mulloway	*Primary* *>35,000 mg.L-*^{1} *May be benefited by increased salinity in Lx not negatively impacted*	*Primary* *<5*	*Secondary - decreases in productivity – trophic dynamics*	*Primary* *<2 mg.L*$^{-1}$

2)

Additional receptors

Both short-headed lamprey (Mordacia mordax) and common galaxias (Galaxias maculatus) were included as additional receptors. Lamprey are included as they have a unique life history that was not yet represented in the included species. Australian lamprey species are anadromous exhibiting a parasitic marine adult phase with an upstream spawning migration into freshwaters. Spawning and larval (ammocoete) development occur in freshwater, where ammocoetes reside for 2-3 yrs before metamorphosing and migrating downstream.

Common galaxias are a catadromous species, similar to congolli, however, their life history is sufficiently different to that of congolli to warrant inclusion. When connectivity exists between riverine, estuarine and marine environments this species commonly has a marine larval phase prior to upstream migration into freshwaters. However, there is evidence to suggest that they can adapt flexible life history strategies to enable recruitment and completion of their lifecycle upstream of barriers, including in Lake Alexandrina.

Both species, particularly lamprey, are under imminent threat due to the current prevailing conditions of limited connectivity. Whilst not considered matters of national conservation significance a prolonging of the current situation threatens short-headed and pouched lamprey (Geotria australis) with extinction in the Murray-Darling Basin.

Level of stressor effect: Southern Bell frog

Completed by: Nick Souter

Date: 10 July 2010

Receptor list (present <u>or</u> MNES)^	Primary Stressors (level of effect)#			
	Salinity	**pH**	**Water levels**	**Dissolved Oxygen**
Southern Bell Frog	*> 7 ms/cm or 8-9 ppt for tadpoles (Cleman & Gillespie 2010 Draft National recovery plan for the Southern Bell Frog* Litoria raniformis *and the SBF EPBC SPRAT). Observed in channel 1 at Mundoo Island when salinity was 7.85 ppt (13 400 EC)*	*unknown*	*Water present in Mundoo Channel connected to the rest of the lake*	*Avoidable for adults*

Receptor list (present <u>or</u> MNES)^	Secondary Stressors (level of effect)#							
	Gibbsite/Al	**Mg**	**MnII/MnO2A**	**Na**	**FeII/FeIII**	**FeOH3A**	**DOC**	**CHGBAL**
Southern Bell Frog	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*

Receptor list (present <u>or</u> MNES)^	Secondary Stressors (level of effect)#							
	SiO2	**Ca**	**Calcite**	**Cl**	**DIC**	**NH4**	**NO3**	**PO4**
Southern Bell Frog	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*

Receptor list (present <u>or</u> MNES)^	Secondary Stressors (level of effect)#				
	TP	**SO4**	**SO4REDN**	**TCHLA**	**TN**
Southern Bell Frog	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*

Attachment D: Salinity and pH consequence assessments at receptor level for all scenarios

Do-Nothing Scenario

Lake Alexandrina pumping (DN_P)

Plankton

- Patches suitable for River-sourced plankton will change over time with increasing salinity driving loss of 98% of their typical habitat by summer 2010/2011 (score 25) which will acidify in Autumn 2012.
- Salinities will be suitable for Low salinity plankton across the whole lake until February-March 2011 when 24% of their habitat will exceed their threshold and 95% of the lake will be more than 51% of their threshold (score 20). Low pH will then cause additional stress.
- If Brackish plankton are present or colonise the site, salinities will be suitable across the whole lake until February 2012 when 8% of Lake Alexandrina will be over their threshold and 46% will be over 51% of their threshold (score 16).
- Estuarine plankton and ostracods will be unlikely to establish.
- Mortality of all the plankton receptors is predicted due to low pH in autumn 2012 and again in autumn-winter-spring in 2013 (scores 20-25). The concurrent contraction of the water level to between 25 and 39% of the baseline lake area in those summers may result in high abundance of plankton in the remaining water, but it may also significantly reduce the area for growth (score 20).
- Extreme acidophiles will be likely to become abundant from Autumn 2013 across most of the lake. They may colonise prior to that when the patches of low pH will be highly dynamic and transient, particularly if the swirls of low pH water represent bulk movement of a volume of acidic water.

Vegetation

- Salinity will become increasingly unsuitable for Floating plants over time with 62% of the available habitat over their salinity threshold and 98% of the habitat over 51% of their threshold by March 2011 (score 20). As for plankton, Floating plants will be strongly limited by low pH (score 25) and receding water levels (score 20) in autumn 2012 and again in autumn-winter-spring in 2013.

Lacustrine macroinvertebrates

- Salinities will remain suitable for survival of adult Freshwater mussel and Yabbies until summer 2010/11, when 90% of their habitat will be over 51% of their threshold and 20% will be over their threshold (score 16).
- Littoral macroinvertebrates will be unaffected by salinity until February 2012 when 25% of their habitat will exceed 51% of their threshold (score 12).
- Brackish macroinvertebrates will be just beginning to be affected when the modelling becomee unreliable with 8% of their habitat over 51% of their threshold and 50% over 26% of their threshold (scores 8 and 12).
- Regardless of varying salinity tolerances, all Lacustrine macroinvertebrates will be lost as a result of low pH (score 25). Water level contraction (25 to 49% of baseline) will have additionally increased their stress.
- As a group there will be not likely to be any directional response from Insect larvae, and thus Generalist shorebirds, to changing salinities. Low pH will be fatal for resident and emergent larvae in March-October 2013 leading to loss of Generalist shorebird prey (score 25).

Estuarine macroinvertebrates

- Salinities across 90% of Lake Alexandrina will be suitable for further establishment of *Ficopomatus enigmaticus* (tubeworms), although declining water levels will limit their spread until low pH caused their progressive loss in Autumn 2012 and 2013 (score 25).
- Other Estuarine macroinvertebrates may colonise although hydrological isolation of Pt. Sturt in summer 2012 will limit their spread and they will be lost to low pH in 2013 as will tubeworms.

Fish

- All the fish receptors will be adversely affected by salinity except for the two most salt tolerant: Small-mouthed hardyhead and Black bream.
- Salinity tolerance of the Common galaxias will be not breached (40 g/L) and they will be less much less affected by lost connectivity (score 12) than Congolli and Short-headed lamprey ammocoetes (both of which will die out in 2010, score 25) but Common galaxias will not have any preferred habitat suggesting recruitment will be poor.
- Yarra pygmy perch threshold will be progressively lost from March 2011, losing all their preferred habitat (south of Pt. Sturt) in January 2012.
- Short-headed lamprey ammocoetes will be also strongly affected by salinity; 23.7% of their habitat will exceed their threshold in January 2012 and 94.6% of their habitat over 51% of their threshold (score 20).
- Other fish receptors will have 44 to 63% of their habitats affected (scores 12-16).
- Low pH will lead to mortality across 75% of fish habitat from autumn to spring 2013 (score 25). The effects on Yarra pygmy perch will occur earlier (autumn 2012) and across a greater proportion of their habitat (90% and then 100% in 2013) relative to other fish receptors because acidification will begin near their core refuge habitat and they will be unlikely to escape to deeper water. Similarly, effects on Murray hardyhead and Congolli will be adverse across a larger habitat area because of their greater exposure to acidic conditions.

