Predicting the ecosystem response of the Coorong to the South Lagoon Salinity Reduction Scheme

A report prepared for the *South Australian Murray-Darling Basin Natural Resource Management Board*

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Executive Summary

Management of large-scale ecosystems like the Coorong is complex and it can be difficult to objectively assess the likely ecological consequences of management decisions. This is particularly the case with the added uncertainty of climate change and sea level rise.

We used a hydrodynamic model and an ecosystem state model for the Coorong in sequence to assess the likely consequences of possible future scenarios for the Coorong. The hydrodynamic model used forcing data for climate, tides, winds and flows over the barrages to provide hourly predictions of water levels and salinity along the length of the Coorong for a 20-year model run. The ecosystem state model uses these simulations together with flows over the barrages as inputs to a scheme for predicting the resultant mix of ecosystems states along the length of the Coorong.

An initial 87 scenarios were assessed for the Coorong. A baseline scenario (i.e. no intervention) was investigated with each of the remaining 86 scenarios consisting of a particular combination of three management strategies, namely pumping water out of the South Lagoon into the ocean, construction of a regulator structure across Parnka channel and excavating the Murray Mouth or Parnka Channel. In order to select the most-promising scenarios to analyse further, deviations from the Baseline scenario were investigated for South Lagoon salinities and water levels. Based on the results, options including a combination of works at Parnka channel and pumping appeared to yield the best results for further development of second-round scenarios.

Twenty scenarios were then developed for further investigation, including the effects of two pumping volumes, delays to the start of intervention and different levels of channel works at Parnka Point. Those with the higher level of pumping were not considered further due to practical problems with the implementation of pumping at that rate. All remaining scenarios had a positive impact compared with the baseline scenario, with substantially lower salinities in the South Lagoon. Scenarios which combined works at Parnka channel with pumping of the South Lagoon had the greatest effect on salinities and water levels in the South Lagoon. Similarly the combination of pumping and channel works showed longer-lasting and more profound effects on ecosystem states.

The effects of delaying the start of intervention with either the pumping or the Parnka channel works beginning later were explored with four scenarios. There was little difference amongst the scenarios, with delays appearing to have a relatively minor impact on the ecological state of the system as a whole. Despite this, we would recommend interventions in as short a time as feasible because there is a risk of additional species loss and ecological deterioration in the system if current conditions continue.

The ecological impact of the scale of works at Parnka channel was also investigated, with six scenarios. Decreasing the capacity of the Parnka channel (i.e. making it shallower) had a large impact on the ecological condition of the South Lagoon, increasing the likelihood that additional pumping would be required to maintain salinity levels essential to functional ecological communities. The effect of the scale of works affected both the time to recover initially and the return time for the appearance of degraded ecosystem states (i.e. 4-5 years). Pumping in isolation led to a lower level of recovery than when in conjunction with channel works and effects did not persist through the model run. The replacement of USED flows through Salt Creek had minor additional benefits.

None of the intervention scenarios investigated was an adequate replacement for a return to barrage flows. As such, the long-term strategy for the Coorong should be to secure water to enable barrage flows to recommence. For those intervention scenarios investigated, a strategy combining an increased capacity at Parnka channel and pumping in the South Lagoon yielded the best results and would be preferred, provided appropriate approvals were possible. A rapid response is also advisable. In addition, we also recommend that a monitoring program be undertaken in conjunction with any intervention to allow further refinement of the ecosystem model and confirmation of the benefits (and any disbenefits) of the intervention strategy.

1 Introduction

Reduced freshwater inflows through the Coorong barrages in the last 5 years have resulted in salinity in the South Lagoon reaching levels that have precluded the presence of a healthy ecosystem in the lagoon. In particular, salinity has exceeded the tolerance levels for survival and reproduction of most molluscs, crustacea, insect larvae, fish, and aquatic plants that comprise the food resource for the many species of waterbirds for which the Coorong is renowned. Preliminary analyses have demonstrated that a series of strategies comprising pumping water out of the South Lagoon and excavating the channel connecting the North and South Lagoons hold promise as means of reducing salinity in the South Lagoon to a acceptable level.

The South Australian Murray-Darling Basin Natural Resource Management Board (SA MDB NRM Board) has commissioned CSIRO and Flinders University to investigate further the viability of such management actions. A further strategy that is considered is the construction of a regulator across the channel connecting the two lagoons whose prime purpose is to maintain ecologically desirable water levels in the South Lagoon. This report presents the results of this analysis. It considers each of the strategies individually and in combination. It considers the relative benefits of variation in pumping rates, timing of pumping, degree and timing of excavation as well as the operation of a regulator. In the first instance, the benefits are defined in terms of impacts on salinity and water level regimes and these are then assessed in terms of their ecological desirability.

The task was divided into two phases. Initially, a large number of scenarios were investigated using a small range of targets for water levels and salinities. The most promising of these scenarios were then further investigated in a second round of analyses, where a detailed investigation of the ecological effects of each occurred, involving predicting the ecosystem states that would occur under each.

The report is organised as follows: The hydrodynamic model used to simulate how salinity and water level respond to management action is described first including an evaluation of model reliability. Next, we present conceptual models of the Coorong hydrodynamics and how these hydrodynamics are altered by hypothetical management action, followed by a description of how the model is applied to evaluate the scenarios. We then describe the ecosystem state model that has been developed for the Coorong, including the changes that were necessary to apply it to this analysis. Next, we outline the scenarios that have been investigated as a part of this analysis, and present the results of both the hydrodynamic modelling and the ecosystem state modelling. Finally, we compare the outcomes for various scenarios and draw conclusions on the relative benefits of each.

2 Hydrodynamic model

2.1 Model description

Here we provide a brief description of the hydrodynamic model applied to investigate the impacts of management intervention on water levels and salinities within the North and South Lagoons of the Coorong. The model structure, calibration and validation have been described in more detail by Webster (2006).

The base hydrodynamic model simulates water motions and water levels along the Coorong from the Mouth to the south end of the South Lagoon as these respond to the driving forces associated with water level variations in Encounter Bay (including tidal, weather band, and seasonal), the wind blowing over the water surface, barrage inflows, flows in Salt Creek (Upper Southeast Drainage), and evaporation from the water surface. The model domain extends from the Mouth to the south end of the South Lagoon (~5 km past Salt Creek) and is shown in Figure 2.1 with the major inflows. This domain is divided into 102 cells each 1 km long in which a momentum equation and an equation describing conservation of mass are solved. Major channel constrictions occur at the Mouth and in the channel connecting the two lagoons past Parnka channel (Parnka channel).

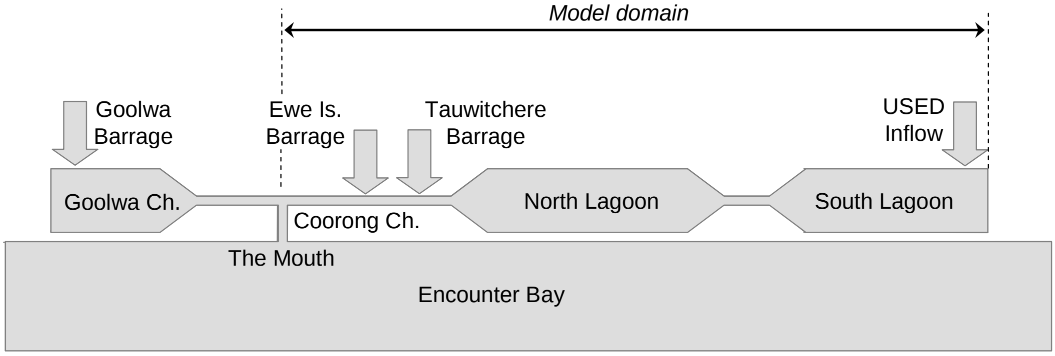

Figure 2.1. Coorong connectedness including major inflows and model domain.

The depth of the Mouth is highly dynamic, increasing during times of significant outflows and tending to infill when flows are small or zero. The last 6 years have experienced very small barrage flows, so it has been necessary to maintain the Mouth in an open condition by dredging. The Mouth depth in the model is adjusted every week to an elevation that allows the model to simulate correctly the tidal attenuation between tides measured at Victor Harbor and at Tauwitchere Barrage inside the Coorong. The channel connecting the two lagoons is highly complicated and convoluted. Rather than attempting to resolve the details of the channel shape, the model assumes that the section of severely constricted channel is 100 m wide and 1000 m long, dimensions approximately consistent with satellite images of the region. The optimal elevation of the Parnka channel was determined to be -0.19 m AHD through calibration.

The currents, water levels, and mixing regimes simulated by the basic hydrodynamic model were used to drive a module representing the salinity dynamics. Salinity was modelled in the 14 cells shown in Figure 2.2 which extend across groups of cells used in the base hydrodynamic model. The salinity module solves equations for the conservation of the mass of salt in each cell and requires the prescription of the salinity of sea water and of the Upper South East Drainage scheme (USED). The salinity of the sea in Encounter Bay was set at 36.7 g L^{-1} and that of the USED to be 16.1 g L^{-1}. The latter is the calculated flow-weighted average of salinity in the Salt Creek discharge between 2001 and 2008.

Figure 2.2. Map of the Coorong showing boundaries of cells used in the salinity module.

2.2 Calibration

Calibration of the model required the specification of four parameters. The first parameter is a factor applied to the wind stress estimated from wind measurements made at Meningie on the southeastern side of Lake Albert. This factor was adjusted so that the modelled water level spectra at Tauwitchere and at Sand Spit Point matched the measured spectra. The optimal factor is 1.6. Wind measurements at the Post Office in Meningie were made twice a day so the value of the factor (above

1.0) is due to a number of reasons including the inability of the wind record to account for gustiness and the separation and terrain differences between Meningie and the Coorong. The second parameter is an evaporation correction factor applied to measured evaporation rates from a Class A pan on Hindmarsh Island. The factor used in modelling has a value of 1.0. The third factor is the horizontal coefficient of mixing for the two lagoons (61 $m^2 s^{-1}$) and the fourth is the effective elevation of the bed of the Parnka channel (-0.19 m AHD). Parameters 2, 3, and 4 were adjusted to obtain the optimal fit in a least-squares sense between measured and modelled salinities in the North and South Lagoons and between measured and modelled water levels at Sand Spit Point in the South Lagoon. The calibration data used for salinity were obtained at 12 sites along both lagoons on 35 occasions by the SA EPA and DEH between 1997 and 2005. The calibration parameters all differ to some extent from the parameters reported by Webster (2006) in an earlier calibration of the model. The differences are due to several factors including a difference in how the effect of wind stress is represented in the model, the addition of two more years of calibration measurements, and differences in the assumed value of the salinities of the sea and of the USED. Overall, the amount of calibration required of the hydrodynamic model is minimal.

2.3 Model uncertainty and validity

All models are imperfect representations of reality. It is necessary to know how credible are hydrodynamic model simulations and particularly how well they are able to represent variation in the system in response to changes in the drivers. An analysis of hydrodynamic model capability for simulating salinity and water level is presented in Appendix A, but the main results are summarised here. In addition to the salinity data used for calibration, there have been additional data obtained by various researchers for the periods 1963-1967, 1976-1979, 1981-1985, 1993, and 2005-2007 that can be used to check the model response to conditions that are quite different from those encountered during the calibration period. In particular, barrage flows prior to 2002 tended to be substantially larger than those after this time.

When modelled and measured salinity values are plotted against one another for sections of each lagoon, the slope of the linear regression is ~0.9 for both the calibration and non-calibration periods. Average modelled salinity and measured salinity differ from one another by an average of 2 g L^{-1} in the North Lagoon and by less than 1 g L^{-1} in the South Lagoon. There is scatter around these regressions, which represents the limitation of the model's ability to simulate the instantaneous salinity at a particular sample collection site. The root mean square (RMS) differences between modelled and measured salinity are 16 and 11 g L^{-1} in the North and South Lagoons, respectively. We have attributed much of this scatter to the incongruity of comparing salinities in cells that are effectively averaged along 5-10 km along the Coorong and across its width of several kilometres with spot measurements that are mostly obtained at the shore. There are certain to be heterogeneities in the salinity structure that are introduced by local evaporation or water input or by swirls in the current that are not resolved by the model. Other errors in the model are certain to be introduced through inaccuracies in prescribing the wind stress, barrage inflows, bathymetry, evaporation rates, and by the neglect of groundwater inputs and losses that are unknown. Structural simplifications in the model will lead to further error including the simplified bathymetry and the assumption of constant mixing coefficients.

The model does well in simulating both the weather-band response (less than 10 day period) and the longer-term seasonal fluctuations in both lagoons. Due to limitations in the form of the meteorological data available, the response of the system to wind fluctuations having periods less than a day is not represented in the model, but for longer periods the measured and modelled level variances differ by 10% or less. Overall, the model does a credible job of simulating the response of the system in both salinity and in water level. The model is capable of explaining ~90% of salinity changes in the system in a statistically-averaged sense, but it should be recognised that an individual modelled salinity value is expected to differ from a measurement due to a number of reasons, but that the bias of the modelled salinity is close to zero.

2.4 The implementation of management scenarios

The management scenarios described in this report include pumping water out of the South Lagoon into the ocean, dredging Parnka channel, constructing a regulator structure across Parnka channel, and dredging the Murray Mouth. Here we describe the conceptual basis that underlies the response of the Coorong to each intervention and how the intervention is implemented in the model.

The Coorong is an inverse estuary; that is, its salinity tends to increase away from its Mouth. The conceptual model which underlies this estuary type is illustrated in Figure 2.3.

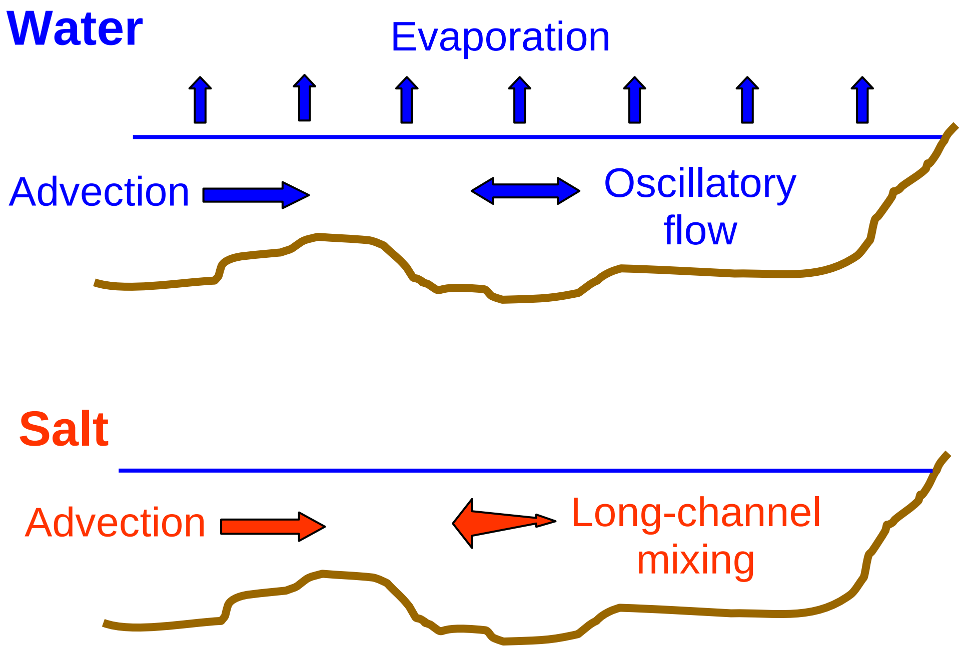

Figure 2.3. Conceptual model of an inverse estuary

Water is lost from along the length of the estuary through evaporation. To maintain the water level within the estuary, sea water flows in from the estuary mouth (Figure 2.3 top). The salt that is carried with the sea water tends to accumulate within the estuary. Back-and-forth water motions within the estuary arise due to sea-level variations including the tides as well as seiching due to varying winds blowing over the water surface. These motions serve to mix the salt accumulating within the estuary back towards its mouth. Over the long term, the inflow of salt associated with evaporated water loss balances the transport of salt in the opposite direction due to oscillatory mixing.

Superimposed on this model of long-term salt transport within the Coorong are seasonal variations associated with the annual cycle of sea level variation and of evaporation (and precipitation) rate. Figure 2.4 conceptualises the seasonal response of the Coorong. During winter, sea levels are highest resulting in the channel connecting the two lagoons (Parnka channel) to be relatively deep allowing for active exchange of water and salt between the lagoons. By early summer, sea levels drop so that the two lagoons become disconnected from one another. The two lagoons remain effectively disconnected through the summer. Through the summer, evaporation causes water levels in the South Lagoon to drop below those in the North Lagoon and salinities to rise as the salt in the lagoon is concentrated in a decreasing volume of water. During autumn, sea levels again rise causing water to flow back into the South Lagoon through Parnka channel.

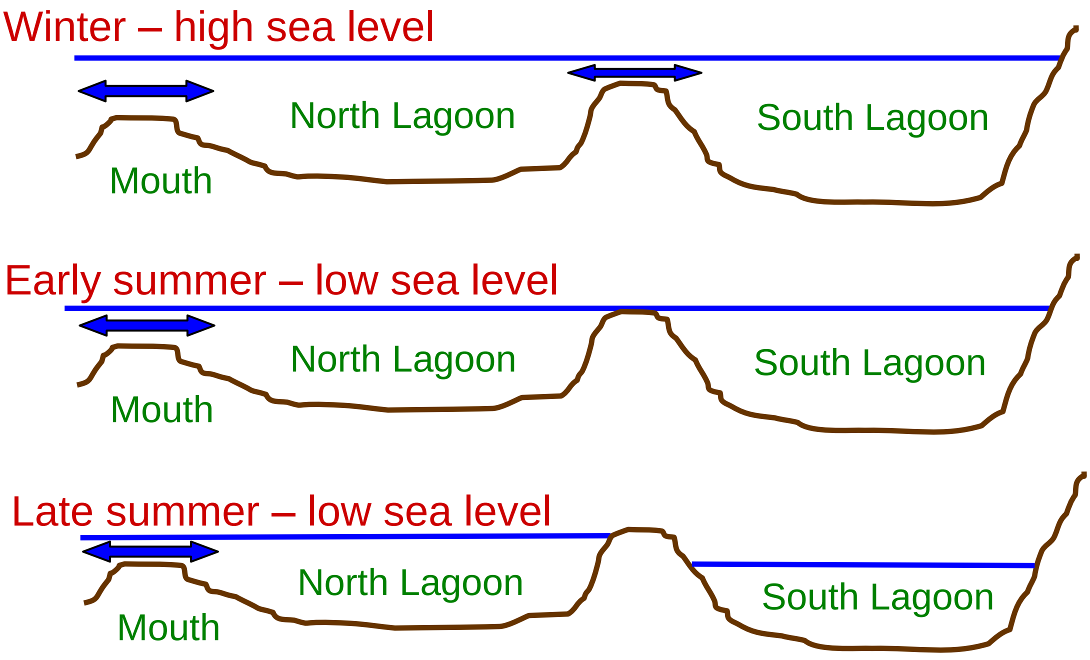

Figure 2.4. Conceptual model of seasonal cycle of water levels in the North and South Lagoons.

Figure 2.5 shows time series of modelled and measured salinity for salinity cells 4 and 11 located halfway along the North and South Lagoons, respectively. Besides demonstrating the model's ability to simulate salinity, the graph shows a number of features about the behaviour of salinity in both lagoons. Salinity is always substantially higher in the South Lagoon than in the North Lagoon. Barrage flows into the Coorong effectively terminated after 2002 and this is clearly reflected in higher salinity in both lagoons after this time. The seasonal cycle of salinity is pronounced in the South Lagoon, but the North Lagoon also has a weaker salinity cycle post 2002. Maximum salinity in the North Lagoon tends to occur in early summer presumably as a consequence of outflows from the South Lagoon as sea levels drop at this time of the year, whereas maximum salinity in the South Lagoon occurs a few months later.

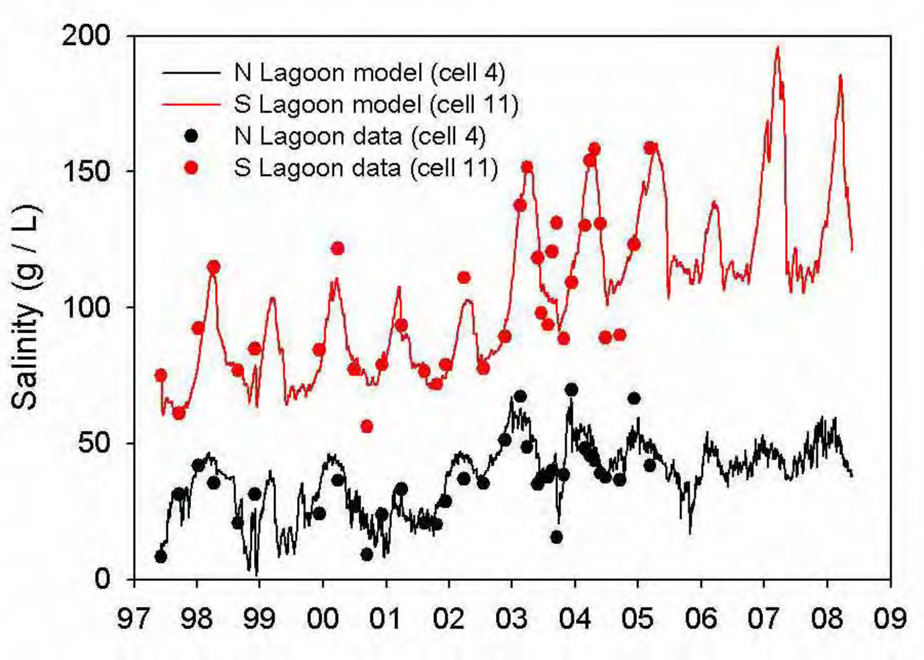

Figure 2.5. Time series of modelled salinity in North Lagoon (salinity cell 4) and in South Lagoon (salinity cell 14). Also shown is measured salinity in each cell.

Figure 2.6 shows measured water levels for Tauwitchere in the North Lagoon and for Sand Spit Point in the South Lagoon. These data have been low-pass filtered to remove fluctuations having periods shorter than 2.5 days. The record for Tauwitchere would be similar to that in Encounter Bay. A seasonal cycle of sea level variation of ~0.4 m range is evident in this record. Water levels in the South Lagoon follow those in the North Lagoon through most of the year, but the divergence in levels between the two lagoons can be clearly seen through summer as South Lagoon levels continue to drop due to evaporation. Summer of 2006 shows a relatively weak salinity maximum compared to the year before and the year after (Figure 2.5). The reason for this variation becomes apparent upon inspection of the water level record for Tauwitchere. Water levels at Tauwitchere did not drop as far nor for so long in summer of 2006 as they did in the preceding and following years. Consequently, we speculate that the South Lagoon was disconnected from the North Lagoon for a shorter time in summer 2006. Therefore, evaporation was less able to increase salt concentrations during this summer. Also, salt exchange between the two lagoons would have been maintained for a greater proportion of summer 2006.

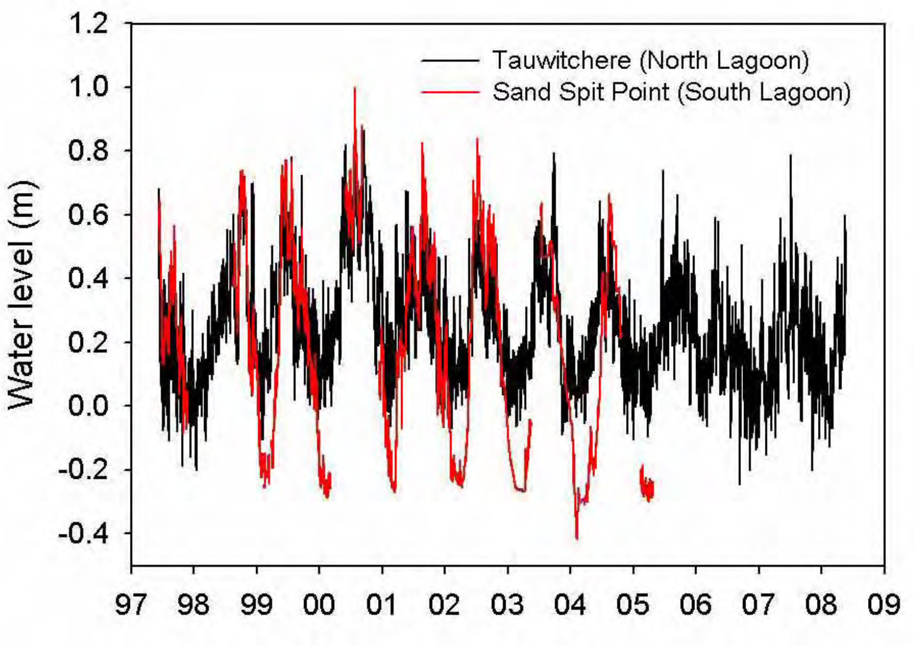

Figure 2.6. Time series of measured water levels at Tauwitchere (North Lagoon) and at Sand Spit Point (South Lagoon).

Pumping the South Lagoon

This intervention involves pumping water from the centre of the South Lagoon and discharging this water into Encounter Bay. In the model, this intervention is represented as the removal of water from hydrodynamic cell 76 which is approximately to the west of Policeman's Point, halfway along the South Lagoon. Two pumping rates were considered initially, 150 and 450 ML day^{-1}, but the 450 ML day^{-1} discharge was subsequently considered to pose too high a risk to the receiving marine environment. In its model implementation, we control both the start time of pumping and its duration. Also, there is the capability to implement a pumping regime that is seasonally dependent.

In conceptual terms, this intervention represents the removal of highly saline water from the South Lagoon which is replaced by an equivalent flow of sea water through the Mouth of the Coorong. The net amount of salt lost from the system is the pumping rate times the difference between the salinity of the pumped water and that of sea water. Thus the efficiency of salt removal depends on the season. Salinity in winter in the South Lagoon is ~3 times sea water, whereas in summer it can be as high as 5 times sea water. Of course, once the salinity in the South Lagoon starts to reduce after the implementation of the strategy, the efficiency of the salt removal will also diminish.

Pumping during winter when the lagoons are relatively well-connected will result in minimal change in water level in the South Lagoon, but summertime pumping will cause water levels to drop further than they would through evaporation alone. Also, summertime pumping will not reduce the salinity in the South Lagoon during this season as the replacement inflow does not occur until autumn when sea levels rise. In fact lowering water levels through pumping would tend to increase the degree of salt concentration in the South Lagoon during summer.

The regulator across Parnka channel

Germination of *Ruppia tuberosa* requires that water levels be maintained sufficiently in the South Lagoon through spring (Brock, 1979). A regulator constructed across Parnka channel could help accomplish this goal. In the model, a regulator is implemented as a dam across the channel between salinity cells 7 and 8. In geographic terms, this structure would be placed at the location of the Needles, which is near the northwestern end of Parnka channel. The regulator can stop flows between the lagoons if the water level in either is below 0.5 m AHD. If desired the dam can be made transparent to flow exchanges. If water levels on either side of the regulator are above 0.5 m, flow occurs along Parnka channel with the model treating the regulator as a sharp-crested weir.

A possible operation strategy for the regulator might be as follows: During winter, the regulator would be open to allow water exchange between the two lagoons. As the water level drops through spring, the regulator would be closed to prevent water draining out of the South Lagoon. During summer, some water level drop would occur in the South Lagoon due to evaporation, but water levels would be higher through summer than if there were no regulator present. In autumn when sea levels rose, the regulator would again be opened to allow flow exchange between the two lagoons in both directions.

Excavating Parnka channel and dredging the Mouth

Deepening and widening Parnka channel in its most constricted sections would allow for enhanced flow exchange between the two lagoons when the sea levels are relatively high in the winter. If excavation were deep enough, then exchange could occur in the summer months also. Further, this would cause water levels in the South Lagoon to follow those in the North Lagoon. Water lost through evaporation would be replaced continuously by flow through Parnka channel. In the model, Parnka channel is represented by a rectangular channel that has a bottom elevation of -0.19 m AHD and a width of 100 m. Modelling the impact of channel excavations would involve prescribing a greater width and/or a lower channel elevation.

Deepening the Murray Mouth beyond its present dredged elevation of a nominal -2.0 m AHD would increase its cross-sectional area and increase the transmissivity of this channel section for sea level fluctuations particularly those having periods of ten days or less. Fluctuations in water level at the northern end of the Coorong are important drivers of the oscillatory water motions within its two lagoons. Thus, an enhancement in these oscillatory motions through Mouth dredging would serve to increase the effectiveness of long-channel mixing for removing salt from the Coorong and so tend to reduce its salinity.

2.5 Model application

The three management strategies above, namely pumping the South Lagoon, the construction of a regulator across Parnka channel, and excavating the Mouth or Parnka channel, are implemented in the model both individually and in combination. The model also has the facility to stage particular strategies so that, for example, pumping could be commenced prior to channel excavation.

Model runs commence on 8 March 2005 with the initial salinity in each cell set equal to salinity measured along the Coorong on that date. The model is forced with measured wind speeds, sea levels, evaporation and precipitation up to 30 June 2008. The USED inflows are the average of measured flows on each day of the year between 2001 and 2008. Thereafter, the model is run for a further 8 years using two blocks of forcing data each 4 years long. Each block of forcing data is comprised of measured wind speeds, sea levels, evaporation and precipitation between 1 July 2004 and 30 June 2008 as well as USED inflows defined for each day of the year as for the initial model simulation period 2005-2008. Note that a consequence of defining forcing in this way is that the salinity and water level responses will have structures that appear to repeat themselves several times during the simulation period. The scenarios assume that there is no flow through the barrages over the length of the simulations and thus represent a continuation of the present dry conditions which have led to the extremely high salinity in the South Lagoon.

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Figure 2.7 shows time series of average salinity in the North and South Lagoons through the simulation period. Results are shown for the baseline scenario (no intervention) and for Scenario 006 which represents pumping at 150 ML day^{-1} for 360 days per year starting on 1 June 2009. The impact of the pumping can be clearly seen, but it takes ~3 years for the salinities in both lagoons to settle down to a new equilibrium after pumping commenced. Time series such as these were used as a basis for the analyses of all the scenarios.

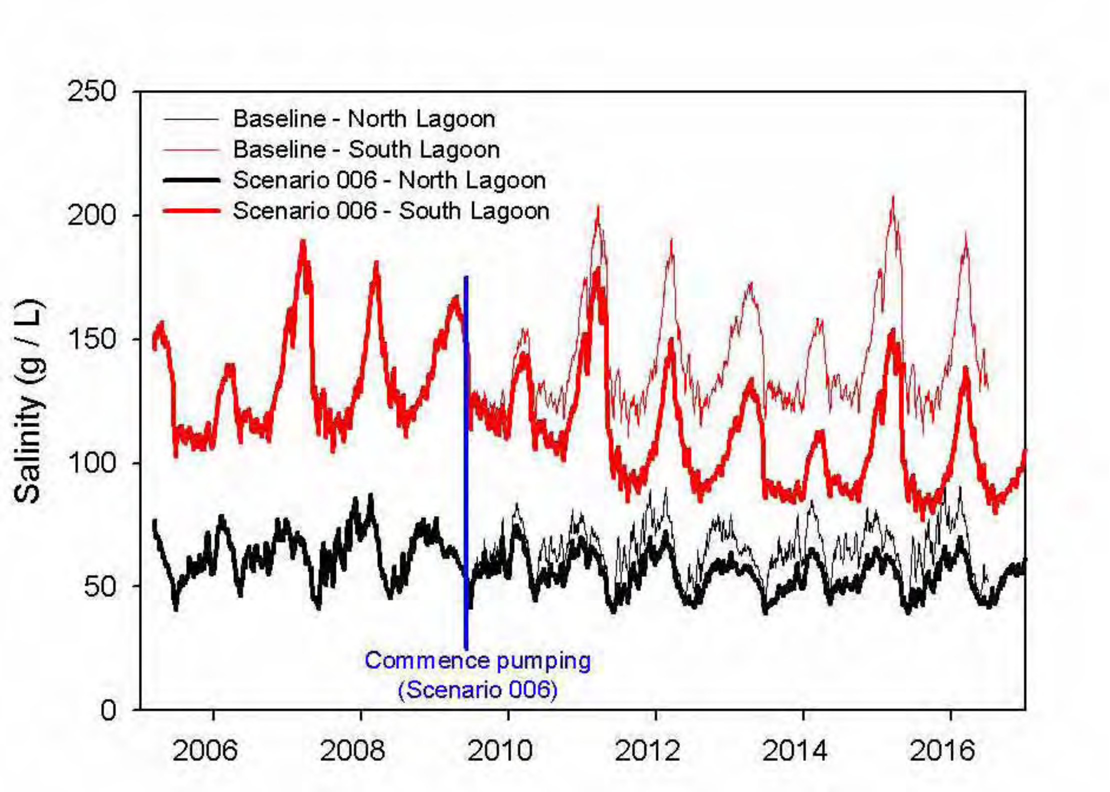


Figure 2.7. Time series of modelled average salinity in the North and South Lagoon. Results are shown for the baseline scenario and for Scenario 006.

3 Ecosystem states model

3.1 Developing an ecosystem states model for the Coorong

Assessing ecological condition at an ecosystem scale is a difficult task. Typically, there are some aspects of an ecosystem that are well-studied and understood (e.g. birds and fish) and others that are less well understood (e.g. groundwater inputs and microbes). In order to assess ecological condition in the Coorong, we developed an ecosystem response model based on what we term "ecosystem states".

Unlike the hydrodynamic model described above, the ecosystem states model is not based on a deterministic understanding of how ecosystems behave. That is, it is not based on equations describing the interactions between each species, their environments, and their competitors and predators. Instead, it is a statistical model, where existing data for the region has been statistically analysed and modelled to identify relationships between the biota that occur within the system at any one point in time and the environmental conditions under which these biota occur.

The ecosystem state model developed for the Coorong under CLLAMMecology identified eight distinct ecosystem states. These could be divided into two 'basins', a marine basin and a hypersaline basin that are most often located within the North and South Lagoons respectively. Within each, there were four states, ranging from a healthy state to a degraded state. The biota and conditions characterizing each of these states are given in Appendix B. Additional information regarding the development and testing of the model is given in Lester and Fairweather (in press a, b), and will become available on the CSIRO website over time.

One of the key driving parameters for the ecosystem model described in Appendix B was the occurrence of freshwater flows over the barrages. This meant that only limited changes in ecological conditions could be modelled unless such flows were present. Given that the scenarios investigated here are designed to be alternatives to having freshwater flows in the short term, we developed a new set of models to describe the behaviour of the system without reference to the flows over the barrages.

In order to do this, we maintained the eight ecosystem states identified for the Coorong, and related them to the salinities, water levels, depths and meteorological conditions in the Coorong. The best results were obtained when the two basins were modelled separately. The model for the marine basin (assumed to occur in the North Lagoon under the current conditions) is shown in Figure 3.1. It describes the ecosystem state of the Coorong relative to the water level, the previous year's water level and depth from two years ago. This model correctly classified 72% of the training data set used and 70% of the test data set, indicating that it discriminated well between the marine ecosystem states.

The hypersaline basin model (used to describe current South Lagoon states) identified a combination of average water level, water level from the previous year, the range in water levels over the year (i.e. change between the maximum and minimum water level over the year) and the maximum salinity for the year as driving the ecosystem state of the basin (Figure 3.2). The hypersaline basin model correctly classified 87% of the training data set and 80% of the test data set under cross-validation. This is a high degree of predictive success given the variability inherent in ecological data sets.