Southern bell frog

- Southern bell frog were expected to perish primarily from disconnection from the main lake body in January 2011 (score 25) and then secondarily by salinity. Prior to drying out, Mundoo Channel salinity will be approaching Southern bell frog's salinity threshold. Water acidification will not affect Mundoo Channel before disconnection from the main lake body but it is likely the soils will be acidified.

Birds

- Fish-eating birds were predicted to leave Lake Alexandrina shortly after Autumn 2012 when low pH will affect their prey across 75% of the lake (score 25) particularly because the remaining 25% of water that will have pH > 6 will be relatively deep and thus not ideal for fishing. Fish kills may lead to transient increases in Fish-eating birds but many birds will be likely to migrate away from Lake Alexandrina before widespread acidification occurs (Autumn 2013) in response to a decrease in food availability.
- Waterfowl will lose their prey in 2013 when pH in Lake Alexandrina falls (75 to 100% Lake Alexandrina: score 25).
- Estuarine birds will be unlikely to use Lake Alexandrina because of limited prey. The exception may be if salinity levels increase after reliable modelling ceases (January 2012), in which case, Estuarine macroinvertebrates will be able to colonise Lake Alexandrina and thus provide a food source to attract the birds.
- Given that significant areas of water in Lake Alexandrina will persist (25% of October 2009 baseline equates to 10,762 ha), birds that remain may be directly affected by low pH and metals, which will be released in association with low pH values (as has been observed in mine waste dams; Attachment C).

Lake Alexandrina cease- pumping (DN_CP)

Plankton

- River-sourced plankton will be unlikely to tolerate increasing salinity beyond summer 2012 and low pH each autumn but may intermittently occur each winter following river inflows.
- Low salinity and Brackish plankton will also decline due to salinity (77 and 53% loss of habitat by March 2015, respectively) but will be less affected by low pH (5% habitat). This compares to 90 -100% loss under the pumping scenario.
- Opportunities will exist for seasonal colonisation of Estuarine plankton and ostracods across increasingly large areas of Lake Alexandrina each summer from summer 2011/12 onwards. In March 2015, approximately 50% of Lake Alexandrina will be suitable for such colonisation.
- Water level will decline from Autumn 2010 onwards reducing the area available for plankton growth by around 30%, which is a greater lake area reduction at a much earlier date than in the pumping scenario (25% by March 2015).

Vegetation

- Salinities will be greater than 73% of the salinity threshold for Floating plants across 74% of Lake Alexandrina from summer 2010/11, which will limite their growth and survival in the cease-pumping scenario. By December 2014, 97% of the lake will exceed the plant's salinity threshold (score 25).
- Similar patterns will occur for salinity in the pumping and cease-pumping scenarios up to January 2012 when the modelling for the pumping scenario becomes unreliable. However, acidification (minor vs. complete loss) and water level effects (25.3% vs. 64.6% lake area) will be much less in the cease-pumping scenario.

Lacustrine macroinvertebrates

- Freshwater macroinvertebrates will be highly stressed by salinity from summer 2010/11 and mortal effects will be predicted in winter 2014.
- Freshwater mussels will experience reproductive failure in July 2014 and major losses of adults in January 2015 (score 25). Similarly, Yabbies will be effectively lost in January 2015 and even more-salt tolerant Littoral and Brackish macroinvertebrates will be strongly affected (score 16).
- Lacustrine macroinvertebrates will be hardly affected by low pH in the cease-pumping scenario compared to complete loss in the pumping scenario from acidification and low water levels.
- Insect larvae will be unlikely to respond to salinity and thus neither will be Generalist shorebirds that prey upon them.

Estuarine macroinvertebrates

- Salinities will be ideal for proliferation of tubeworms across most of the lake from spring 2010 onwards in both scenarios (noting that salinity modelling will be not reliable post-January 2012) thus dispersal, pH, substrate and water depth will be the main limiting factors.
- Salinities will be too low to be optimal for other Estuarine macroinvertebrates in both scenarios, but will be within their tolerance ranges so colonisation/proliferation in the southern parts of Lake Alexandrina may occur.
- Overall Estuarine macroinvertebrates would be more likely to expand their range in the cease-pumping than the pumping scenario.

Fish

- All the fish receptors will be adversely affected by salinity in the cease-pumping scenario. The exceptions will be the two most salt tolerant species: Small-mouthed hardyhead and Black bream.

- Short-headed lamprey ammocoetes will be also strongly affected by salinity but on-going disconnection *per se* will lead to their loss by the end of 2010 (score 25).
- Murray Cod, Common carp and Golden perch will have major habitat losses by March 2015 (score 20).
- Complete loss of habitat will occur for Yarra Pygmy Perch in February 2012. For Murray hardyhead and Yarra pygmy perch the loss of sheltered, fringing habitat from drawdown post-January 2012 will be catastrophic in its own right (score 25).
- Australian smelt, Bony herring and Murray hardyhead will be adversely affected (score 16) even though salinity will be not over their threshold.
- The thresholds for loss of Common galaxias and Congolli will be not breached (worst case will be 22.8% habitat over 51% of their threshold in March 2015, score 12) but on-going disconnection will be catastrophic for Congolli (score 25) and recruitment by Common galaxias will be poor.

Birds

- Waterfowl will be lost from 97% of their habitat by March 2015 in response to loss or declines in Floating plants, zooplankton and macroinvertebrates (score 25). The other birds will be not affected by salinity losses of prey.

Lake Albert Do-Nothing pumping (DN_P)

Plankton

- The salinity concentration across Lake Albert will exceed 51% of the salinity threshold for Brackish plankton (which typically dominate Lake Albert's planktonic communities) as early as November 2009. Winter freshening will reduce salinity each year but by June 2013 the whole of the lake will have salinity too high for Brackish plankton (score 25).
- Similarly Estuarine plankton will be at first stressed by high salinity and then salinities will exceed their threshold in June 2013 (score 25). Conditions will be suitable for colonisation of Estuarine ostracods from December 2010 if they migrate from more saline environments.
- Salinities will be suitable for Marine plankton in 2012 and 2013 but they will be less likely to colonise than Estuarine ostracods given their greater dispersal distance and intolerance of low winter salinities below (25 g/L).

Vegetation

- Salinity will rapidly become unsuitable for Floating plants with 100% of the available habitat over their salinity threshold by December 2009, only a few months after the action begins (score 25).