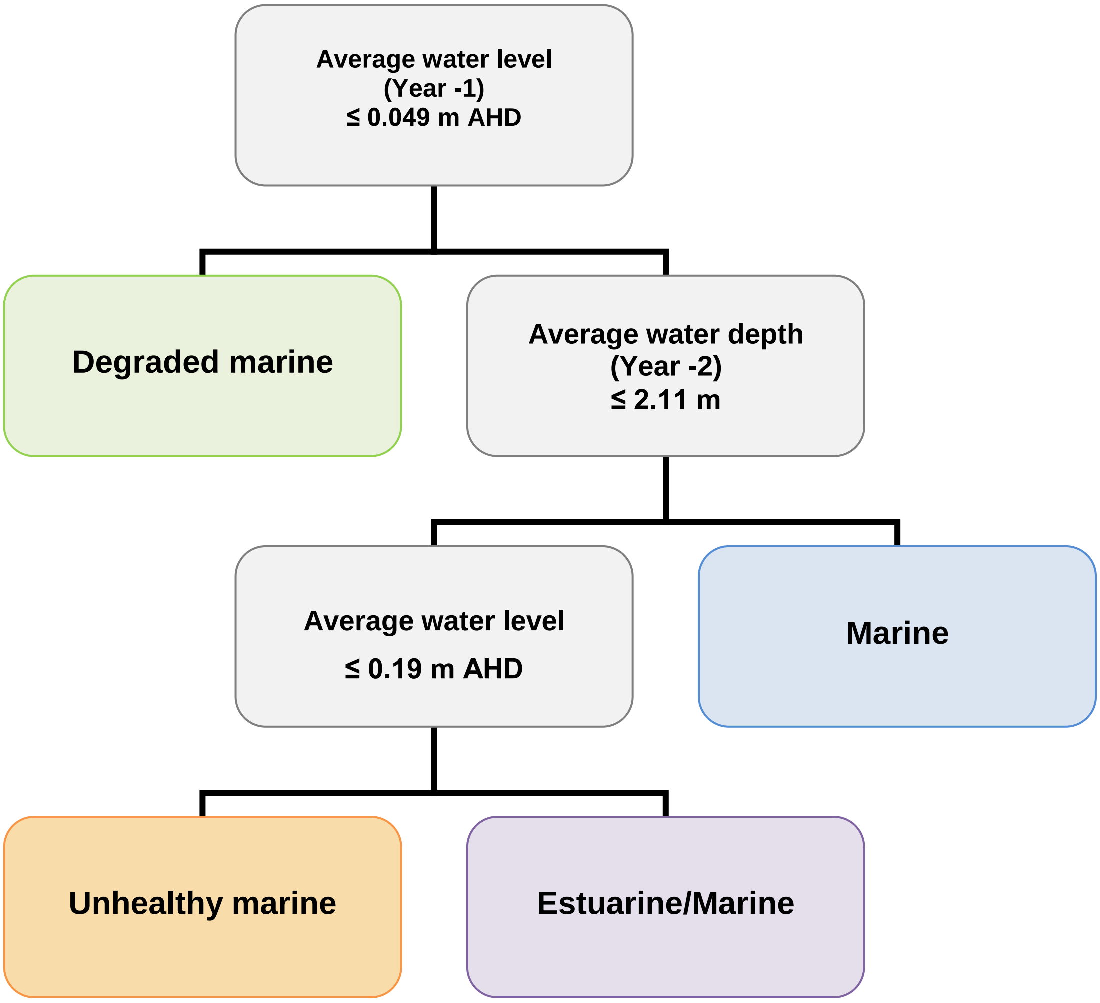


Figure 3.1 Marine (or northern) basin model for the Coorong excluding flow parameters as predictive variables.

All of the parameters identified as driving the ecosystem states of the Coorong can be calculated from output from the hydrodynamic model. The hydrodynamic model simulates hourly water levels and salinities along the length of the Coorong for each scenario. These data are then used to calculate the average water levels, depths and salinities as required by the ecosystem response models (i.e. Figure 3.1 and 3.2). By using these parameters as input for the ecosystem response model, we are able to predict the mixture of ecosystem states present in the Coorong each year for the duration of the model run at each of the 14 salinity cells, which we have referred to as ‘sites’.

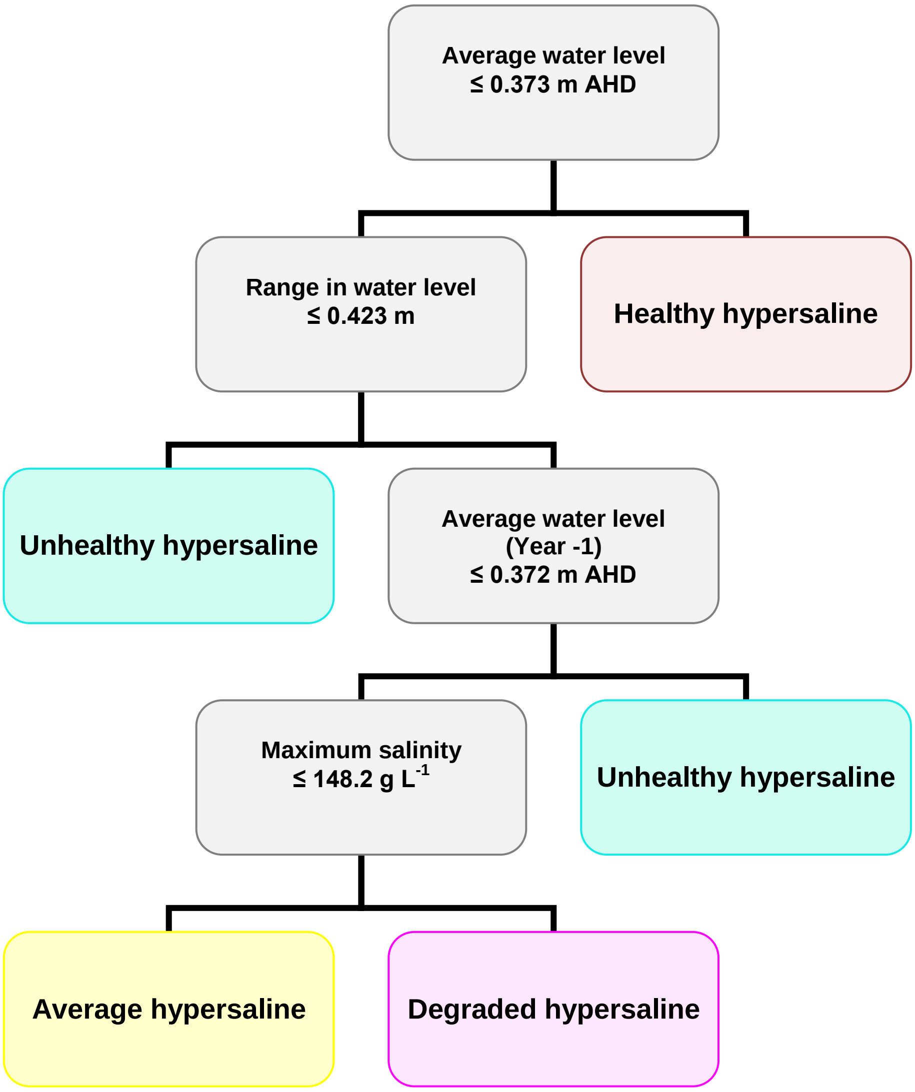


Figure 3.2 Hypersaline (southern) basin model for the Coorong excluding flow parameters as predictive variables.

The major area of uncertainty inherent in the ecosystem response model is in its ability to correctly predict the recovery of the system. The model was developed using data from 1999 to 2007, which was a particularly dry period, and one during which the ecological condition of the Coorong was deteriorating. Therefore, the model behaves as though the trajectory of decline is the same as the trajectory of recovery and that both occur over the same length of time. This is unlikely to be true, and represents a major uncertainty of the model, but until data describing the recovery of the system are available, there is no way to quantify the scale of the uncertainty. Should an intervention occur in the South Lagoon in line with one of the scenarios investigated here, any data collected during and after the intervention could be used to refine the model to address this uncertainty about recovery trajectories.

3.2 Defining criteria for ecological assessment

The marine and hypersaline basin models of ecosystem states were used to identify parameters that would provide guidance about the ecological condition of the southern North Lagoon and the South Lagoon. These were used to assess the scenarios investigated in the first round of scenario analyses. Maximum salinity in the South Lagoon, and average water levels in both lagoons, were selected as being most likely to identify scenarios that would have the greatest impact on the ecological condition of the Coorong.

In addition to these targets identified from the ecosystem state models, expert opinion was also sought from Associate Professor David Paton and Dr Mike Geddes of the University of Adelaide. This ensured that any ecological targets specific to the key species in the Coorong were identified, and provided a check to the parameters suggested by the ecosystem state models. The targets for maximum salinity in the South Lagoon were set at 100 g L^{-1} for summer and 60 g L^{-1} for winter. We also included the minimum water levels reached for the South Lagoon and minimum salinity for both lagoons in the assessment of the ecological desirability of each scenario.

For the second round of analyses, the initial set of parameters was again used to assess each scenario (excluding those with the high rate of pumping). This round also included a detailed assessment of the ecological impact of each scenario, by identifying the ecosystem states present over time, using the ecosystem state models described above. This allowed the interaction between the various parameters and the non-linearities inherent in the ecosystem's response to be fully addressed.

4 Scenarios

4.1 First round

The first round of scenario analyses included a broad range of 87 scenarios that were combinations of the interventions described above: pumping from the South Lagoon at one of two rates, differences in the duration and start date of pumping, works at Parnka channel to one of two depths, increased dredging at the Murray Mouth and the use of a regulator at Parnka Point for one of two lengths of time per year.

A baseline scenario (Scenario 000) was also investigated as the ‘no intervention’ case. The remaining 86 scenarios looked at each possible intervention in isolation, and in conjunction with other possible strategies to identify the potential effects likely from each. This round of analyses was not intended to be exhaustive, but to provide an envelope of likely responses within the system, and help define a more focused set of effective intervention strategies.

Within this document, we provide a brief summary of the results of these remaining 86 scenarios. Descriptions of each scenario and the water levels and salinities for each (in isolation and compared with the baseline scenario) are available on request.

Each of the 86 scenarios was investigated with respect to the physico-chemical parameters outlined above. Scenarios were scored based on the values for each of maximum South Lagoon salinity, minimum South Lagoon water level, minimum southern North Lagoon salinity and maximum southern North Lagoon water level. Based on these, the scenarios that involved combinations of pumping from the South Lagoon and works at Parnka channel were clearly the most-promising. Figure 4.1 shows South Lagoon salinities for a representative selection of scenarios to illustrate this point, with S40 having a much smaller interquartile range than the other possibilities. There was less difference amongst scenarios with respect to changes in South Lagoon water levels, with several options having similar effects in raising minimum water levels (Figure 4.2).

Changes to the southern North Lagoon water levels and salinities were not of an order to eliminate any possibilities based on the effect of that scenario on the North Lagoon. Differences in water levels were small and maximum salinities barely increased for any scenarios. Minimum salinities did drop for a number of scenarios, but were always within a hypersaline range.

In order to select the most-promising scenarios with which to move to the more detailed analysis, we plotted the sum of the deviations in South Lagoon salinity from the baseline scenario against the sum of the deviations in South Lagoon water levels (Figure 4.3). Given that the aim of any intervention would be to decrease South Lagoon salinities and to increase South Lagoon water levels (if possible), the scenarios that showed the most promise would have the most negative sum of deviations relative to the baseline scenario for salinity, and the greatest positive sum of deviations for water level. This would place the scenario in the bottom right-hand quadrant of Figure 4.3. Scenarios in that region were all combinations of pumping the South Lagoon and works at Parnka channel, with a range of rates, commencement dates for pumping and scale of channel works.

Based on these results, options including a combination of works at Parnka channel and pumping appeared to yield the best results. This led to the development of the second round of scenarios.

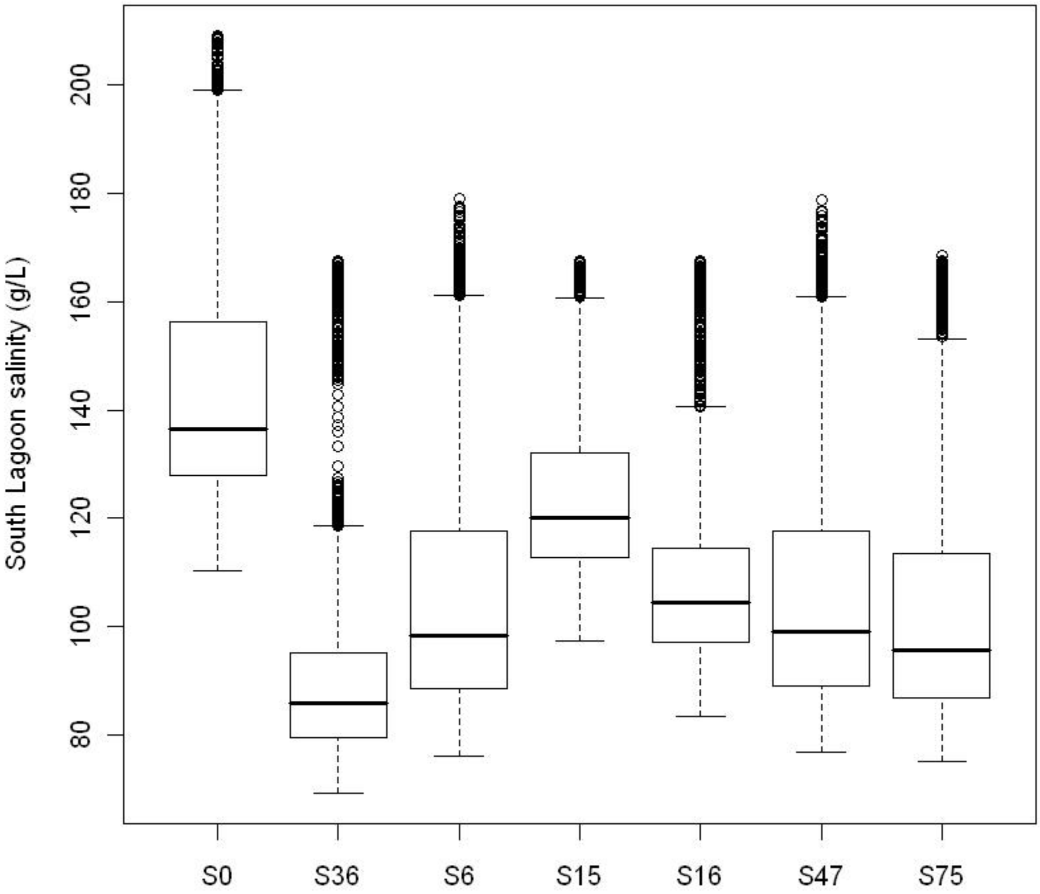


Figure 4.1. Boxplots of South Lagoon salinities for a representative selection of scenarios

S0 is the baseline scenario. S36 involves works at Parnka channel to a depth of -0.8 m AHD with 360 days of pumping annually at 150 ML day^{-1} commencing in autumn. S6 involves pumping for 360 days annually at 150 ML day^{-1} beginning in autumn. S15 includes works at Parnka channel to a depth of -0.4 m AHD, with S16 the corresponding scenario to a depth of -0.8 m AHD. S47 investigates the use of a regulator from September to November annually in conjunction with summer pumping for 360 days at 150 ML day^{-1}. Finally, S75 involves doubling the Murray Mouth transmissivity and summer pumping for 360 days at 150 ML day^{-1}.

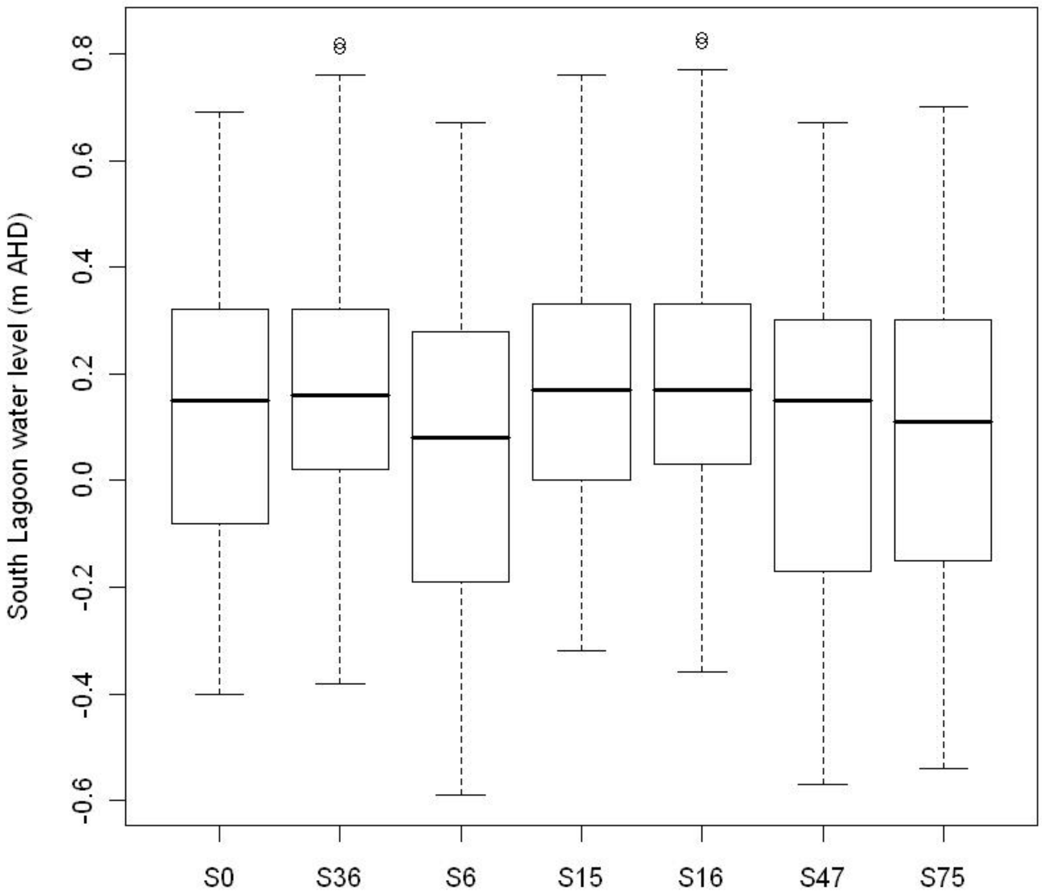


Figure 4.2. Boxplots of South Lagoon salinities for a representative selection of scenarios. See Figure 4.1 for explanation of each scenario.

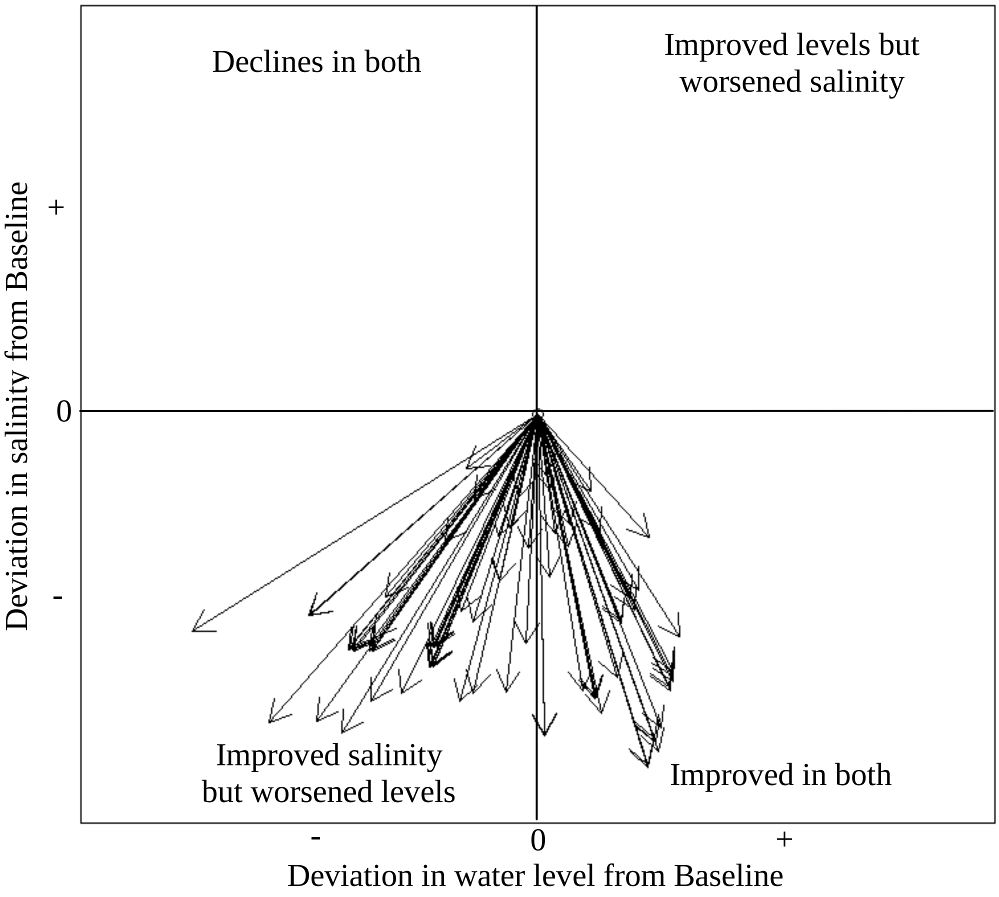


Figure 4.3. Comparison of the effect of each first-round scenario relative to the Baseline for South Lagoon salinity and water levels

This figure shows a vector for each scenario indicating the magnitude and direction of change from the Baseline scenario with respect to water levels and salinity. Length of each vector is proportional to the strength of the deviation from the Baseline condition (as shown by the 0,0 origin). Vectors in the bottom-right quadrant indicate an improvement for both variables (i.e. higher water levels and lower salinities).

4.2 Second round

After consideration of the first 87 scenarios, we developed a further twenty scenarios for further investigation. This second round included simulating the effects of the two pumping volumes, delays to the start of intervention (including the earliest likely starting times identified by the SA MDB NRM Board and delaying one or more action for a 12 month period), and different levels of channel works at Parnka Point. The effects of a return to a condition of significant barrage flows were also investigated. Following the compilation of the list, the higher pumping volume (450 ML day^{-1}) was identified as likely to cause problems to the receiving marine environment, so it is not reported further here. The remaining thirteen scenarios are described in Table 4.1.

Output for each of these 13 scenarios is given within this document below.

Scenario name*	Pumping volume (ML day^{-1})	Pumping duration	Season to start pumping	PC$^{\#}$ depth (m AHD)	PC works completed	Other actions
302	150	360 days 3 years	Winter 2009	-0.8	Winter 2009	-
304	150	360 days 3 years	Spring 2009	-0.8	Winter 2009	-
306	150	360 days 3 years	Winter 2009	-0.8	Autumn 2010	-
308	150	360 days 3 years	Spring 2009	-0.8	Autumn 2010	-
310	150	360 days 3 years	Winter 2009	-0.4	Winter 2009	-
311	150	360 days 3 years	Winter 2009	-0.4	Autumn 2010	-
312	150	360 days 3 years	Spring 2009	-0.4	Autumn 2010	-
313	150	360 days 3 years	Spring 2009	-0.8	Winter 2009	150ML day^{-1} replacement USED flow
315	150	360 days 3 years	Winter 2009	-	-	-
317	150	360 days 3 years	Spring 2009	-	-	-
318	-	-	-	-	-	1997 barrage flows returned (continuous)
319	-	-	-	-0.8	-	1997 barrage flows returned (continuous)
320	-	-	-	-	-	1997 barrage flows returned (one year only - 2009)

Table 4.1. Second round of scenarios investigated

* Note that the scenarios are not numbered consecutively due to the exclusion of those with the higher level of pumping. $^{\#}$PC is an abbreviation of Parnka channel. - indicates that no action was included in that scenario. Continuous flows repeat the 1997 barrage flow for each year in the model run after 2009.

5 Salinity and water level results

The scenarios varied in their effect on water levels and salinities in both the North and South Lagoons of the Coorong. In the outputs given below, we have included all water levels and salinities from the beginning of 2009 onwards. This includes some (variable) length of time before the intervention has occurred or taken full effect. The rationale for this was to include an indication of the cost of delaying the beginning of intervention, and the length of time before the full effect of intervention was felt.

For the South Lagoon, with the exception of those scenarios investigating a return to flow conditions, no scenarios were successful in achieving a maximum summer salinity of 100 g L^{-1} and a maximum winter salinity of 60 g L^{-1} (Figure 5.1). In fact, no interventions other than a return to flows ever fell below the target of 60 g L^{-1}, let alone as a maximum. There was, however, a substantial decrease in median salinity as a result of all interventions. There was very little impact on North Lagoon

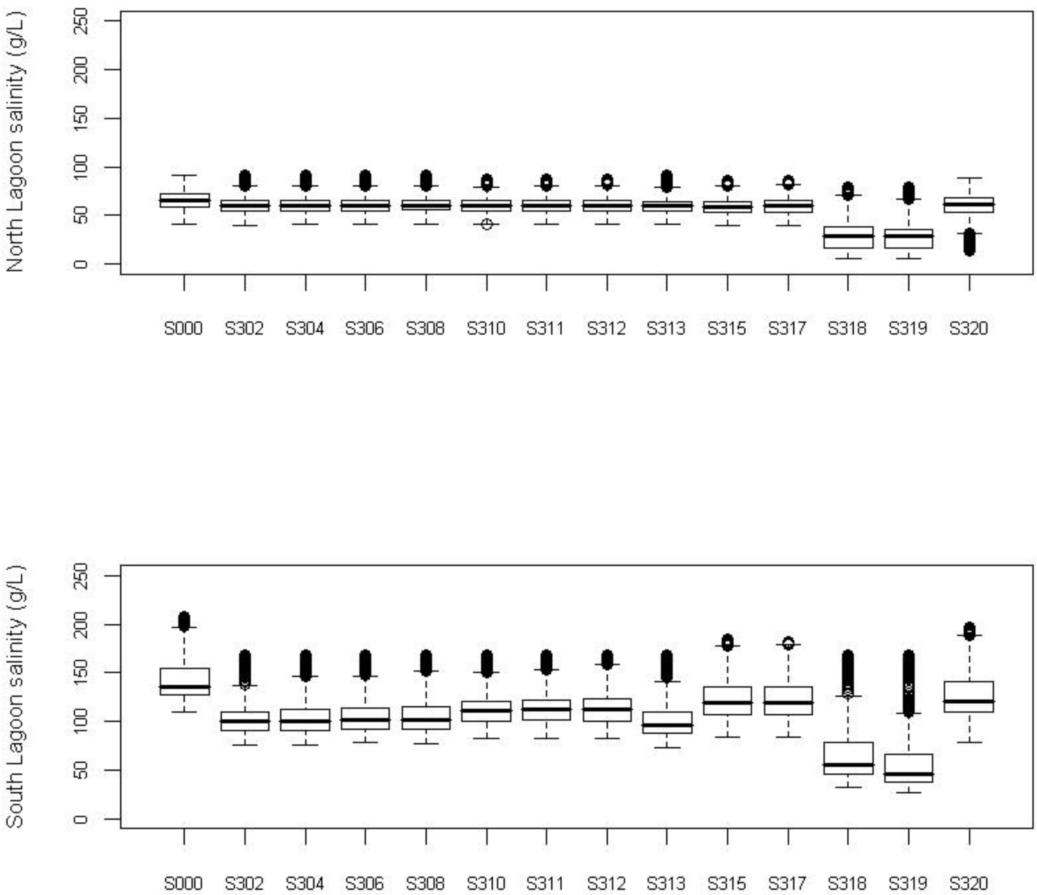


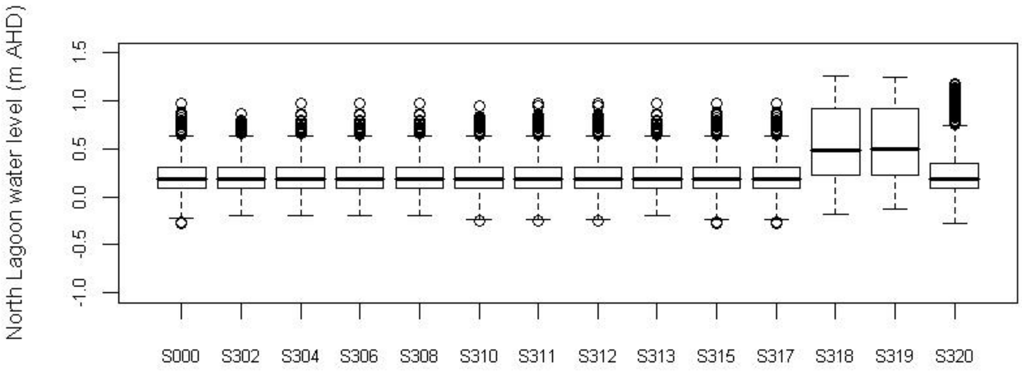
Figure 5.1. Boxplots of North and South Lagoon salinities for second round scenarios. See Table 1 for a description of each scenario.

salinities as a result of any of the scenarios, again with the exception of those investigating a return to continuous flow conditions (Figure 5.1).

As for North Lagoon salinities, there was very little difference in North Lagoon water levels as a result of any intervention (Figure 5.2). Those scenarios involving a return to continuous flows had higher median water levels and a greater range of water levels, but the various scenarios were remarkably similar.

Median South Lagoon water levels were similar for all scenarios, and also similar to the baseline (Figure 5.2). The minimum South Lagoon water levels did increase under all scenarios, but only those including flows over the barrages were substantially higher than the baseline. The interventions with the lowest South Lagoon water levels were those involving pumping without concurrent works at Parnka channel.

Based on these results, there is little hydrodynamic difference between the 10 scenarios investigated excluding a return to flows. This provides little guidance as to which strategies are most likely to maximise the ecological benefits of any intervention.



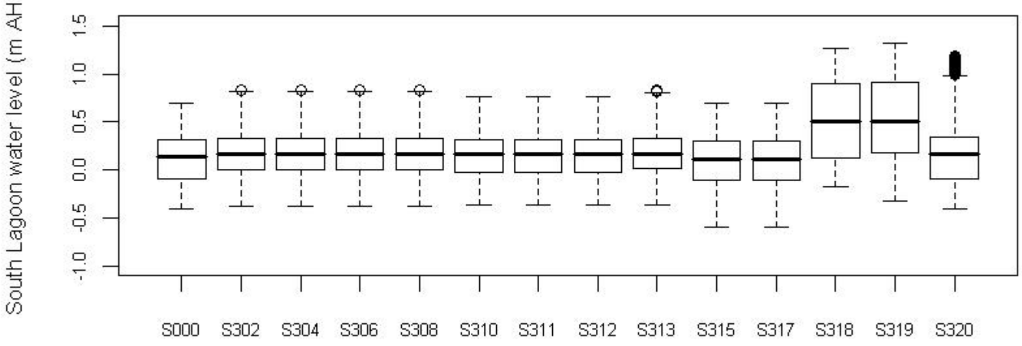


Figure 5.2. Boxplots of North and South Lagoon water levels for second round scenarios. See Table 1 for a description of each scenario.

The easiest way to summaries the effects of all the scenarios is to look at the changes in each relative to the baseline conditions, as was done for the original 87 scenarios. Water levels and salinities are the two drivers of ecological conditions (in various forms) for both the North and South Lagoons. Identifying which scenarios result in the most change from the Baseline condition can assist in the decision-making process. This also acts as a summary of all 14 scenarios (i.e. the Baseline and 13 others). Figure 5.3 shows the changes in terms of South Lagoon water levels and salinity.

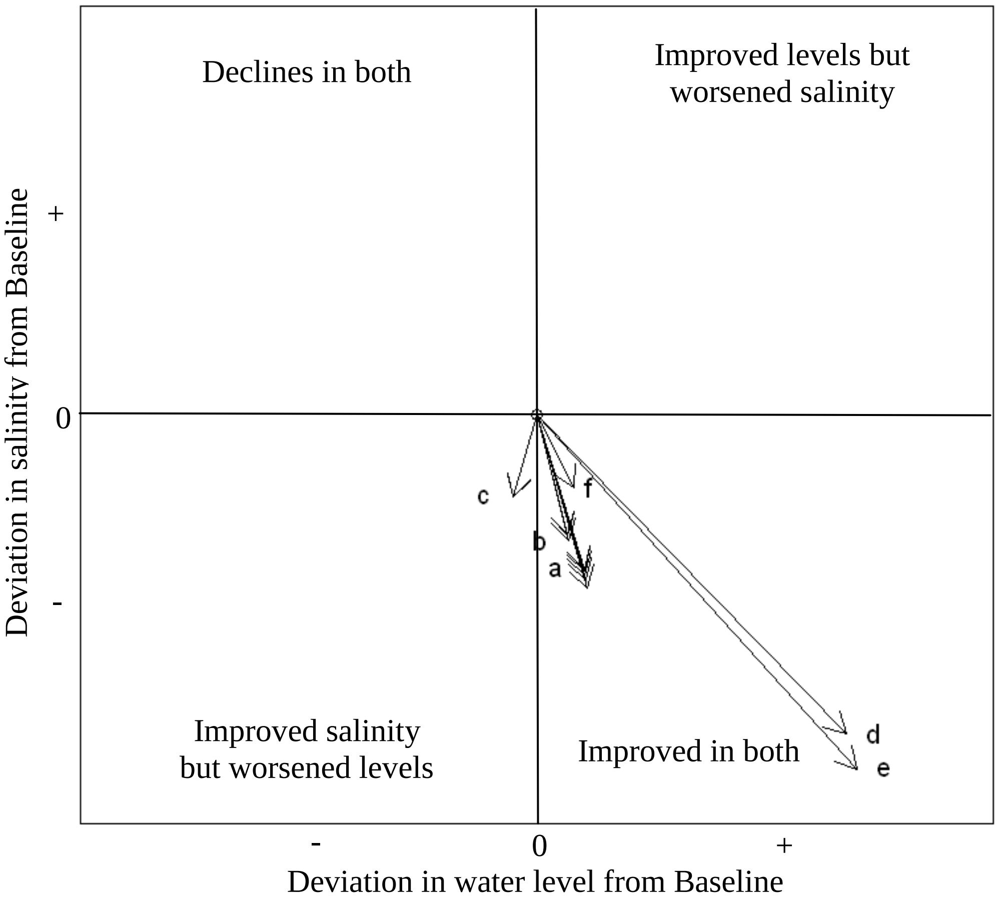


Figure 5.3. Comparison of the effect of each scenario relative to the Baseline for South Lagoon salinity and water levels

This figure shows a vector for each scenario indicating the magnitude and direction of change from the Baseline scenario with respect to water levels and salinity. Length of each vector is proportional to the strength of the deviation from the Baseline condition (as shown by the 0,0 origin). Vectors in the bottom-right quadrant indicate an improvement for both variables (i.e. higher water levels and lower salinities). 'a' indicates the vectors for Scenarios 302, 304, 306, 308 and 313. 'b' indicates the vectors for Scenarios 310, 311 and 312. 'c' indicates the vectors for Scenarios 315 and 317. 'd' is Scenario 318. 'e' is Scenario 319. 'f' is Scenario 320.

There are several distinct groups of scenarios. The scenarios that show the most deviation from the Baseline, and an improvement for both for South Lagoon water levels and salinities, were those that involve a return to flow conditions (318 and 319). Returning flows for a single year with no other interventions had the lowest level of improvement for both water levels and salinities (Scenario 320). Scenarios 315 and 317 had the next smallest impact on salinity and actually had lower water levels than the Baseline (i.e. declines in both water level and salinity). This is unsurprising, given that these were the two scenarios investigating the effects of pumping alone. The last two groups of vectors had very similar impacts on water levels and salinities in the South Lagoon (Scenarios 302, 304, 306, 308, 310, 311, 312 and 313). These scenarios all involved a combination of works at Parnka channel and pumping. The larger scale of works had a greater impact on both variables. No effect due to delays in pumping or channel works was apparent in this figure.

Figure 5.4 shows the corresponding comparison for the North Lagoon. Here, the only scenarios to have an appreciable positive impact on either water levels or salinities were those involving a return to flows (Scenarios 318, 319 and 320).

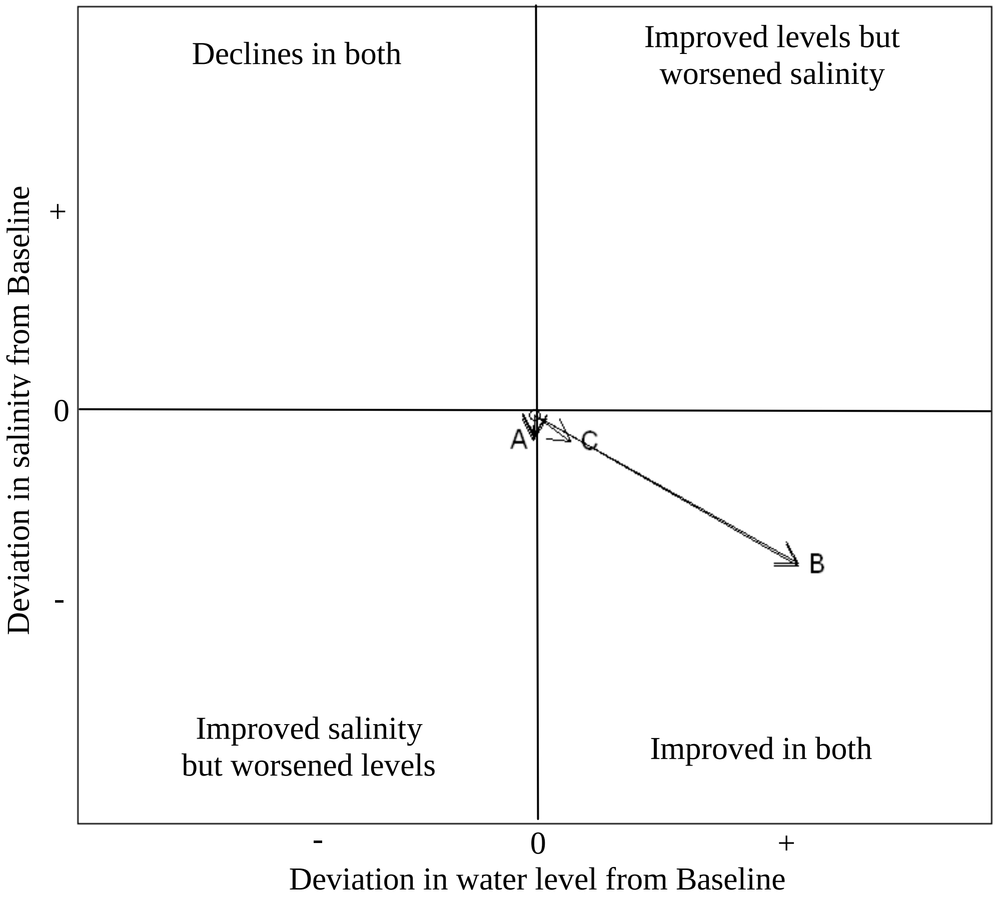


Figure 5.4. Comparison of the effect of each scenario relative to the Baseline for North Lagoon salinity and water levels

This figure shows a vector for each scenario indicating the magnitude and direction of change from the Baseline scenario with respect to water levels and salinity. Vectors in the bottom-right quadrant indicate an improvement for both variables (i.e. higher water levels and lower salinities). 'A' indicates the vectors for Scenarios 302, 304, 306, 308, 310, 311, 312, 313, 315 and 317 'B' indicates the vectors for Scenarios 318, 319 'C' indicates the vector for Scenario 320.