Lacustrine macroinvertebrates

- Littoral and open water habitat of suitable salinities for Yabbies, the most salt sensitive macroinvertebrate will be present in October 2009 and lost by January 2010 (score 25).
- Adult Freshwater mussels, Littoral macroinvertebrates and Brackish macroinvertebrates will be increasing stressed by salinity until thresholds are breached in winter 2013. For example, the main lake will be over the threshold for adult Freshwater mussel (10 g/L) in November 2009, but Narrung Narrows (approximately 5% of Lake Albert and 15% of the lake fringes) will provide habitat of decreasing size until June 2013, when this area will exceed their threshold as well.
- No Lacustrine macroinvertebrates will survive in Lake Albert beyond winter 2013.

Estuarine macroinvertebrates

- Insect larvae, and therefore Generalist Shorebirds, will not be affected.

Fish

- Increasing salinity in Lake Albert will lead to significant loss of all fish receptors except for Small-mouthed hardyhead, which will be strongly affected. The maximum salinity of 60 g/L in Lake Albert in summer 2014 will be still within Small-mouthed hardyhead tolerance although 85% of their habitat will have salinities greater than 51% of their threshold (score 20).
- Suitable habitat for Murray Cod will be lost across the whole of Lake Albert in summer 2009/10. Golden perch and Common carp will be increasingly affected by salinity but may persist in refuge areas until winter 2013.
- Although Murray Cod, Golden perch and Common carp have very similar salinity thresholds, mortal effects on Murray Cod populations will be three and a half years earlier because water in the Narrung Narrows is thought to be too shallow to provide adequate refuge. This suggests that some Murray Cod may survive in Narrung Narrows but not beyond winter 2013 and that effects on Common carp and Golden perch may be greater than predicted based on C_h and C_t alone because of competition and predation processes in the very confined and shallow area of Narrung Narrows.
- By the end of 2010, Congolli and Short-head lamprey will have been lost due to on-going disconnection through the barrages. Congolli will also be affected by disconnection which coupled with relatively high salinities in Lake Albert from January 2010 (C_h 90%, C_t 51%, score 20) will be likely to reduce recruitment and led to their loss by spring 2011.
- Australian smelt and Bony herring will be able to use only 2% of Lake Albert by winter 2013, which coupled with likely increasing predation and competition means they will be effectively lost.
- Overall, salinities will increase to lethal (or at best sub-lethal) concentrations for all fish receptors. Those fish remaining will be confined to small areas of higher than ideal salinities, which will be likely to increase sub-lethal effects and stress caused by competition and predation.

Birds

- Waterfowl will experience very poor foraging conditions, and thus are likely to avoid Lake Albert (score 25). They may stay or return to feed on the more salt-tolerant zooplankton and macroinvertebrates that survive until winter 2013.
- Fish-eating birds may remain at Lake Albert throughout the action period given that Small-mouthed hardyheads will persist and fish kills will provide abundant food.

Lake Albert Do-Nothing cease-pumping (DN_CP)

Plankton

- Communities of plankton in Lake Albert will be subject to loss from high salinities during 2010 and it is unlikely that any plankton other than Estuarine ostracods will be present when the first acidification event in summer 2010 begins (15% of Lake Albert). The Estuarine ostracods that survive these first acidification events will also be lost to high salinity in early 2011.
- If any Marine or Estuarine plankton colonise Lake Albert or persist into spring 2011 they will die from widespread acidification at that time.
- The acidification in spring 2011 will creat suitable conditions for Acidophilic plankton, however, the acidophilic plankton and any remaining acid sensitive plankton will be desiccated by the drying of the lake in early 2012.

Vegetation

- Any Floating plants remaining at the beginning of the action period will be lost within a few months.

Lacstrine macroinvertebrates

- Salinities will become too high for Yabbies in early summer 2010/11 in both the pumping and cease-pumping scenarios.
- While other Lacustrine macroinvertebrates will persist until winter 2013 in the pumping scenario, all will be lost in the cease-pumping scenario by autumn 2011 due to combination of acidification and drying.

Estuarine macroinvertebrates

- Salinities will exceed the threshold for all taxa in the Insect larvae group in autumn 2011 at the same time as pH drops to below their threshold and the lake dries to only 27% of the baseline.
- These combining factors will result in loss of all Insect larvae from Lake Albert in autumn 2011 whereas there will be no directional effects on them in the pumping scenario.

Fish

- With ceased pumping, salinities in Lake Albert will exceed the thresholds of all fish.
- Rising salinity will cause fish kills from summer 2010/11 onwards. If any fish survive the rising salinity, they will be lost to low pH (< 4) or by falling water levels in spring 2011.

Birds

- Food resources for Waterfowl will be lost within a few months due to salinity under both the pumping and cease pumping scenarios.
- Generalist shorebirds will be not effected upon in the pumping scenario but lost all their prey during summer 2010/11 if pumping ceased.
- Fish-eating birds had minimal loss of prey in the pumping scenario whereas in the cease-pumping scenario all fish died prior to winter 2011.

Foraging opportunities and feeding success for all birds will become so poor in Lake Albert that they will leave between spring 2010, when the food resources begin to wane, and spring 2011 when the lake dries.

Seawater Scenario

Lake Alexandrina pumping to Lake Albert (SW_P)

Plankton

- In winter 2010, freshening from river inflows will have a minor positive effect in River-sourced plankton but by March 2011 (a few months after seawater will be let into the lake) salinities will be too high for them to persist (score 25). There may have been short-lived pulses of River-sourced plankton in areas under River Murray influence when the river will be flowing in 2011.
- Salinities will increase beyond the threshold for Low salinity and Brackish plankton across 100% of the lake in February and March 2012, respectively, resulting in loss of the Lake Alexandrina plankton community that exist at the beginning of the action period.
- Salinity concentrations will become increasingly favourable for Estuarine plankton to proliferate (15 – 80 g/L) from winter 2011 if can disperse into the lake.
- Regardless, salinities will continue to increase and by spring/summer 2015 will exceede the Estuarine plankton threshold across 100% of the lake (score 25) and the Estuarine ostracods across 91% (score 25).
- Marine plankton may enter with seawater and grow in Lake Alexandrina between January and August 2012 when salinities will be suitable until salinity exceeds their threshold (including copepods) in increasing areas of Lake Alexandrina from autumn 2013 (100% in March 2015; score 25), thus will not proliferate for long, if at all.
- Salinities become favourable for Hypersaline plankton from autumn 2015 (> 50 g/L) and they may have found a dispersal vector by which to enter the lake from the Coorong.

- It is unlikely that Extreme halophillic plankton will colonise Lake Alexandrina because salinities will not exceed 100 g/L and they will tend to use habitats with more than 150 g/L. (NB: 100 g/L appears to be the limit for data contained in the files from which the data cubes used for this analysis will be built. Raw model output files show values up to 101 g/L).
- All plankton will be adversely affected in the 20 -24% of Lake Alexandrina which will dry between October 2009 and March 2011 but 76 - 80% of the Lake Alexandrina habitat will be still available for growth of plankton receptors.
- No significant effect of pH on plankton will occur in Lake Alexandrina for this highly mobile receptor group (< 5% habitat between January and June 2010).