6 Ecological impacts

This section evaluates each scenario relative to the baseline scenario and then relative to the other options explored during the second round of scenarios. These comparisons have been based on the ecological response models developed, and the physico-chemical targets set by expert opinion. For each of the second-round scenario, a brief description and individual graphical output can be found in Appendix C. Results will be presented from 2008 to 2016 to give the initial condition and then capture the effect of the intervention.

6.1 Ecological impacts compared to baseline scenario

All scenarios investigated had a positive impact compared with the baseline scenario. All resulted in substantially lower salinities than those observed under the baseline conditions in the South Lagoon. Those scenarios that combined works at Parnka channel and pumping of the South Lagoon had the greatest effect on salinities.

Water levels were adversely affected in the South Lagoon by scenarios involving pumping only. There were observed declines during the years in which pumping occurred, but no additional change after the cessation of the intervention. Where pumping was combined with works at Parnka channel, the effect on water levels was generally positive, with increased connectivity resulting in evaporative losses over summer being replaced by water from the North Lagoon in contract to when pumping was undertaken on its own, or under baseline conditions. There were some short periods of lower water levels than the baseline for a number of the scenarios investigated (e.g. Scenarios 302, 304 and 306).

The ecological effects arising from these improvements in water levels and salinities were obvious in all scenarios. Again consistent with water quality results, scenarios involving pumping only showed the smallest and most transient improvements in ecosystem states, while the addition of works at Parnka channel had longer-lasting and more profound effects.

The ecological effects obvious in the North Lagoon of the various scenarios were very minor. There were occasional changes in the ecological condition of southern-most sites, except under continued flow conditions, when the Lagoon as a whole was maintained in the estuarine/marine state.

6.2 Effects of delaying start of intervention

Scenarios 302, 304, 306 and 308, explore the effects of delaying the start of intervention, with either the pumping or the Parnka channel works beginning later. Scenario 302 has both interventions commencing in winter 2009, which was the earliest date identified for a possible start. Scenario 304 has channel works commencing in winter 2009, but pumping in spring 2009. Scenarios 306 and 308 have the same respective start dates for pumping as 302 and 204 (so winter and spring 2009), but delay the channel works to autumn 2010, in line with suggestions that the approval process may be protracted, or that works may be easiest to complete over summer when water levels are low.

There was little difference evident amongst the four scenarios (Figure 6.1). As would be expected, the scenarios where interventions occurred earlier showed earlier shifts to less-degraded states. However, the overall effect was relatively minor, with only a small additional proportion of sites in degraded states with slight delays in the commencement of intervention. A difference of only 8% of sites in a more degraded condition was evident between the earliest and latest intervention times explored. These were concentrated at the southern end of the South Lagoon, where the start of recovery was delayed with each additional delay in intervention.

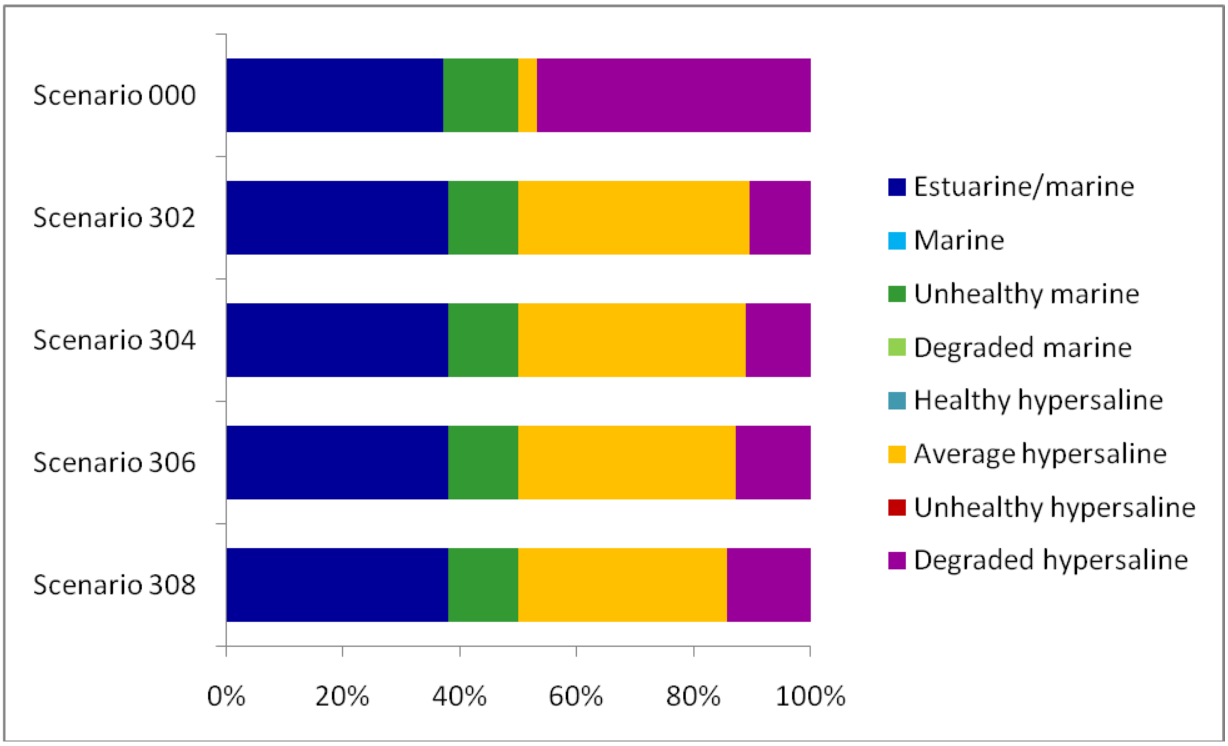


Figure 6.1. Comparing the proportions of sites occupying each ecosystem state between 2008 and 2016 between scenarios exploring the effect of delaying the start of intervention

No differences in the North Lagoon states were evident as a result of delaying intervention.

As has been noted above, these results indicate when conditions within the Coorong are favourable for a given set of organisms. They do not address the issue of how long it will take species to re-colonise areas from which they have already been lost. While it may seem from these results that there is little risk in delaying the intervention in the South Lagoon, what we are, in effect doing, is delaying the achievement of physical conditions that are conducive to the desired biota by a similar length of time (or possibly more due to seasonality). There are two major risks associated with such a decision. The first risk is that any refuge populations of species already lost from the South Lagoon may also be lost from the North Lagoon, which would dramatically (and perhaps indefinitely) increase the amount of time to re-colonise the South Lagoon. The second risk is that the degraded hypersaline state is the worst condition in which the system has been observed so far. We do not know how long it can be maintained in that state, nor whether there are even more degraded states for it to approach. With each successive year the system remains in its current condition, we increase the risk of the system deteriorating further beyond the experience of this modelling. As such, although the delays appear to have a relatively minor impact on the ecological state of the system as a whole, we would recommend interventions in as short a time as is feasible.

6.3 Effects of scale of works at Parnka channel

The ecological impact of the scale of works at Parnka channel can be assessed by comparing the results of Scenarios 302, 306 and 308 with Scenarios 310, 311 and 312, respectively. Each of the latter is equivalent to the former, with a bed elevation in the Parnka channel of -0.4 m AHD in the latter scenarios versus -0.8 m AHD for the first three scenarios mentioned.

Decreasing the capacity of the Parnka channel by increasing its bed elevation (and thus making it shallower) had a large impact on the ecological condition of the South Lagoon. While scenarios involving the greater depth had between 20% and 28% of sites in degraded states over the model run (see Figure 6.1), those scenarios where the channel height was lowered to only -0.4 m AHD resulted in the South Lagoon supporting degraded sites for 46% to 52% of site-years (Figure 6.2). The differences occurred at the start of the model run, with the smaller channel capacity increasing the time to recovery, particularly for the southern end of the South Lagoon, but differences were also evident toward the end of the model run, when southern sites began to degrade following the cessation of pumping. While the deeper channel resulted in the ecological states remaining stable over the model run after the initial recovery, the scenarios with the shallower channel changed back to a degraded condition towards the end of the run after pumping stopped. For each of Scenarios 310, 311 and 312, the southern end of the South Lagoon moved from the healthy hypersaline state to the degraded hypersaline state in 2015 (4 years after the cessation of pumping), and this condition extended northwards in 2016.

No impact of changing the scale of works at Parnka channel was observed in the North Lagoon.

In the long term, should conditions not improve with respect to flows over the barrages, a shallower channel at Parnka channel increases the likelihood that additional pumping will be required to maintain salinities in the South Lagoon at levels conducive to functional ecological communities. The effect of the scale of works at Parnka channel affected both the time to recover initially but also resulted in a return to degraded conditions four to five years after the cessation of pumping.

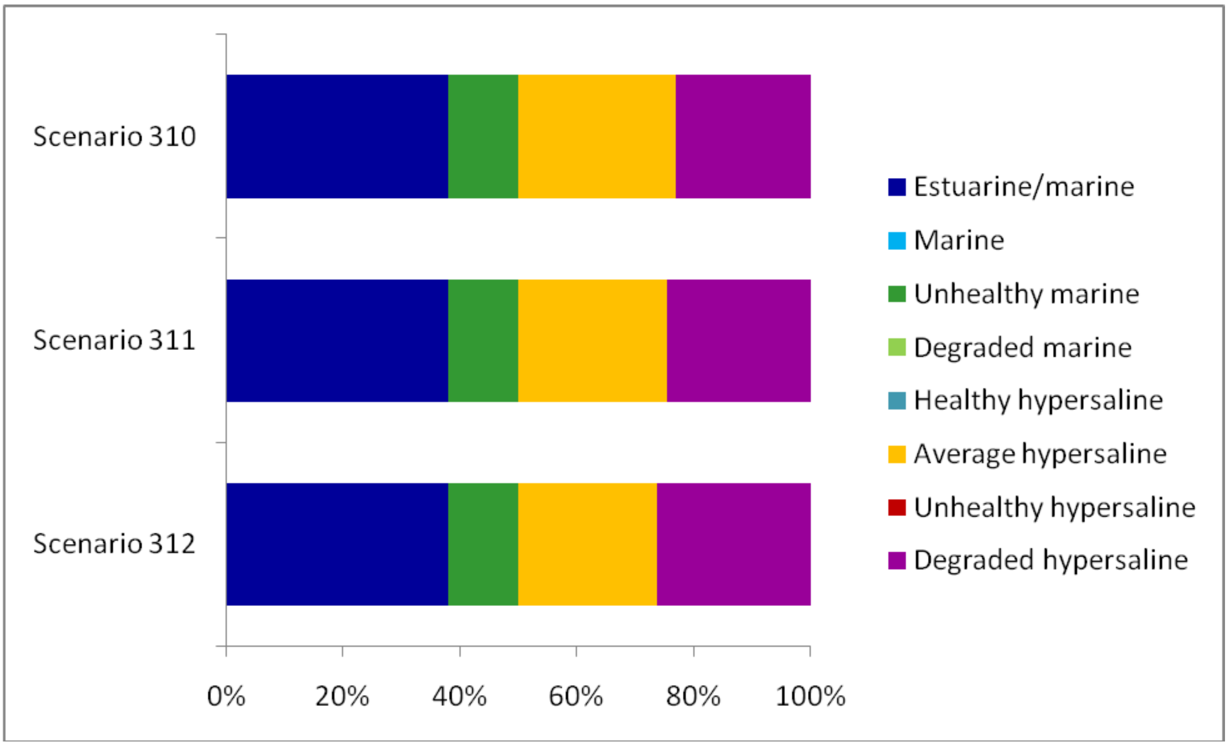


Figure 6.2. Comparing the proportions of sites occupying each ecosystem state between 2008 and 2016 between scenarios exploring the effect of the scale of works at Parnka channel

6.4 Effects of other interventions

Three scenarios involving other interventions were explored as a part of the second round of scenario analyses. These scenarios included one (Scenario 313) where the volume pumped from the South Lagoon was replaced by an equivalent USED flow through Salt Creek from Morella Basin. This scenario assumed that sufficient volumes would be available, which may be unlikely, particularly during drought years. Scenarios 315 and 317 investigated the ecological impact of pumping alone (with no works at Parnka channel).

Replacement flows at 150 ML per day through Salt Creek had very little impact on the distribution of states represented within the South Lagoon (Figure 6.3). Comparing Scenario 313 with 304 (same pumping, timing and Parnka channel works; Figure 6.1), there is almost no change in the mix of ecosystem states. The addition of replacement flows assisted in the first year of pumping to recover the southernmost site of the South Lagoon marginally faster than occurred with average flows through Salt Creek. This suggests that the volumes currently passing through Salt Creek may already be affecting the condition of the South Lagoon, particularly around Salt Creek, and that resources may be better spent on other interventions, at least in the short term.

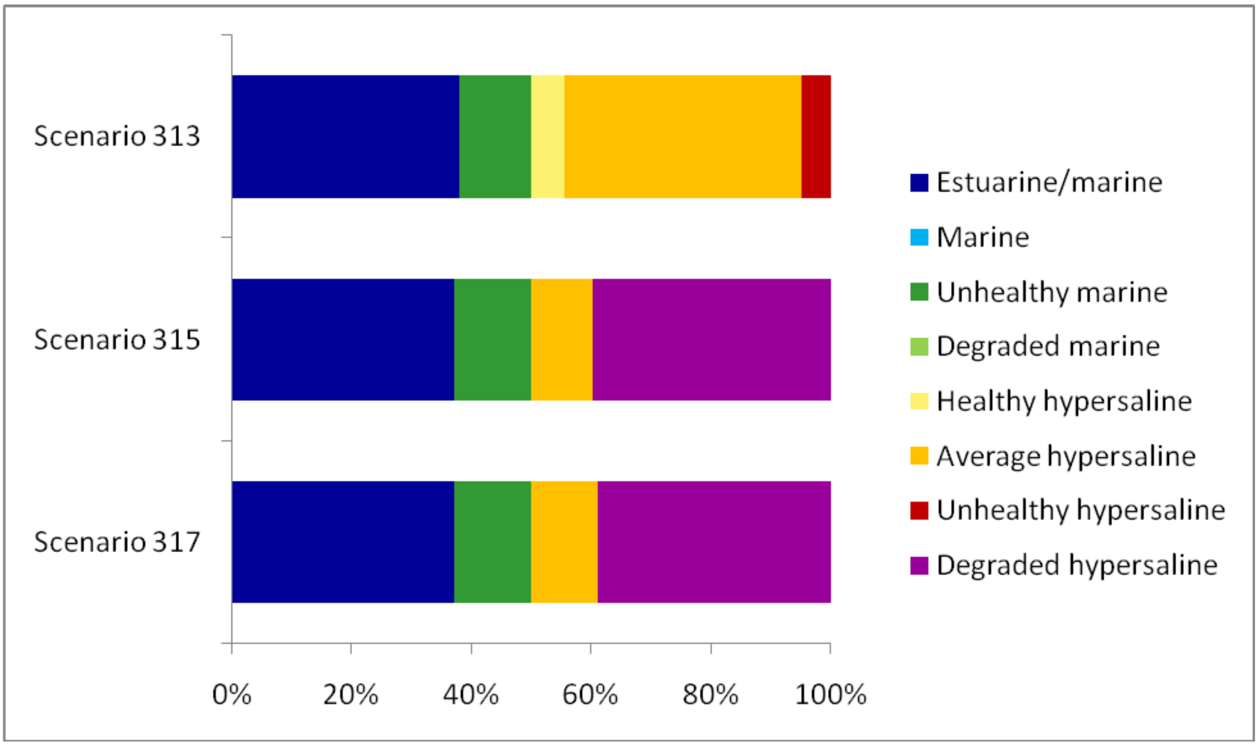


Figure 6.3. Comparing the proportions of sites occupying each ecosystem state between 2008 and 2016 between scenarios exploring other interventions

The effect of pumping on its own (Scenarios 315 and 317) was much less effective than when undertaken in conjunction with works at Parnka channel (see Scenarios 302 and 304 for the same pumping volumes and timing). While pumping on its own effectively recovered the condition of the northern end of the South Lagoon from the degraded hypersaline state to the average hypersaline state, this change did not penetrate along the length of the lagoon. The distance to which the recovery occurred fluctuated between years, but was at a maximum in 2013 (for both Scenarios 315 and 317) when just over half the South Lagoon was in the average hypersaline state.

No difference in the ecological states in the North Lagoon was observed as a result of these interventions.

Without the additional connectivity afforded by works at Parnka channel, evaporative losses concentrated the salt in the southern end of the South Lagoon to levels above the threshold between the degraded hypersaline and average hypersaline states. This means that some of the South Lagoon becomes available as a refuge for species previously found there, but risks relating to the proximity to degraded conditions persist.

6.5 Effects of returning flows

One of the risks identified with the current condition of the Coorong is that the hypersaline refuge that exists at the southern end of the North Lagoon may be lost should flows over the barrages return to normal levels before conditions in the South Lagoon have been restored to the point that species can re-colonise. In order to assess this risk, we investigated three scenarios (Scenarios 318, 319 and 320). Two scenarios assumed that flows returned at median levels continuously, one with no interventions (Scenario 318) and one assuming that irreversible channel works had occurred at Parnka channel (Scenario 319). The third scenario (Scenario 320) looked at the return of a median flow year for only one year, and then a return to dry conditions.

The resolution of the ecological model for the North Lagoon was not sufficient to identify differences in the northern and southern sections (Figure 6.4). This may suggest that while some South Lagoon species have found refuge, conditions are not unsuitable for species found there on a more regular basis, so the model continues to indicate the marine/estuarine state, despite the presence of additional species. Expert opinion comparing the current condition of the North Lagoon with the condition indicated with this model suggests that the model may not be adequately capturing the range of conditions along the North Lagoon. If verified, this would be a limitation of the current model. As a result, we have largely based our assessment of the effect of a return to flow for the North Lagoon on the hydrodynamic conditions predicted.