Vegetation

- Floating plants will be moderately affected by the 20-24% loss of habitat caused by reduced water levels.
- Salinities in Lake Alexandrina will rapidly become too high for Floating plants after seawater is introduced in October 2010. All of Lake Alexandrina (100%) will be above their salinity tolerance by June 2011, resulting in loss from Lake Alexandrina.
- In comparison to the salinity effects, the effects of pH will be insignificant.

Lacustrine macroinvertebrates

- As salinities in Lake Alexandrina increase over time, mortality across 100% of Lake Alexandrina (score 25) will occur for: Yabbies and adult Freshwater mussel in March 2011; Littoral macroinvertebrates in January 2012 and for Brackish macroinvertebrates in April 2013.
- Water level reduction and drying of specific edge habitats may exacerbate the salinity stress (with the possible exception of adult Freshwater mussel).
- Short-lived pulses of acidification will affect up to 5% of the Lacustrine macroinvertebrates habitat for six months (January to June 2010) and thus will be relatively insignificant compared to salinity and water level changes.
- Yabbies will not escape the rapidly incoming seawater and given that Brackish macroinvertebrates will be more abundant in the south of Lake Alexandrina, mortality will occur sooner than predicted above because seawater will enter in the south and salinity increase will be particularly rapid in that region.

Estuarine macroinvertebrates

- After seawater is let in (October 2010), the lake will become increasingly favourable for further establishment or colonisation of estuarine taxa and in November 2011 more than 94% of the lake will have salinities within the estuarine range.
- Tubeworms will be the only Estuarine macroinvertebrate in significant numbers in Lake Alexandrina in October 2009 and conditions will become ideal for expansion until February 2013 when salinities will exceed their threshold in 10% of Lake Alexandrina (*Boccardiella limnicola* will be likely to follow these trends). Salinities in Lake Alexandrina will become increasingly unsuitable from summer 2012/13 so that by February 2015 more than 97% of their potential Lake Alexandrina habitat will be over their thresholds.
- In December 2014, the seawater entering the lake will briefly 'freshen' the water below Point Sturt to within the tolerance of Tubeworms but they will be lost from the lake by the end of the action period.
- Near total loss (90%, score 25) will occur for *Simplisetia aequisetis*by February 2015 from increasing salinity, however, water level reductions in specific areas south of Pt. Sturt will be likely to further limit their growth and expansion early than 2015.
- A similar pattern of near total loss by February 2015 will occur for the other Estuarine macroinvertebrates (97% loss) except for Amphipoda, *Arthritica helmsi* and Large bivalves for which 100% mortality will occur earlier in April 2014.

- Community shifts during the period that the lake will be within the estuarine salinity band (primarily October 2010 to autumn 2103) will be likely to depend on larval colonisation rather than adult dispersal. It is also likely that the high turbidity in Lake Alexandrina will limit colonisation by Large bivalves.
- The Estuarine macroinvertebrates will not be likely to have been affected by the short-lived pulses of low pH in western and northern Lake Alexandrina between January and June 2010 because seawater will not have yet been let in, thus, the only Estuarine macroinvertebrate in the lake at the beginning of the action period will be Tubeworms and they will be confined to south of Pt. Sturt at that time.
- The salinity threshold for Insect larvae (138 g/L) will not exceed although salinities will reach 70 g/L across 100% of their Lake Alexandrina habitat and 100 g/L across 50% habitat at the end of the action period, which may have cause sub-lethal effects (score 16, 20).

Fish

- Water levels and the very short pulses of low pH will not have a significant effect on the fish receptors therefore the primary driver of fish population dynamics will be salinity in this scenario.
- The rapidly increasing salinity after seawater is introduced will progressively cause the loss of all the resident Lake Alexandrina fish receptors.
- Salinities will become unfavourable in some areas of Lake Alexandrina from late spring/early summer 2010, immediately after seawater introduction.
- Salinity across 100% of the lake will exceed the threshold of the most salt sensitive fish receptor, Yarra pygmy perch, in October 2010. However, it is likely that they will have already been lost prior to October 2009 (Bice 2010).
- Salinities across the whole lake will increase to beyond the thresholds of Common galaxias and Congolli in March 2011 and for Murray cod, Golden perch, Common carp and Short-headed lamprey ammocoetes by February/March 2012. Then by April 2013 Australian smelt, Bony herring and Murray hardyhead will perish.
- Partial connectivity when seawater is introduced may facilitate essential life history passage for Common galaxias, Short-headed lamprey and Congolli but the very high salinities in the lake will strongly limit recruitment.
- From October 2010 when seawater is first let in, Small-mouthed hardyhead will likely benefit from higher salinities in Lake Alexandrina and from reduced competition resulting from the loss of fish with lower salinity tolerance. The range for Small-mouthed hardyhead will expand and cover 100% of Lake Alexandrina by October 2010. These fish will tolerate winter freshening and thus conditions will continue to improve for them over time until summer 2014/15 when salinities will increase to greater than their threshold across 91% of the lake.
- As salinity increases in Lake Alexandrina, conditions for Yellow-eyed mullet will also improve with 100% of Lake Alexandrina suitable by March 2012. Those fish that enter with seawater and survive will persist in Lake Alexandrina until salinities exceed their upper threshold (40 g/L) in January 2014
- Black bream as well as Mulloway juveniles and resident larvae will benefit from increased salinity up to (but not greater than) seawater concentrations (35 g/L). Therefore they will be likely to flourish in Lake Alexandrina between October 2010 when seawater is first let in and winter 2013 when salinities will rise to higher than seawater concentrations provided that they survive delivery into Lake Alexandrina with the seawater. There will be significant loss of individuals due to the manner in which seawater will be delivered and because fish will have only limited opportunity to escape back to the sea through the barrages when they are briefly open each year. Therefore, adverse effects may be greater than predicted here from salinity alone.

Southern bell frog

- The entire habitat for Southern bell frog will be lost to increasing salinity during spring 2010 and by disconnection to main lake water body (disconnection follows increase in salinity). It is unlikely that they will persist beyond summer 2010/11.

Birds

- Generalist shorebirds will be unlikely to be affected by salinity.
- Estuarine shorebirds may benefit from increasing lake salinity via the colonisation and/or proliferation of Estuarine and Marine macroinvertebrates (particularly larger polychaetes) until autumn 2013 when salinities will become to high for these prey items.
- Salinity thresholds will be reached for all the resident fish receptors by April 2013, which will have a major adverse effect on foraging by Fish-eating birds in the longer-term (fish kills may have provided short-term food resources). The exception will be Small-mouthed hardyhead, which will be likely to proliferate in Lake Alexandrina as salinities increase until summer 14/15 when their threshold will be breached as well across 91% of their habitat. Introduction of estuarine and marine fish may offset losses and resulted in some improved habitat (in terms of food availability if these fishes did colonise Lake Alexandrina). This made the assessment of the secondary effects of salinity on Fish-eating birds complicated but given that it will be likely that some food resources would be available most of the time until summer 2014/15 they will most likely experience no directional effect until that time.
- The water level reductions modelled for Lake Alexandrina will be unlikely to have a significant effect on distribution of foraging habitat for Generalist and Estuarine shorebirds. Water level regime will periodically inundate mudflats, however, the foraging value of mudflats at the low water levels seen in this scenario is unknown.

Lake Alexandrina cease-pumping to Lake Albert (SW_CP)

Plankton

- Ceasing to pump to Lake Albert will have very little effect on overall plankton community dynamics in Lake Alexandrina under the seawater pumping scenarios.
- River-sourced plankton will still perish but they will do so nearly a year later in the cease pumping (January 2012 vs. March 2011) scenario. Their high potential for reseeding means it will be unlikely to represent a significant difference in terms of ecosystem composition.
- Low salinity and Brackish plankton will be lost at very similar timing (early to mid 2012) which is indicative of the rapid rate of salinisation.
- Opportunities for Estuarine, Marine and Hypersaline plankton to colonise the lake will be very similar although Estuarine ostracods will experience less favourable conditions for slightly longer and over a slightly greater area (91 vs 94%) when pumping ceases.
- Water levels and pH will be effectively the same between the two scenarios and it is unknown whether other potentially limiting factors such as dispersal and predation will be different if pumping to Lake Albert ceases. Therefore ceasing to pump to Lake Albert will have no significant effect on plankton communities in Lake Alexandrina.

Vegetation

- Floating plants may persist in some areas of Lake Alexandrina for 8 months longer (June 2011 vs. January 2012 for total loss) if pumping ceases than if it continues but this is unlikely to be ecologically significant, particularly in terms of provision of food to higher trophic levels (e.g. Waterfowl).

Lacustrine macroinvertebrates

- There will be no significant difference between the pumping and cease pumping scenarios for Lacustrine macroinvertebrates.

- Freshwater and Littoral macroinvertebrates will have total loss dates that will be approximately 8 months later in the cease-pumping scenario but these will be unlikely to represent significant ecological differences.

Estuarine macroinvertebrates

- There will be minor, probably insignificant, differences in timing and extent of effects on Estuarine macroinvertebrates. Tubeworms may persist in low numbers for an additional 8 months under the cease-pumping scenario but conditions will be so poor during that time that it will be unlikely to have a significant effect on distribution, abundance or condition.

Fish

- Ceasing to pump to Lake Albert will have a minor effect on the timing of loss of lacustrine fish from Lake Alexandrina but the overall patterns of near complete loss of all lake fish will be the same.
- The exception will be Small-mouthed hardyhead that lost more habitat (96 vs. 91%) nearly a year earlier in the cease-pumping scenario. This will be likely to be a result of the 5-10 g/L differences in salinities between the two scenarios being near its threshold and that salinities will increase towards this threshold rapidly in the latter part of the action period.
- Opportunities for colonisation by estuarine fish (Yellow-eye mullet, Black bream and Mulloway) will be essentially the same between the pumping and cease-pumping scenarios. In both cases the fish will be limited by the seawater delivery mechanism causing injury or death and by salinities ultimately exceeding their tolerances in 2013.

Southern bell frog

- Mortality will occur in January 2012 in both the pumping and cease-pumping scenarios and thus there will be no effect of ceasing to pump.

Birds

- Given that the receptors above will be not significantly affected by ceasing to pump to Lake Albert, then neither will be the birds that depend upon them.

Lake Albert pumping (SW_P)

Plankton

- Brackish salinity plankton will be predicted to die out (score 25) across the majority of Lake Albert in winter 2010 and across the whole lake in March 2011 because summer salinities will be too high and will become increasingly unfavourable.
- If Estuarine, Marine or Hypersaline plankton will be to enter the lake, the salinities will be favourable for colonisation at least in patches of the lake between: February 2010 and February 2012 for Estuarine plankton; February 2010 and October 2012 for Estuarine ostracods; Febuary 2011 and winter 2012 for Marine plankton and during 2012 for Hypersaline plankton.
- During these periods resources will be available for growth because of a lack of competition with less saline tolerant plankton, which will be already lost or declining markedly. However, the lack of other plankton will increase the pressure on these invading plankton from predation by fish, macroinvertebrates and planktivorous birds. Considering all these factors it will be highly unlikely that a successful shift in plankton from the typical Brackish assemblages to more saline tolerant ones will occur and thus Lake Albert will be relatively devoid of plankton from spring 2010.

Vegetation

- Salinities across the whole lake will exceed the tolerance of Floating plants by December 2010 resulting in complete loss.

Lacustrine macroinvertebrates

- As salinities increase over time, 100% mortality will occur for: Yabbies in January 2010; for Littoral macroinvertebrates and adult Freshwater mussel in January 2011 and for Brackish macroinvertebrates in February 2012.
- This will result in complete loss of Lacustrine macroinvertebrates by February 2012.

Estuarine macroinvertebrates

- Insect larvae will be supported across the whole of the lake until 2012 when up to 98% of their habitat will be affected by salinities at 72% of their threshold. This may infer sub-lethal effects.
- Increasing salinity will provide increasingly suitable conditions for the establishment of other Estuarine macroinvertebrates from December 2009 until April 2012 when salinities breach their optimum. By July 2012 salinities will be greater than the thresholds of most Estuarine macroinvertebrates across 98% of the lake. That said, it will be highly unlikely that most Estuarine macroinvertebrates could get into Lake Albert via the pumps. Those with the greatest chance of successful dispersal into Lake Albert will be Tubeworms and *Boccardiella limnicola*. *Arthritica helmsi* may possibly be transported in but it will be unlikely.
- Overall it will be unlikely that significant populations of Estuarine macroinvertebrates other than saline tolerant Insect larvae will occur in Lake Albert under this seawater pumping scenario.

Fish

- The whole of the lake will be above the salinity tolerance of Short-headed lamprey ammocoetes by January 2011 and for Congolli and in June 2012(score 25). However, disconnection will cause loss of Short-headed lamprey and Congolli by the end of 2010 and severely reduce Common galaxias recruitment, leading to their loss by autumn 2012 (score 25).
- Salinities will exceed the thresholds for: Murray Cod, Golden perch and Common carp from February/March 2011 (score 25) and Australian smelt and Bony herring by February 2012.
- Small-mouthed hardyhead will benefit from the higher salinities in Lake Albert and their range will most likely expand to 100% of Lake Albert during 2010. Any fish that are transported into Lake Albert from Lake Alexandrina will be at risk of being damaged or killed by pumping mechanisms and therefore any increases in Lake Albert populations will most likely have depend on recruitment of existing Lake Albert populations. Small-mouthed hardyheads will be likely to proliferate until summer 2012/13 when small areas of Lake Albert exceed their salinity tolerance (4%) and 97% of the lake will be greater than 51% of their tolerance. By October 2012, mortality will occur across 92% of their habitat and they will only be able to survive in the fresher areas of Narrung Narrows (approximately 10% of Lake Albert) from which they will not be able to escape back into Lake Alexandrina because of the bund.
- Yellow-eyed mullet, Black bream and Mulloway will be highly unlikely to colonise Lake Albert because of the large distance from the barrages to the Lake Albert entrance, barriers to movement and risk of death or injury if pumped from Lake Alexandrina to Lake Albert.