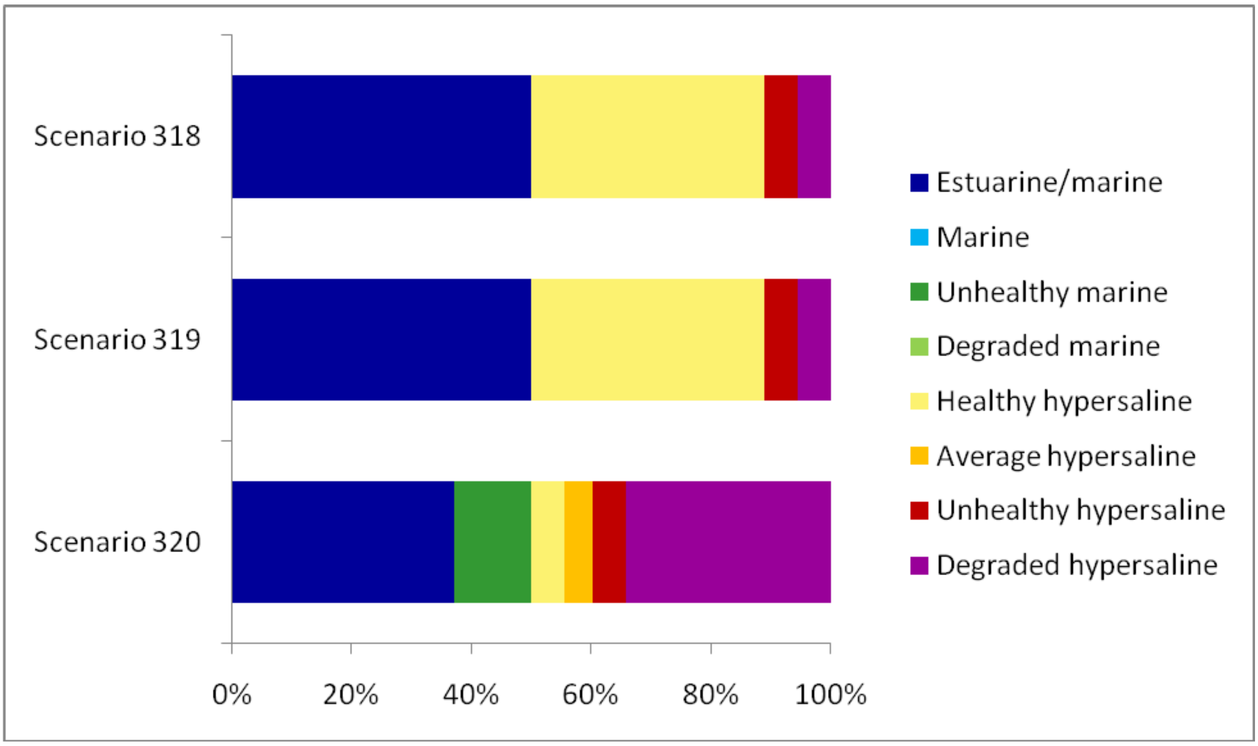


Figure 6.4. Comparing the proportions of sites occupying each ecosystem state between 2008 and 2016 between scenarios exploring the effects of returning flows

Scenario 318 investigated the effect of a return to continuous median flows over the barrages. Under these conditions, water levels in South Lagoon followed those observed in the North Lagoon, and so were substantially higher than for the baseline scenario. Water levels in the North Lagoon, however, changed little from the baseline, suggesting that large-scale additional and continuous inundation of mudflats north of Parnka Point would be unlikely, so appropriate foraging habitat for wading birds should be maintained. Salinities in both the southern North Lagoon and the South Lagoon, however are dramatically affected in a short period of time. The average salinity in the southern North Lagoon for the first three years of median flows dropped to an average of around 30 g L^{-1} or approximately equal to that of seawater. For the next three years of flow, there was a further decline to 22.6 g L^{-1}. Salinities in the South Lagoon were also markedly lower than during dry conditions. The first three years of returning flow showed a decline to an average 79.1 g L^{-1}, and the next three years of flows to an average of 43.6 g L^{-1} along the length of the South Lagoon. These values are an average over the year, and there are also seasonal fluctuations occurring, with higher salinities likely in summer and autumn and lower salinities in winter and spring (see Appendix C).

Scenario 319 investigated a similar return to median flows, but assumed that the works at Parnka channel had already been undertaken. The effects for this scenario were similar to those observed for Scenario 318, although the increased connectivity within the system tended to produce even lower salinities (on average around 6 g L^{-1} lower than those reported for Scenario 318).

Scenario 320 analysed the effect of a single year of median flows, with a subsequent return to dry conditions. The effect of a median flow year on water levels in the South Lagoon was immediately obvious, and was maintained in the system for approximately two years. During this time, water levels in the South Lagoon followed those of the North Lagoon, but North Lagoon water levels were not affected, to either be substantially higher or substantially lower. Salinities also dropped dramatically in two years after the commencement of flows. Average salinity in the South Lagoon for the period dropped by as much as 36 g L^{-1}. At the same time, salinities in the southern North Lagoon declined less dramatically (dropping 15 g L^{-1} from 69 g L^{-1} to 54 g L^{-1}). Salinities lower than the baseline persisted in the South Lagoon for approximately four years, but gradually returned to baseline levels.

While continuous median flows are unlikely to occur, particularly in the next few years, these results show that unless the South Lagoon is recovered to a point where species preferring hypersaline conditions can thrive, there is a risk they will be lost within the system if large flows do return suddenly. A single median flow year seems unlikely to cause a loss of any refugia currently present in the system, but potentially low level of resilience in the current ecological communities of the Coorong due to ongoing adverse conditions means that this risk cannot be discounted.

7 Summary and recommendations

We investigated an initial 87 scenarios to identify which combinations of pumping from the South Lagoon, undertaking works at Parnka channel, increasing dredging at the Murray Mouth and installing a regulator at Parnka Point were likely to have the greatest benefit on the Coorong. Based on physico-chemical criteria, set with a view to the ecological impact, scenarios that combined works at Parnka channel and pumping from the South Lagoon were identified as most-promising. This led to a second round of scenario analyses, including 20 scenarios that investigated two rates of pumping, two scales of channel works and various start dates for each, along with several investigating a return to flow conditions. Results are not presented for those scenarios with the higher rate of pumping due to concerns about the effect of the volume of discharge to the receiving marine environment.

Hydrodynamic results for the second round of scenarios showed that all options (excluding those involving a return of barrage flows) were very similar in the water levels and salinities attained in both the North and South Lagoons. The main differences between them were that pumping in isolation resulted in lower South Lagoon water levels, and that salinities began to rise before the end of the modelling run than occurred in those scenarios when channel works were also carried out at Parnka channel.

Based on ecological assessments, all second-round scenarios showed a substantial improvement from the baseline conditions. Delaying either pumping or works at Parnka channel did affect the amount of time until the system began to recover, with delays in recovery in the order of one year. While this may seem minor, it does not guarantee that these delays were ones that the system would be equipped to handle, given its current degraded condition, and we recommend intervention as quickly as possible.

The scale of works at Parnka channel had a much larger ecological impact, with the smaller-scale works resulting in a much lower level of recovery than the larger-scale works. Pumping in isolation also led to a lower level of recovery than when undertaken in conjunction with works at Parnka channel and the effects did not persist through the model run. Replacement USED flows through Salt Creek had a minor additional benefit. Additional modelling focusing on the effects of USED flows on the South Lagoon of the Coorong will be undertaken to better understand their ecological implications.

The results clearly show that no intervention investigated here was a replacement for a return to barrage flows. Both the hydrodynamic and the ecological effects were unable to be replicated, and the long-term strategy for the Coorong should be to secure water to enable barrage flows to recommence. A single year of median flows had some benefits for the system, but over the model run, these were eroded, particularly in the South Lagoon after a return to dry conditions. Ongoing median flows had a substantial impact on the system as a whole. The marine basin (northern) model did not detect any refuge at the southern end of the North Lagoon, which may be due to a lack of resolution in that model, so we are unable to comment on ecological effects of a return to flows on any such refugia.

Hydrodynamic results are such that we are unable to rule out any potential for the loss of such a refuge should median barrage flows be restored, so we recommend action to allow those species to recolonise the South Lagoon, to increase their geographical range in the Coorong.

Finally, we recommend that a monitoring program be undertaken in conjunction with any intervention to allow the further refinement of the ecosystem models and assessment of the benefits (and any disbenefits) of the intervention strategy.

8 References

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9 Appendices

9.1 Appendix A - Error analysis for the hydrodynamic model

Introduction

It is important to know how much reliance can be placed on model predictions. At best, a model is only an approximation to reality. Here we address the issue of how much reliance can be placed on the model simulations for future scenarios. The hydrodynamic model was purposely kept simple with a minimum of tuning parameters (4), which were determined through calibration using salinity and water level data collected in the period 1997-2005. In addition, other salinity data have been collected over the years by various investigators (Table A.1):

Data source	Data period	Measurement method
Noye (1967)	1963-1967	unknown
Krause and Bennett (unpublished)	1976-1979	unknown
M. Geddes (unpublished)	1981-1985	conductivity
Owen (1993)	1993	conductivity
EPA-DEH	1997-2005	chlorinity
EPA-DEH	2005-2007	conductivity

Table A.1 Data used in the constructions and validation of the hydrodynamic model

We have run the model from 1963-2008. From 1985 to 2008, we were able to force the model using measured meteorological parameters, barrage flows estimated from recorded gate openings, and Mouth opening calculated from the measured transmission of the tidal elevations at Tauwitchere. Prior to 1985, these measurements were mostly not available. Between 1963-1985, the meteorological forcing was taken to be a repeat of the measured time series of wind, evaporation and precipitation between 1985 and the present. Flows through Tauwitchere and Ewe Island Barrages were prescribed to be fixed proportions of the monthly flows estimated using BigMod and the degree of Mouth opening was modelled using these derived barrage flows. Consequently, the hydrodynamic simulations for prior to 1985 should be considered to be drawn from more uncertain input data than for those simulations for post-1985.

Salinity

Figures A.1 and A.2 compare model simulations of salinity to measurements obtained between 1963-2007 in the North and South Lagoons. Note that data used during model calibration are plotted as blue points and the others as red. The model simulations are plotted as a grey band. The upper and lower limits of the band represent the range of modelled salinity in each lagoon. Overall, it would seem that the modelled salinities follow the measurements reasonably well with the majority of measurements falling within the range of simulated salinity at the same time.

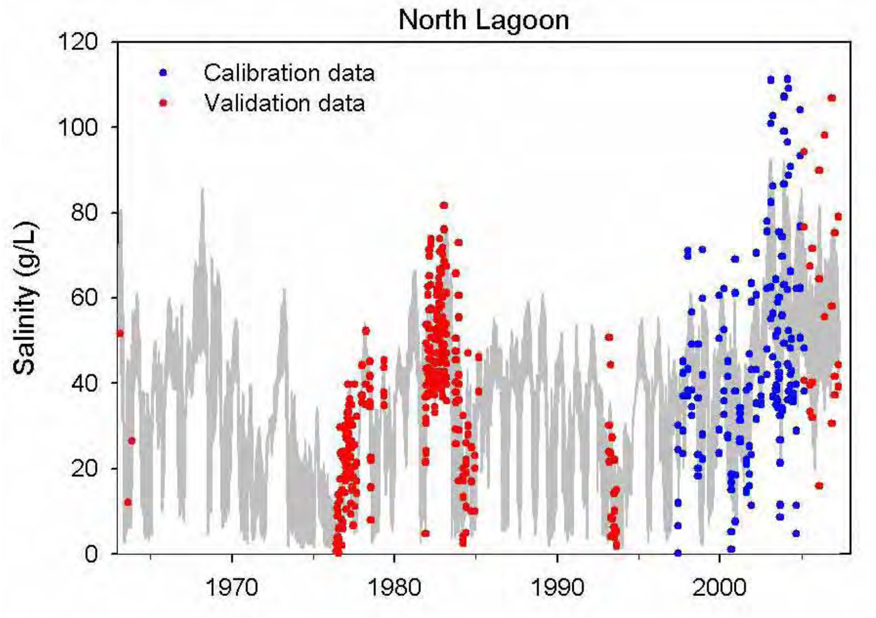

Figure A.1. Comparison between measured (coloured points) and modelled (grey band) salinities in the North Lagoon. The blue points are data used in the model calibration. The upper and lower sides of the grey band represent the range of salinities modelled in the lagoon at a particular time.

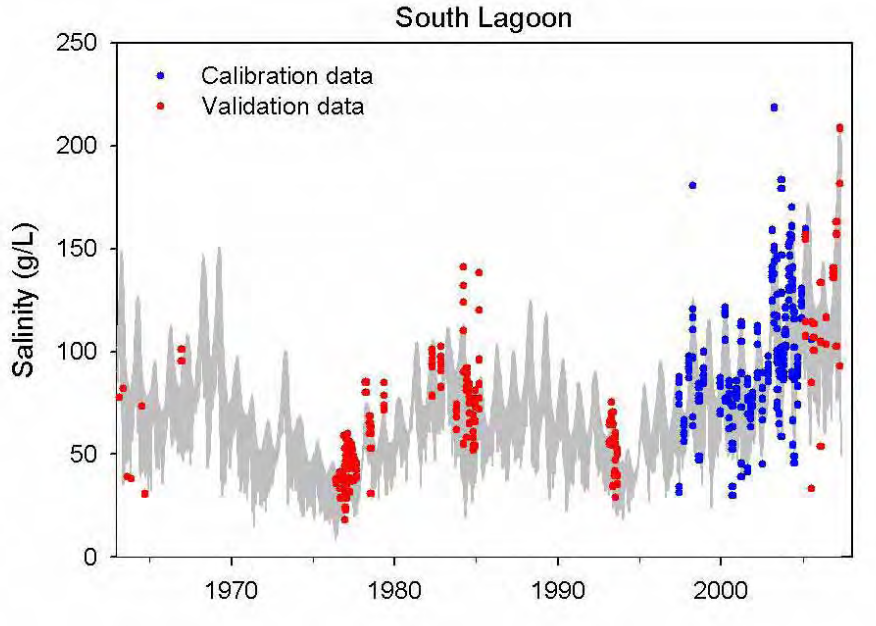

Figure A.2. As in Figure A.1 but for the South Lagoon.

We undertook a direct comparison between the measurements and the modelled salinity for the same time. Results are shown for cells 6 and 7 taken together in Figure A.3. Cells 6 and 7 are the southernmost cells in the North Lagoon and they show the largest degree of scatter in the relationship between measured and modelled salinity of any of the sets of cells considered (3-5, 6-7, 8-11, and 12-14). We can ask the question that considering this degree of scatter, does the model represent the behaviour of the actual system? In Figure A.2 the dashed lines represent the linear regressions for the sets of points during the non-calibration and calibration periods. Both regressions pass close to zero, but their slopes are 0.93 and 1.20, respectively. Using all the measurements together, the slope of the linear regression is 1.04. Ideally, this slope should be 1:1 (the grey line). Nevertheless, the similarity between the slopes and the value of 1.0 does suggest that in a statistically averaged sense at least the model captures variation in salinity in this part of the Coorong over a wide range of conditions including periods having significant barrage flows and periods when there have been almost none.

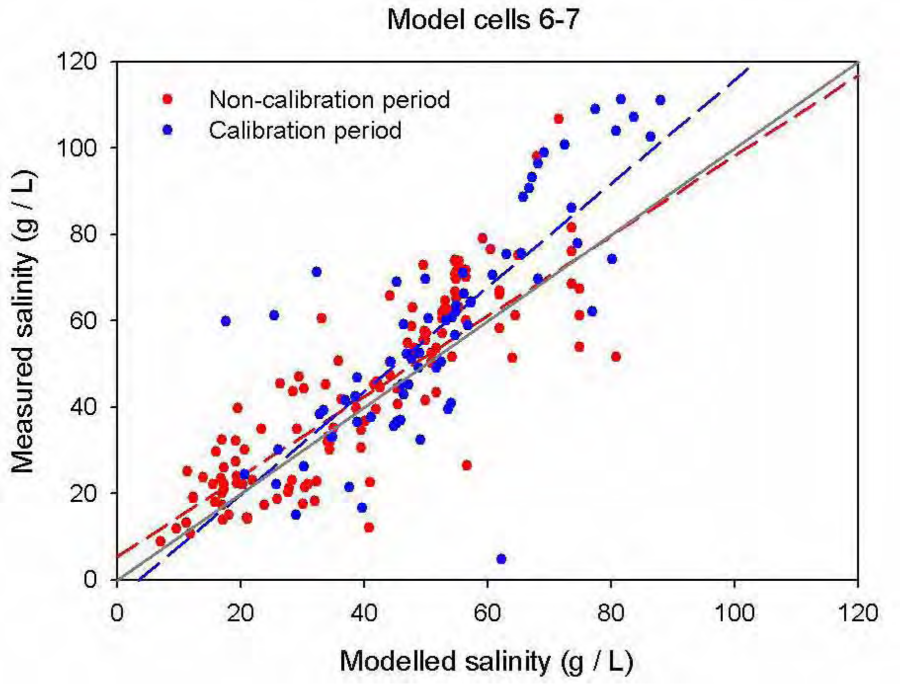

Figure A.3. Comparison between modelled salinity and salinity measured on collected water samples for model cells 6 and 7. The grey line is the 1:1 relationship.

Part of the scatter of the points around the 1:1 line is certainly due to sampling issues. Figure A.4 shows time series of salinity calculated from a continuously recording conductivity sensor at Mark Point (salinity cell 3). Comparison of these salinities with those collected from the analysis of grab samples at a close location showed significant differences at times. The time series of measured salinity showed high frequency fluctuations at this time which are almost certainly associated with significant spatial variation also. The precise time and collection location of a sample for analysis is likely to have a significant effect on its salinity. Considering that the modelled salinity cell 3 implicitly represents an average salinity over a 5-km length of the Coorong and across ~1.5-km width, a large part of the scatter in the model-measurement comparison is certainly due to the problem of sampling in a heterogeneous salinity regime and comparing these measurements to what is effectively a spatial average. Nevertheless, the time series of modelled salinity captures much of the high frequency variation exhibited by the measured time series. The scatter exhibited by the relationship between measured and modelled salinity is smaller for the other cells than it is for cells 6 and 7 perhaps reflecting smaller spatial salinity gradients in the regions they represent.