Birds

- The effects on Fish-eating birds will be catastrophic (score 25) from February 2012 because salinity thresholds for bony herring and other fish will be breached even though Small-mouthed hardyhead will have still been available as prey.
- Waterfowl will be strongly affected from December 2009 when Floating plants will be lost although they may survive on Brackish zooplankton until January 2012. After this Waterfowl may find food resources in the form of incoming Estuarine and Marine macroinvertebrates but the amount and quality is difficult to predict. Thus Waterfowl will be likely to leave Lake Albert in summer 2011/12 although they may periodically return later in 2012 to feed if prey is available.

- Generalist shorebirds will be the least affected of the bird receptors but even these will be affected across 98% of their habitat and may leave Lake Albert in winter 2012 because of poor foraging success.

Lake Albert cease-pumping (SW_CP)

Plankton

- Communities of plankton in Lake Albert will be subject to loss from high salinities during 2010 and it is unlikely that any plankton other than Estuarine ostracods will be present when widespread acidification began in summer 2010 (100% of Lake Albert).
- Acidification of this magnitude will be fatal to any surviving Estuarine ostracods as well as any Marine or Hypersaline plankton that may colonise Lake Albert.
- The acidification of the lake will create suitable conditions for Acidophilic plankton but these and any remaining acid-sensitive plankton will be desiccated by the drying of the lake in early 2012, regardless.

Vegetation

- Salinities will be too high for Floating plants within a few months as for the pumping scenario.

Lacustrine macroinvertebrates

- All Lacustrine macroinvertebrates will be lost from high salinity by summer 2010/11. At approximately the same time, acidification events will begin to occur and the lake will be also drying out.
- No Lacustrine macroinvertebrates will persist in the pumping scenario either but ceasing to pump will cause loss a year or more earlier and cause complete loss of all aquatic habitat through drying.

Estuarine macroinvertebrates

- Salinities will exceed Insect larvae thresholds in autumn 2011 at about the same time as acidification occurs and the lake dries. Flying adults will not be affected but it is unlikely that emerging larvae would persist if eggs are laid.

Fish

- Salinities will exceed the threshold of all fish.
- Rising salinity will cause fish kills from summer 2010/11. If any fish survive the increasing salinity then they will be lost to low pH when the pH drops to less than 4 or by the lake drying during spring and summer 2010/2011.

Birds

- Food resources for Waterfowl will be lost within the first few months.
- Generalist shorebirds will lose all their prey in autumn 2011 when pumping ceases.
- Fish-eating birds will be leave Lake Albert around spring 2010 perhaps after a period of high food availability when fish kills occur.
- Feeding success for all birds will become so poor in Lake Albert that they will leave the wetland during the action period whether pumping ceases or not.

Murray Mouth and Coorong: Seawater

- The effect of cease pumping will be evident in the seawater scenario in terms of reducing the Estuarine macroinvertebrate habitat areas adversely affected by high salinity and low water levels from 80% to 65% in the Murray Mouth region.
- No effect of cease pumping will be seen in North Lagoon and South Lagoon habitats in this scenario in terms of salinity. However, when pumping ceases there will be

decreasing water levels in the Murray Mouth and North Lagoon, which caused sediments to dry out from January to March at sites 1-3 and from September to March at sites 15-17 on an annual basis.

- This contrasts to the Seawater pumping scenario where sediments at site 1 will dry out from September to March and at sites 2-8 in January to March each year, suggesting that ceasing to pump will affect water levels further into the Coorong for longer than when pumping to Lake Albert occurs (effect of drying is less pronounced when pumping to Lake Albert is occurring). This drying of sediments will affect juvenile survivorship and given that the drying will occur in summer when production rates will be at their highest this may have a significant effect on populations that will be already under threat.
- It is not known whether recruitment will occur through the Murray Mouth or whether it is an internal process within the Coorong therefore this is identified as a major knowledge gap. It is not known how much of this water level effect will be due to the South Lagoon Salinity Reduction Scheme as opposed to the action of introducing seawater to Lake Alexandrina but it will be a significant effect on the mudflats. Little or no effect of cease pumping on water levels will be seen at South Lagoon sites.

Freshwater scenario

Lake Alexandrina pumping (FW_P)

Plankton

- Salinities will be too high for River-sourced plankton across 98% of the lake in December 2009. The northern parts of Lake Alexandrina under River Murray influence will often have salinities below 3 g/L in winter and spring, which will support transient populations that will seasonally extend into the central areas of the lake in winter.
- Salinities in the remaining areas of Lake Alexandrina will be suitable for Low salinity plankton and they will be likely to dominate the lake plankton community (even though salinities reached 51% of their threshold across 53% of their habitat from February 2010).
- Salinities will be also suitable for Brackish plankton particularly in the southern parts of Lake Alexandrina in summer. Therefore the plankton communities typical of Lake Alexandrina communities (River-sourced and Low salinity) will persist with dominance by . Brackish plankton that normally occur in Lake Albert will also be present from summer 09/10 to June 2012 when salinities will be in their range, resulting in a variable plankton community over space and time but one that will be likely to be highly productive.
- The lake area reduction of 24% will induce a minor to insignificant effect on all plankton because it will result in a major reduction in open water volume, which is their preferred habitat.

Vegetation

- Salinity thresholds will be not reached for Floating plants at any time during the action period, except for 8.4% of the lake in March 2010. However, 97.5% of Lake Alexandrina will be over 51% of their salinity threshold from December 2009 so it will is likely that the plants would be subject to sub-lethal effects.
- Their open water habitat will be reduced by approximately 24%, which may increase their salinity stress. However, the plants will be likely to be mobilised by wind and thus not have been spread evenly across the water surface making it difficult to evaluate likely salinity effects.

Lacustrine macroinvertebrates

- Salinities will exceed the threshold for Freshwater macroinvertebrates across 91% of their habitat in summer 2009/10 with only slight ‘freshening” each winter. It is unlikely they will persist at this level of stress for the whole five years of the action period.

- The salinity threshold for mortality of Adult Freshwater mussels will be not breached. Salinities will be greater than 51% of their threshold across 60% of their littoral habitat (sub-lethal effects) but lower open water salinities may ameliorate that effect.
- Salinity thresholds will be not breached for the other receptors in this group. However, salinities will be sub-optimal (greater than 51% of salinity threshold) for Yabbies from January 2010.
- Although the acidification events will be short lived and patchy they may induce a proportionally greater effect on Lacustrine macroinvertebrates than other receptors due to their accumulation in the southern areas of the lake and reductions in habitat from falling water levels. Thus it is likely that low pH will lead to mortality across 5 to 10% (or more) of the habitat actually being used by Lacustrine macroinvertebrates. Under these conditions, the effect will be moderate (score 10) rather than negligible.

Estuarine macroinvertebrates

- Summer salinities in the areas south of Point Sturt will be suitable for the survival of Estuarine macroinvertebrates already in the lake. However, the freshening each winter will be likely to either lead to mortality of Estuarine macroinvertebrates near the barrages or at least halt their expansion further into Lake Alexandrina.
- Given that the barrages will be closed throughout the action period there will be little chance of reseeding after winter freshening. Over time, the cumulative effects of winter freshening may lead to a near complete loss of Estuarine macroinvertebrates.
- Isolated pockets of low pH (< 6) will cause mortality of Insect larvae in 1% of Lake Alexandrina. As for the Lacustrine macroinvertebrates above, this 1% area of Lake Alexandrina affected by pH will equate to 5 -10% of actual Estuarine macroinvertebrate habitat. A drop in pH will have a catastrophic effect in those patches but will be unlikely to affect the population as a whole.

Fish

- Salinity thresholds will not be reached for any of the fish receptors in this scenario.
- The reduction of Lake Alexandrina area by 24 % over the action period will be also unlikely to have a significant effect except on Yarra pygmy perch and Murray hardyhead that prefer protected areas such as sheltered bays and wetlands.
- On-going disconnection will lead to losses of Congolli and Short-headed lamprey by the end of 2010 and potentially reduce recruitment success for Common Galaxias.

Southern bell frog

- Salinities across the whole Southern bell frog habitat will be greater than their threshold (>9 g/L) after March 2012. The high salinities combined with ongoing disconnection from Lake Alexandrina and possibly drying of the channel itself will result in a catastrophic effect in March 2013 (score 25).

Birds

- No effects will occur for Waterfowl, Generalist shorebirds and Fish-eating birds.
- Estuarine shorebirds will be unlikely to find suitable prey and thus will avoid the lake.

Lake Alexandrina cease pumping (FW_CP)

Plankton

- Over the whole of the action period the River-sourced plankton will be not significantly affected by ceasing to pump to Lake Albert compared to if pumping continued. The period of survival, post-reseeding from river inflows each winter, may differ between pumping and cease-pumping in any given year due to spatio-temporal differences in river salinity influences. It will also be likely that River-sourced plankton will have better opportunities in the central parts of Lake Alexandrina in the pumping scenario compared to the cease-pumping. However, overall they will be a minor part of the lake plankton community and will be contained to the northern areas in winter in both scenarios.

- The slight increase in salinities between pumping and cease-pumping in Lake Alexandrina will be enough to change the effect for Low salinity plankton from 53% of Lake Alexandrina greater than 51% threshold in pumping (no threshold breach) to 97% of Lake Alexandrina greater than 51% threshold and 15% over their threshold in cease-pumping.
- For Brackish plankton the slight increase in salinity will also made a significant difference. In the pumping scenario, salinities will be too low for colonisation in Lake Alexandrina prior to November 2009 and after June 2012 and in excess of 51% of their threshold in maximum of 5.6% of Lake Alexandrina (March 2010). By comparison in the cease-pumping scenario, salinities will be suitable for colonisation from the beginning of the action period to in excess of 51% of their threshold in maximum of 63% of Lake Alexandrina (March 2015) under the cease-pumping scenario.
- In neither scenario will salinity be high enough to support colonisation of Estuarine or Marine plankton.
- Overall the plankton communities in Lake Alexandrina will not be significantly affected by ceasing to pump to Lake Albert but there it is likely that there will be a different community composition with the cease-pumping scenario favouring more salt-tolerant taxa within the Low salinity and Brackish plankton receptor groups.

Vegetation

- More of Lake Alexandrina will be less suitable for Floating plants and losses will be much higher when pumping ceases compared to pumping (78% vs 8%).

Lacustrine macroinvertebrates

- The effect of cease-pumping on Lacustrine macroinvertebrates will be minimal because it will only increase the maximum area of unsuitable habitat from 91 to 98%.
- If pumping to Lake Albert ceases, then the area of Lake Alexandrina greater than 51% of Freshwater mussel threshold will increase from 60 to 98% and their salinity threshold will be exceeded in 5% of their preferred habitat (whereas their threshold will be not exceeded in the pumping scenario). This will lead to some mortality and more intense sub-lethal effects in the cease-pumping scenario.
- For Yabbies, ceasing to pump will be the difference between no areas (0%) and 50% of Lake Alexandrina exceeding their threshold, which is a major negative shift.
- There will be no significant effects of cease-pumping on the more salt-tolerant Littoral and Brackish macroinvertebrates.

Estuarine macroinvertebrates

- Ceasing to pump to Lake Albert will have no significant effect on the Estuarine macroinvertebrates. If anything, it may lead to greater persistence of established Estuarine macroinvertebrates near the barrages but the changes in salinity will be so slight with respect to shifting between fresh, brackish and estuarine conditions that it will be unlikely to lead to enhanced proliferation of this receptor group.

Fish

- For Murray cod, Golden perch and Common carp the effect of ceasing to pump will be an increase in area that exceeds 51% of their threshold from around 8% to 64-81%.
- For Australian smelt, Bony herring and Murray hardyhead, the difference will be that 60% of their habitat will be over 51% of their threshold in the cease-pumping scenario whereas none of the lake will exceed 51% of their threshold if pumping continues. Ceasing to pump to Lake Albert will have no significant effect on Common galaxias or Small-mouthed hardyhead.
- In both scenarios, Congolli and Short-headed lampreys will perish due to lack of functional connectivity.
- Yarra pygmy perch will be the fish receptor most strongly affected by ceasing to pump because of their low mobility and preference for fringing areas south of Point

Sturt where salinities will be the highest. In the pumping scenario, their salinity tolerance will be not exceeded but 100% of their habitat will have salinities greater than 51% of their threshold. By contrast, in the cease-pumping scenario 10% of their habitat will have salinities greater than their threshold in February 2012, which will increase to 95% by March 2014. It is likely that Yarra pygmy perch will be lost before the action starts in October 2009 but these results suggest that if any do survive they will be lost from Lake Alexandrina if pumping to Lake Albert ceases.

Southern bell frog

- Southern bell frog habitat will become too saline a year earlier (January 2011) if pumping ceases than if pumping continues (March 2012). In both scenarios, Mundoo Channel will become isolated, disconnected from Lake Alexandrina in March 2012 and dry.

Birds

- It is unlikely that Generalist shorebirds and Fish-eating birds will be affected by ceasing to pump to Lake Albert based on the lack of change in their prey. Fish-eating birds may have a change in diet and may experience periods of higher hunting success in the cease-pumping scenario but overall there will be little to suggest that availability of fish will change. Waterfowl will be likely to follow changes in Floating plants and zooplankton but if they prefer Floating plants they will experience a reduction in foraging success of up to 70% in the cease pumping scenario. Whereas, if they equally prefer zooplankton of different salinity tolerances, then they will not be affected.