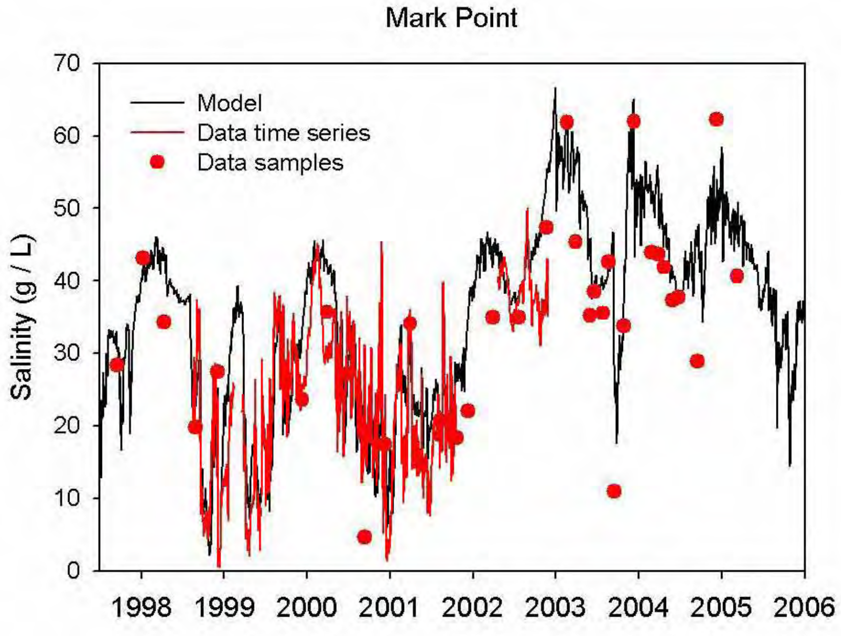

Figure A.4. Comparison between time series of model simulations for salinity cell 3 and measured salinity at Mark Point. Also shown are salinities measured on collected water samples at this site.

Figure A.5 shows the comparisons between measured and modelled salinity for cells 8 to 11 which represent the northern half of the South Lagoon. In this case the slopes of the regressions fitted to the non-calibration period and the calibration period are 0.85 and 0.95, respectively, with a slope of 0.92 calculated when all the data were regressed together. These calculations have excluded the suspect point shown in Figure A5. This sample was collected in 2005 when the salinity in the South Lagoon was everywhere ~100 g L^{-1} or more. So, we speculate that this measurement might have been influenced by the local input of groundwater or surface run-off. When this point is included in the regression for all points, the slope reduces from 0.92 to 0.90. Most of the salinity measurements were obtained on shore-collected samples and it is possible that these samples may have been affected by ground water or surface run-off and so contribute to the scatter between measured and modelled salinity.

The regressions for measured versus modelled salinity for all the data from cells 3-5 and for cells 11-14 had slopes of 0.81 and 0.90 respectively. In both cases, the regression slopes were closer to 1.0 for the calibration period (0.87 and 0.91) than for the non-calibration period (0.82 and 0.84). We recall that the model for the majority of the non-calibration period was run using derived forcing data.

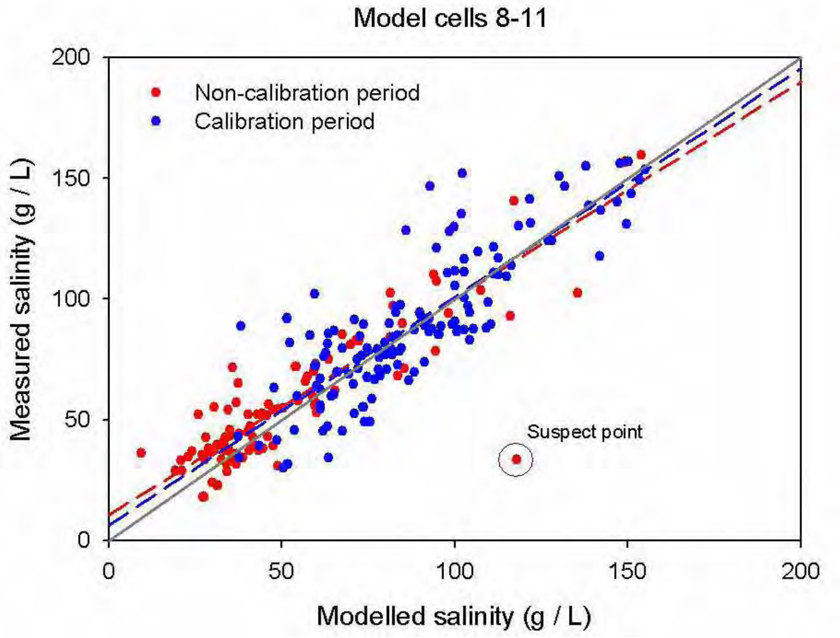

Figure A.5. Comparison between modelled salinity and salinity measured on collected water samples for model cells 8 to 11. The grey line is the 1:1 relationship.

Water level

Water levels in the North Lagoon of the Coorong averaged over periods of greater than a week are determined mainly by the level in Encounter Bay provided the Mouth is reasonably open. Consequently, averaged water levels in the North Lagoon are only weakly affected by model accuracy and comparisons between these modelled and measured water levels in the North Lagoon are good. Averaged water levels in the South Lagoon are also mainly determined by sea levels between approximately April and November, but during the summer months when sea levels drop and the connection between the two lagoons becomes constricted, South Lagoon water levels diverge from those in the sea and in the North Lagoon. During the summer months, averaged water levels in the South Lagoon are determined by evaporation which continuously reduces the water level and by some leakage through the channel separating the two lagoons which tends to counteract the evaporative loss to some extent.

The calibration procedure for the Coorong involved the selection of an optimal channel depth for the connection between the two lagoons, an evaporation factor to be applied to a pan evaporation rate to obtain a rate for the Coorong, as well as a factor to be applied to wind measurements at Meningie for estimating wind stress over the Coorong from these measurements. Modelled water levels during summer are affected mainly by the selection of the first two calibration coefficients. Figure A.6 shows measured and modelled water levels for Sand Spit Point near the south end of the South Lagoon. These have been averaged over a period of 10 days. Mostly, these measured and modelled water levels follow one another at this site quite well. The average difference between them is 0.03 m with the model having the higher average water level. The RMS difference between the two time series is 0.11 m. Another simple test of the model is its ability to simulate the lowest water level in summer. The average difference between the measured and modelled water level minimum over the period shown in the Figure shown is 0.02 m with an RMS difference of 0.08 m.

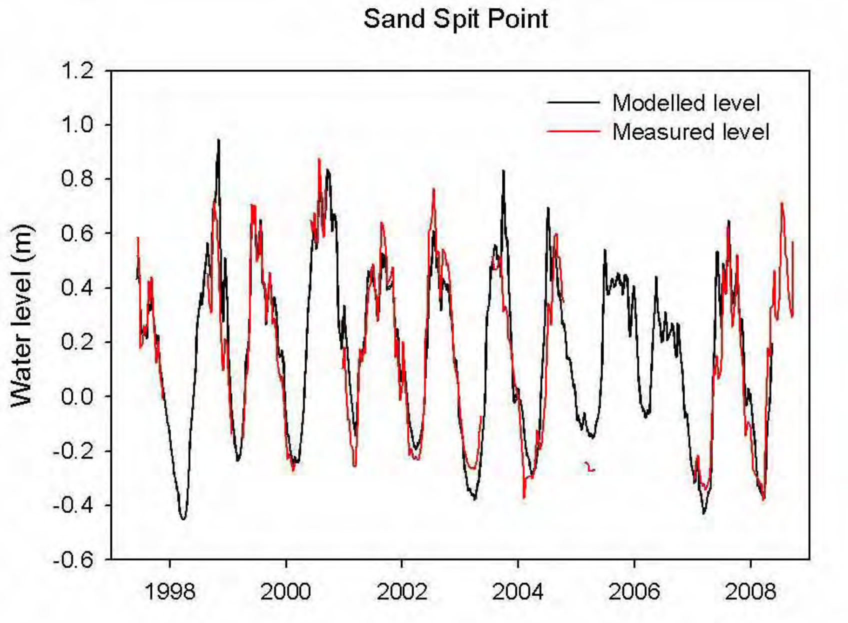

Figure A.6. Comparison between measured and modelled time series of water level for Sand Spit Point in the South Lagoon. These data have been averaged over 10-day periods.

Variations in water level at periods less than a week or so are mainly due to wind stress acting on the water surface which tends to cause the water to pile up against the downwind end. The response of the system can be described using the analysis technique of spectral analysis in which the amount of variance at each frequency of variation is calculated. Figure A.7 shows the power spectra for the measured and modelled water levels at Sand Spit Point. Over most of the cycle periods shown, the spectra follow one another confirming that shorter period variations in water level in the South Lagoon are mainly due to the action of the wind. At cycle periods of less than ~1 day, the spectra diverge. The wind stresses were mostly calculated from meteorological observations taken twice a day and so higher frequency fluctuations can’t be represented in the forcing data used to drive the model. The model simply does not represent actual water level fluctuations having periods less than a day. For periods between 1 and 10 days the model variance exceeds the measured variance by an average of 10%; that is, the model slightly overestimates measured water level variations. For longer periods the reverse occurs, but the calculation of spectra at periods longer than 10 days becomes increasingly unreliable for statistical reasons.

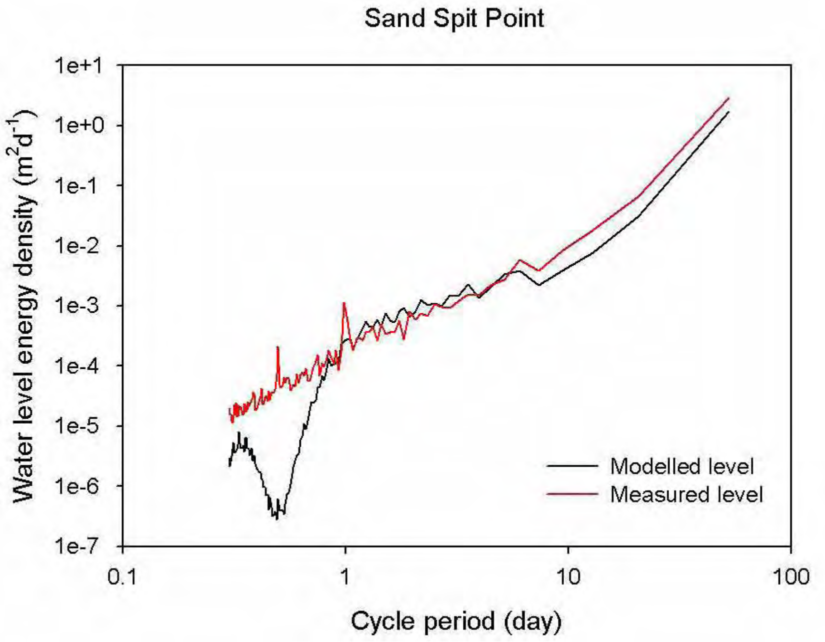

Figure A.7. Power spectra of water level from Sand Spit Point calculated from measured and modelled time series.

For the North Lagoon, we compare measured and modelled water levels at Tauwitchere. The modelled and measured spectra between periods of 1 and 10 days compare very well with one another and have an average difference of only 1 %. For periods of greater than 10 days, the average water level differed by 2 mm and the RMS difference between the two time series is 0.07 m.

Conclusions

Individual salinity measurements show significant deviations from modelled salinity at the same time and in the cell which includes the measurement site. We have attributed much of this difference to the incongruity of comparing salinities in cells that are effectively averaged along 5-10 km along the Coorong and across its width of several kilometres with spot measurements that are mostly obtained at the shore. There are certain to be heterogeneities in the salinity structure that are introduced by local evaporation or water input or by swirls in the current that are not resolved by the model. Errors in the model are also introduced through inaccuracies in prescribing the wind stress on the water surface from measurements obtained at Meningie some 10's of kilometres away. Further, barrage flows are estimated using a water balance scheme in BigMod and not by direct measurement. Evaporation is estimated from pan measurements and even though a constant correction factor was determined through calibration, there is no certainty that this factor is constant. Water gains or losses to the lagoons through groundwater ingress or egress were not included as these rates are unknown. Structural simplifications in the model will lead to further error including the simplified bathymetry and the assumption of constant mixing coefficients.

Nevertheless, the slopes of the regressions for the combined data sets are 0.87, 1.04, 0.92, and 0.87 for cells 3-5, 6-7, 8-11 and 12-14, respectively. This suggests that the model is capable of explaining ~90% of salinity changes in the system in a statistically averaged sense. The scatter around these regressions such as shown in Figures A.3 and A.5 represents the limitation of the model's ability to simulate the instantaneous salinity at a particular sample collection site, but we contend that the underlying dynamics is faithfully represented in the model and that in can be used with confidence for evaluating the relative merits of remediation strategies for modifying the salinity regime.

Hydrodynamic models tend to do well at simulating the water level response to forcing and this is the case here. The model does well in simulating both the weather band response (less than 10 day period) and the longer-term seasonal fluctuations in both lagoons. Although, due to limitations in the form of the meteorological data available, the response of the system to wind fluctuations having periods less than a day is not represented in the model, but for longer periods the measured and modelled level variances differ by 10% or less. The longer term seasonal fluctuations in the North Lagoon and in the South Lagoon mostly follow those in Encounter Bay when the Mouth is in a reasonably open condition. But during the summer months the North and South Lagoons become separated due to the seasonal fall in sea level. The further fall in South Lagoon water level due to evaporation and its subsequent refilling are well captured by the model.

9.2 Appendix B – Description of the ecosystem states of the Coorong

The ERM model for the Coorong identified eight distinct ecosystem states. The states are presented as a logic tree (Figure B.1), where each box represents a logic statement. Where the condition is true, the tree should be followed to the left-hand side. Where the condition is false, the tree proceeds to the right, until a shaded terminal node is reached. This terminal node determines which state the Coorong is in at any given location and time, based on its environmental characteristics.

The environmental parameters that differentiated amongst the various states were a combination of water quality, quantity and flow variables. They included the average daily tidal range, maximum number of days since flow has crossed the barrages, average water level and salinity at the location, and average depth of water in the previous year. The appearance of average tidal range as the first split variable effectively divided the Coorong into two basins, with four states possible within each basin. The northern basin existed around the Murray Mouth estuary and down to the northern part of the North Lagoon, to about Noonameena, where the states were essentially marine in character (on the right side of Figure B.1). The southern basin included the southernmost part of the North Lagoon and the entire South Lagoon, and had four hypersaline states (shown on the left side of Figure B.1).

We have given each of the eight states a name for ease of interpretation (Figure B.1). The names chosen were based on the environmental conditions under which each state exists, and the biota that is supported by each. The trend of declining biotic richness and the variables for which thresholds were significant (e.g. length of time since flow over the barrages) led us to believe that the states represent a continuum from a healthy ecosystem to a more degraded ecosystem in each basin. We have named the states accordingly. However, these names do not imply that a single state (e.g. the ‘healthy’ state) should, or even could, necessarily exist in each region. Finally, despite the labelling of ‘unhealthy’ and ‘degraded’ for several states, this is not to say that no biota exists. As is described below, each state continues to support some range of biota that is available as food and habitat resources.

The northern basin consisted of four states, including those named estuarine/marine, marine, unhealthy marine and degraded marine. These states had greater tidal ranges than those four of the southern basin: healthy, average, unhealthy and degraded hypersaline. The biological and environmental characteristics of each state are shown in Table B.1. For five of the eight states, the long-term differences in multivariate displays of community composition and environmental parameters are shown in Figures B.2 and B.3, respectively. Only five states are shown because of missing values excluding a sixth state, and two states did not appear within the long-term (1999-2007) analyses. For these five states, however, there were significant differences in the community composition between states (ANOSIM Global $R = 0.402$, $p = 0.001$; all pair-wise comparisons between states were also significant with the exception of the estuarine/marine and unhealthy marine states), based on the macrophyte, bird and commercial fish abundances found, and in the environmental parameters found (ANOSIM Global *R* = 0.536 *p* = 0.001; again, all pair-wise comparisons where there were more than two sites in each state were statistically significant). This difference between the biotic composition of each state supports the notion that the model is describing distinct ecosystem states. There is a large distinction between the marine and the hypersaline basins, with the closed and open symbols clearly differentiated. The distinction within these two groups is smaller, with several groups overlapping, indicating that, although statistically significant, there are similarities within the groups of states. The environmental characteristics of all states were much more distinct, with very little overlap between any of the states. This may be a reflection of the more complete environmental data on which this is based, and additional biological data may better illustrate the distinction between the various marine and hypersaline states.

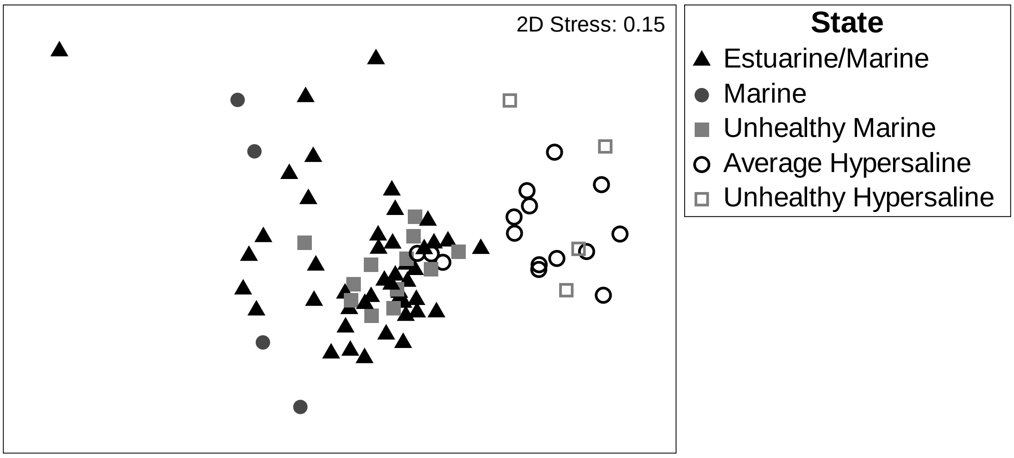

Figure B.2. nMDS plot of long-term biological characteristics for the ecosystem states of the Coorong.

This figure is based on a Bray-Curtis similarity matrix of standardised, log(x+1)-transformed abundance data for macrophytes, birds and commercial fish for 12 sites between 1999 and 2007 (minus cases with missing values, n = 80). A maximum of 25 runs were used.