Freshwater Lake Albert pumping (FW_P)

Plankton

- Lake Albert will be too saline for Brackish plankton from January 2010. Winter freshening will reduce the salinity to within their tolerance in 2010, but from spring 2010 onwards the whole of the lake will be too saline (score 25).
- Estuarine plankton will be progressively stressed by high salinity until salinities exceed their threshold across 98% of the lake by July 2015 (score 25).
- Conditions will be suitable for colonisation of Estuarine zooplankton and ostracods from December 2010 if they can migrate from more saline environments such as the Murray Mouth. Regardless, colonising Estuarine zooplankton and ostracods will be under increasing salinity stress and by the end of the action period (autumn 2015) they will be lost from 98 and 82% of Lake Albert, respectively.
- Colonisation by Marine plankton will be less likely than colonisation by Estuarine ostracods. Water level and pH will not adversely affect plankton thus salinity will be the key driver of plankton community structure.
- Overall it will be likely the existing plankton would be lost as salinity increases. There is a possibility of colonisation by new, more salt-tolerant plankton if a migration mechanism is found. However, salinities will become increasingly hostile for estuarine taxa and thus only those that can tolerate marine or hypersaline conditions will survive to the end of the action period. If more saline tolerant plankton do proliferate they will become a different but still important food resource for higher trophic levels depending on their palatability and/or toxicity.

Vegetation

- Salinity rapidly will become unsuitable for Floating plants with 100% of the available habitat over their salinity threshold by December 2009, only a few months after the action began (score 25).

Lacustrine macroinvertebrates

- Mortality will occur for Yabbies and Freshwater mussels across 98 to 100% of Lake Albert in January 2010, respectively. The 2% remaining habitat for Freshwater mussels, within the Narrung Narrows, will persist until July 2014 (score 25).
- At the same time, habitat suitable for Littoral macroinvertebrates will be lost except for Narrung Narrows (85% loss, score 25).
- Brackish macroinvertebrates will come under increasing salinity stress and by the end of the action period will be lost from all but Narrung Narrows (85% loss, score 25).
- Very few Lacustrine macroinvertebrates will survive beyond winter 2010. Brackish macroinvertebrates will be the last of this receptor group to remain but they will be under extreme salinity stress from April 2012 onwards. Those that persist into the later years of the action period will be confined to Narrung Narrows and thus may be subject to high levels of stress from other factors such as predation and competition.

Estuarine macroinvertebrates

- No directional effect on Insect larvae will occur except for during summer 2009/10 when low water levels will affect them.

Fish

- Increasing salinity in Lake Albert will lead to either major or catastrophic losses of all fish receptors, except for Small-mouthed hardyhead that will be able to tolerate the maximum salinities in summer 2014 (although C_h = 76% and C_t = 51%, score 20).
- Murray Cod, Golden perch, Common carp and Short-headed lamprey ammocoetes will be lost in summer 2009/10.
- Australian smelt and Bony herring will have only 8% of Lake Albert with suitable salinities by autumn 2014, thus they will be under salinity stress for most of the action period.
- For Congolli and Common galaxias, adverse impacts will be significant by January 2010
  (C_h = 89% and Ct = 51%, score 20) and increase by the end of the action period (Ch = 86% and Ct =100%, score 25). However, disconnection will be likely to cause loss of Congolli by the end of 2010 and limit Common galaxias recruitment such that they too will be most likely lost by spring 2013.
- Small-mouthed hardyhead will be likely to remain in Lake Albert but experience salt stress in 76% of their habitat by March 2015.
- Any fish remaining will be confined to small areas of higher than ideal salinities and thus would be likely to be experiencing sub-lethal effects as well as being stressed by other ecological process such as competition and predation enhanced by crowding.

Birds

- Waterfowl experienced very poor foraging conditions and will be likely to avoid Lake Albert (score 25), perhaps returning to feed on the more salt-tolerant zooplankton and macroinvertebrates that survive until spring 2014.
- No directional response will occur for Generalist shorebirds.
- Fish-eating birds will remain throughout the action period given that Small-mouthed hardyheads persist, albeit in potentially reduced abundance. They may experience periods of high food availability and hunting success in Lake Albert from summer 2010 from fish kills and congregation in Narrung Narrows.

Freshwater Lake Albert cease-pumping (FW_CP)

Plankton

- Communities of plankton in Lake Albert will be subject to loss from high salinities during 2010 and it will be unlikely that any plankton other than Estuarine ostracods will be present when the widespread acidification begins in autumn 2011.
- If any Marine or Estuarine plankton colonise Lake Albert or persist into autumn 2011 they too will perish from widespread acidification.

- Acidification in spring 2011 will create suitable conditions for Acidophilic plankton, however, if they do colonise the drying of the lake in early 2012 will desiccate them.
- This contrasts with the situation in Lake Albert when pumping continues where existing plankton will be lost to high salinity rather than acidification.

Vegetation

- No aquatic vegetation will persist in Lake Albert.

Lacustrine macroinvertebrates

- The salinity will be too high for Yabbies in early summer 2010/11 in both the pumping and cease-pumping scenarios.
- Very similar die-off patterns will occur for Freshwater mussels in the two scenarios (99 to 100% in summer 2009/10).
- Littoral macroinvertebrates will persist in 25% of Lake Albert until the end of the action period in the pumping scenario but will be lost in 2010 in the cease-pumping scenario.
- Brackish macroinvertebrates will experience 85% habitat loss in the pumping scenario by March 2015 compared to 96% loss in 2010 in the cease-pumping scenario. When pumping ceases, widespread acidification will occurring leading to the loss of all Lacustrine macroinvertebrates. The lake will be also drying out at this time and thus the aquatic habitat will be entirely lost irrespective of water quality.
- No Lacustrine macroinvertebrates will persist in either the pumping or the cease-pumping scenarios but ceasing to pump will cause catastrophic losses several years earlier and ultimately cause complete loss of all aquatic habitat.

Estuarine macroinvertebrates

- Salinities will exceed the thresholds for all Insect larvae in spring 2011 at the same time as pH will drop to below their threshold and the lake dries to only 19% of the baseline. These combining factors will result in loss of all Insect larvae from Lake Albert in autumn 2011, whereas there will be no directional effects on them in the pumping scenario. Given that the adult insects can fly, ceasing to pump to Lake Albert will not be catastrophic at a population level although there will be losses of all resident and emerging larvae.

Fish

- Disconnection will lead to loss of Congolli and Common galaxias by the end of spring 2010.
- Rising salinity will cause fish kills from summer 2010/11 onwards.
- Salinities will exceed the threshold of all fish receptors by winter 2011.
- If any fish survive the rising salinity then they will be lost to low pH (autumn 2011) or by falling water levels in autumn 2011.

Birds

- Waterfowl will be lost within a few months.
- Generalist shorebirds will be not affected in the pumping scenario but will lose all their prey during spring 2011 if pumping ceases.
- Fish-eating birds will have minimal loss of prey in the pumping scenario whereas in the cease-pumping scenario all fish will die out by the end of winter 2011. The fish kills may provide periods of high food availability for the Fish-eating birds but ultimately their food will run out.
- Few, if any, birds will be likely to remain long after spring 2010 when the food resources begin to perish and all will leave by spring 2011 when the lake dries.