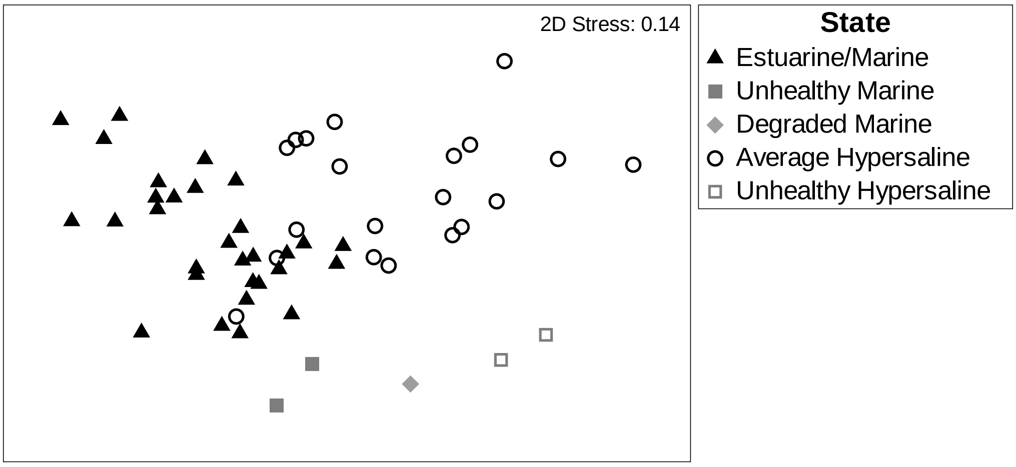

Figure B.3. nMDS plot of long-term environmental characteristics for the ecosystem states of the Coorong.

This figure is based on a Euclidean similarity matrix of normalised data for modelled salinity, depth and water levels, flow characteristics, meteorological and water quality data for 12 sites between 1999 and 2007 (minus cases with missing values, n = 55). A maximum of 25 runs were used.

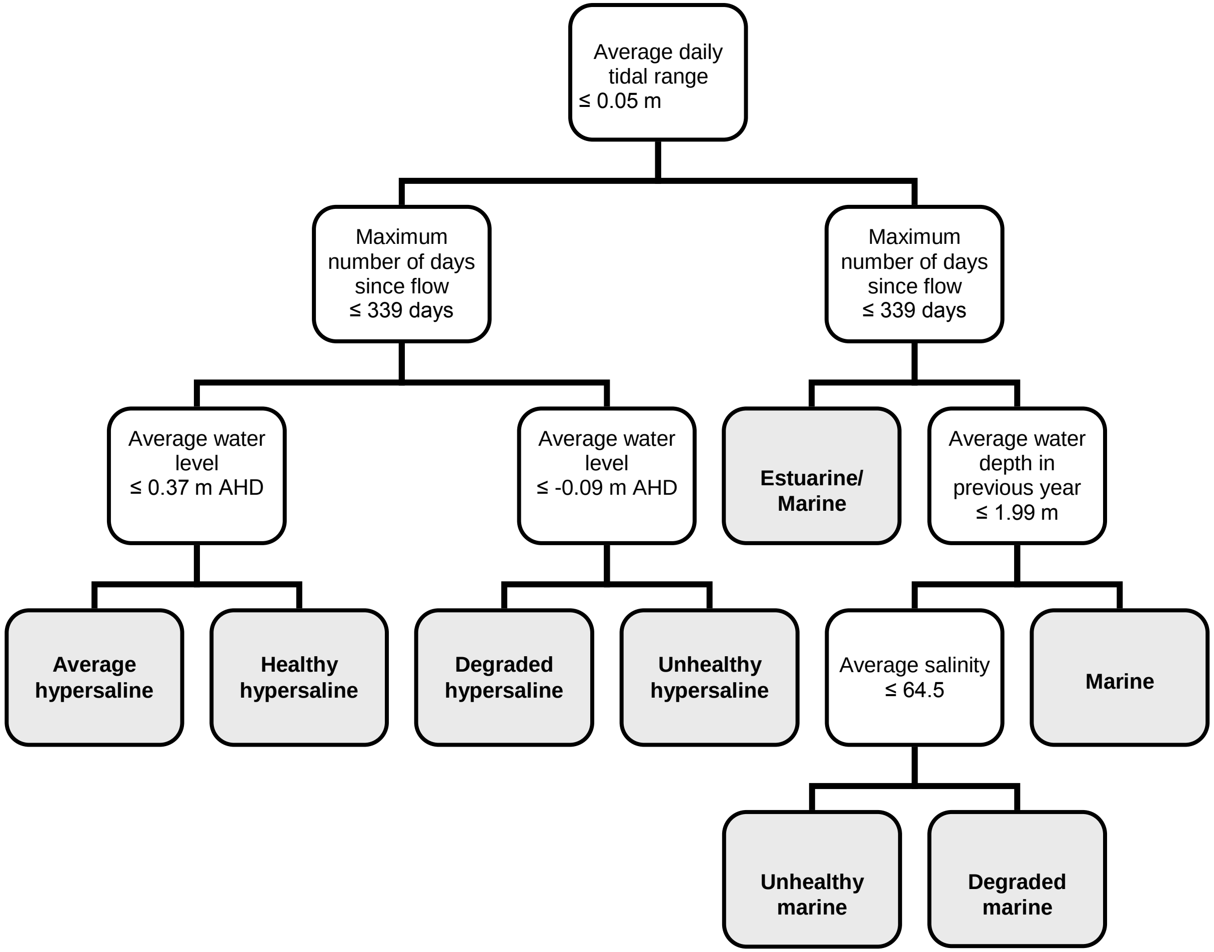

Figure B.1. Ecosystem states model for the Coorong as a whole

This figure presents a logic tree which can be followed to identify the ecosystem state for a given location and time in the Coorong. Each white box contains a splitting parameter and a threshold value. Where the value for the parameter is less than or equal to the threshold value, the tree should be followed to the left. Where it is higher, the tree should be followed to the right. When a grey terminal node box is reached, the state has been identified.

	Marine states				Hypersaline states			
Variable	**Estuarine/ marine**	**Marine**	**Unhealthy marine**	**Degraded marine**[a]	**Healthy hypersaline**	**Average hypersaline**	**Unhealthy hypersaline**	**Degraded hypersaline**
Biological characteristics								
Fishing birds	High	Moderate	High	High	Very low	Low	Moderate	Very low
Shorebirds	Low	Very low	Low	Moderate	Moderate	Very high	Very high	High
Waterfowl	High	Moderate	Moderate	Moderate	Very high	Very high	Moderate	Very low
Estuarine fish	High	Very high	High	Low	Very low	Very low	Very low	Very low
Marine fish	High	Very high	Very high	Very low	Very low	Low	Moderate	Low
Benthic invertebrates	Very high	Moderate	High	Low	NA	Low	Very low	Very low
Ruppia tuberosa[b]	Very low	Very low	Low	NA	NA	Very high	High	NA
Environmental characteristics								
Days since flow	Low	High	High	High	High	Low	High	High
Flow volume	Moderate	Very low	Very low	Very low	Very low	Moderate	Very low	Very low
Salinity	Low	Very low	Moderate	Moderate	High	High	Very high	Very high
Tidal influence	High	High	High	High	Very low	Very low	Very low	Very low
[TKN]	Low	Very low	Very low	NA	Very high	High	High	High
[TP]	Low	Very low	Very low	NA	Moderate	High	High	Very high
Turbidity	Low	Very low	Low	NA	Very high	Moderate	High	Moderate

Table B.1. Relative biological and environmental characteristics of observed ecosystem states

Terms within the table are internally standardised from very low to very high. [a] Caution should be used in interpreting these results, as only one case for the degraded marine state exists in each of the long-term (1999-2007) and short-term analyses (2005-2007). [b] *Ruppia tuberosa* was only present in the long-term analyses because it was only monitored annually. NA indicates that no data was available for that state for the specified parameters. [TKN] represents concentration of total Kjeldahl nitrogen and [TP] represents concentration of total phosphate.

Describing the ecosystem states

Affected by tidal influences from the Murray Mouth, the **estuarine/marine** state was characterised by lower average salinities and a shorter period since flow occurred over the barrages than other states. This input of both marine and fresh water also led to the state having the highest average water depths and water levels and high variability in water levels across the time period (quarterly for shorter-term analyses and annually for longer-term analyses). In addition, the water quality characteristics of this state may also have reflected both tidal (i.e. via the Murray Mouth) and freshwater (i.e. via the barrages) influences, with low nutrient concentrations (e.g. ammonia and TKN), low chlorophyll (a and b) concentrations and low turbidity. This state supported large numbers of marine and estuarine fish (e.g. yellow-eyed mullet *Aldrichetta forsteri*, mulloway *Argyrosomus japonicus*, greenback flounder *Rhombosolea tapirina*, black bream *Acanthopagrus butcheri* and Australian salmon *Arripis truttaceus*), which were characteristic of this state. The presence of a variety of fish species and tidal influence was reflected in the birds that were present, with the state dominated by piscivores (e.g. several cormorant species *Phalacrocorax spp.* and Australian white ibis *Threskiornis molucca*). There were also other bird groups associated with this state, including waterfowl (e.g. Australian shelduck, *Tadorna tadornoides*) and migratory waders (e.g. curlew sandpiper) present. The aquatic macrophyte, *Ruppia tuberosa*, a potential food source for some bird species, was also associated with this state, although it was limited in distribution. There were also large numbers of invertebrates that characterised this state, with high abundances of amphipods, *Simplisetia aequisetis* (a polychaete), and adult and juvenile *Capitella* spp. (polychaete taxa).

The **marine** state had the lowest average salinity of all the states (although it was not significantly lower than for the estuarine/marine state). Like the estuarine/marine state, it also had low average water levels, but had the highest variability in water levels across the time period. Compared with the estuarine/marine state, this state was characterised by greater time between water inputs, and more days since flow occurred over the barrages. The water quality may have reflected mostly marine inputs, with the lowest average concentrations of total phosphate, TKN and turbidity across all states. Biologically, this state was dominated by marine and estuarine fish species, including the Australian salmon, bronze whaler shark (*Carcharhinus brachyurus*) and black bream, with fewer yellow-eyed mullet and greenback flounder than the other northern basin states. Fewer piscivorous birds were present (in comparison to other northern basin states), with greater numbers of waterfowl species (e.g. musk duck *Biziura lobata* and pacific black duck *Anas superciliosa*) present. There were also fewer amphipods and capitellids (a family of polychaetes), but greater numbers of *Nephtys australiensis* (another polychaete) and *Arthritica helmsi* (a bivalve).

As occurred for the estuarine/marine and marine states, the **unhealthy marine** state also had relatively low average salinities (but slightly higher than estuarine/marine). The average water levels were still high, but there was greater variability in the average water levels across the time period for this state. As for the marine state, the average maximum number of days since flow occurred over the barrages was higher than for the estuarine/marine state, indicating greater time between inputs of freshwater. This lack of freshwater may be reflected by this state having low average depths compared to other states in the northern basin. Average water quality characteristics such as nutrient concentrations (e.g. ammonia, total phosphate and TKN) and turbidity values were low. The unhealthy marine state still maintained a diverse fish population, with high abundances of yellow-eye mullet and bony bream (*Nematolosa erebi*). The bird species for this state were dominated by piscivores, including great, little black and little pied cormorant species (*Phalacrocorax carbo, Phalacrocorax sulcirostris and Phalacrocorax melanoleucos,* respectively) and hoary-headed grebes (*Poliocephalus poliocephalus*). Other prominent species included curlew sandpiper (a migratory wader) and black swan (*Cygnus atratus*, a waterfowl), which may be attracted by the presence of *Ruppia tuberosa* and by the high abundances of adult and juvenile invertebrates, including capitellids, *Simplisetia aequisetis* (both polychaetes) and *Arthritica helmsi* (a bivalve).

The **degraded marine** state was represented by only a single case in each of the short- and long-term datasets used in the determination of this model (located at Noonameena in the short-term and Parnka Point in the long-term analyses). As a result, we have provided little detail for the characteristics of this state, simply giving some direction as to what this state may represent. It appears that this state had higher average salinity with lower water levels and inputs. Water quality, although only collected for the long-term dataset, appeared to remain low for concentrations of some nutrients (e.g. ammonia) but be degrading with higher values for others (e.g. TKN concentrations and turbidity). The fauna that was associated with this state included a mix of piscivorous and wading birds, few fish species and chironomid larvae as the only benthic macroinvertebrates present.

In the southern basin, the **healthy hypersaline** state had higher average salinity values than for the states of the northern basin. This state was characterised by low average variability in water levels across the time period, and with a high average water level. The healthy hypersaline state also had high average depths (only lower than the estuarine/marine and marine states in the northern basin) and the lowest average maximum number of days since flow occurred over the barrages. Thus, the healthy hypersaline state featured frequent freshwater flows, with the average maximum interval between flows being only 11 days; much lower than for all other states. Frequent freshwater inputs were also reflected by this state having the highest average days with flow and the highest average flow volume of all states. With such frequent freshwater inputs, the water quality of this state was characterised by the highest concentrations of nutrients (e.g. ammonia and TKN) and highest turbidity of all states. The healthy estuarine state also had high average chlorophyll concentrations. The absence of estuarine and marine fish species (e.g. black bream, greenback flounder and yellow-eyed mullet) may have been due to the higher salinities of this state compared with the northern states, or to high nutrient concentrations, some of which are potentially toxic to fish. The bird fauna was dominated by large numbers of waders and waterfowl, including the grey teal (*Anas gracilis*), black swan, chestnut teal (*Anas castanea*) and red-necked avocet

(*Recurvirostra novaehollandiae*). Compared to other states, there were lower numbers of other wader species and piscivores, including the red-capped plover (*Charadrius ruficapillus*), red-necked stint and whiskered tern (*Chlidonias hybridus*). There were also lower numbers of invertebrates associated with this state, particularly juvenile capitellids, *Simplisetia aequisetis* and *Arthritica helmsi*. However, there were higher numbers of juvenile insects (other than chironomids) compared with all of the other states.

Like the healthy hypersaline state, the **average hypersaline** state was characterised by higher average salinities than the northern basin. It had moderate change in water levels across the time period analysed (that is, quarterly for the short-term and annually for the long-term analyses). This state had low average depths and received freshwater influences from flow over the barrages reasonably often, with few days between flows. Consistent with freshwater inputs, the water quality indicated high nutrient concentrations (e.g. TKN and ammonia) and the presence of algae and diatoms, with high concentrations of both chlorophyll a and b and high turbidity. The high values of potentially undesirable water qualities (e.g. salinity and ammonia levels) may have been responsible for the lower abundances or absence of various fish species. There were very few fish species associated with this state, with very low numbers of greenback flounder and mulloway and no black bream. Corresponding with the lower numbers of fish, there was also a lack of piscivorous birds associated with this state (with the exception of the Australian pelican, *Pelecanus conspicillatus*). Instead, the bird species associated with this state included other functional groups, including waders (e.g. banded stilt *Cladorhynchus leucocephalus*, red-necked stint and red-necked avocet) and waterfowl (e.g. grey teal). *Ruppia tuberosa* was also more dominant within this state, with greater coverage than other states where it was present. There were also very few invertebrate taxa associated with this state (e.g. *Capitella* spp., *Nephtys australiensis* and their juvenile equivalents), but chironomid larvae and amphipod species were present in higher numbers than were found at other states.

The **unhealthy hypersaline** state had higher average salinities than the healthy or average hypersaline states. It is also characterised by low average water levels. Despite average depths being mid-range compared with other states, the maximum was relatively low with only 0.4 m difference between the average and maximum depths. Thus, this state was also characterised with low variability in water levels across the time period. The unhealthy hypersaline state had a high average maximum number of days since flow occurred over the barrage, indicating low freshwater flows influencing the state. Like other southern lagoon states, the water quality indicated high average nutrient concentrations (e.g. ammonia and total phosphate) and high turbidity. Like the healthy hypersaline state, such high nutrient levels may have been responsible for the low numbers of fish present, except the high numbers of hardyhead present within this state, although high salinities would also significantly affect fish diversity. The low numbers of fish species also led to the relatively low abundances of some piscivorous bird species, including great cormorant and fairy tern (*Sterna nereis*). Some piscivorous species still occurred within the state in reasonable numbers, including the hoary-headed grebe and

Australian pelican. Other characteristic bird taxa included banded stilt and Australian shelduck. The state supported a very small diversity of invertebrates (e.g. a few *Simplisetia aequisetis*, *Capitella* spp. and *Arthritica helmsi*), but still high numbers of chironomid larvae.

Like the previous southern basin states, the **degraded hypersaline** state had a high average salinity, the highest of all states detected for the Coorong. It also had the lowest average water levels, with a maximum water level of only -0.10 m AHD during the time period. With such low water levels, this state was also characterised by having the lowest average change in water levels over the time period and the lowest average depths. This was likely to be due to the low input of freshwater received from the flow over the barrages, given that this state has the highest minimum number of days since flow (excluding the degraded marine state). Attributes of the water quality for this state were variable, with low average ammonia concentrations, but high average total phosphate concentrations and high turbidity (similar to the average hypersaline state) and higher average TKN. This state was therefore characterised by more variability in nutrient concentrations, compared to others in the southern basin. The state supported relatively few fish species and was dominated by the presence of small-mouthed hardyhead, which are tolerant of high salinity. Similarly, there was also a lack of invertebrate species, including those known to be more salinity-tolerant (e.g. chironomids). The bird taxa characterising this state were waders and waterfowl, with high numbers of banded stilt and red-necked stint, also with silver gull (*Larus novaehollandiae*), masked lapwing (*Vanellus miles*) and Australian shelduck. Similarly to the other hypersaline states, there were lower numbers of piscivorous species, including the Australian pelican and whiskered tern, and the waterfowl grey teal.

While the ERM performs well in describing the ecosystem states that have occurred in the nine years for which we had sufficient data, we acknowledge that other states are likely to (at least potentially) exist that are not adequately represented within this time frame. One that we have identified as likely to occur is an estuarine state, potentially requiring significant, ongoing freshwater inputs, such as have not occurred during the previous decade. Another is a state even less speciose than the degraded hypersaline state in the southern basin, or than the degraded marine state in the northern basin. The existence of both of these states is hinted at in anecdotal accounts of the system, either from the general public or researchers who have worked in the system for many years, and from the trends in data collected during 2008 after the development of these models, particularly in the South Lagoon. The possible existence of other states that fall outside the bounds of the data set is important to keep in mind when interpreting these results with a view to further management of the system.

9.3 Appendix C – Additional results for second-round scenarios

This appendix presents additional output for each of the second round scenarios (excluding those involving pumping at 450 ML day^{-1}). A brief summary of the key findings for each scenario is given, along with figures presenting the changing water levels and salinities for both the North and South Lagoons, and also the changing distribution of ecosystem states along the length of the Coorong.

Scenario 000

The baseline scenario (Scenario 000) showed the ecological effects of continued dry conditions. The scenario involved no flows over the barrages for the duration of the model run, with the only freshwater input into the system being average flows through the Salt Creek. South Lagoon water levels disconnected annually over summer, dropping well below North Lagoon levels, and salinities rose in response (Figure C.1).

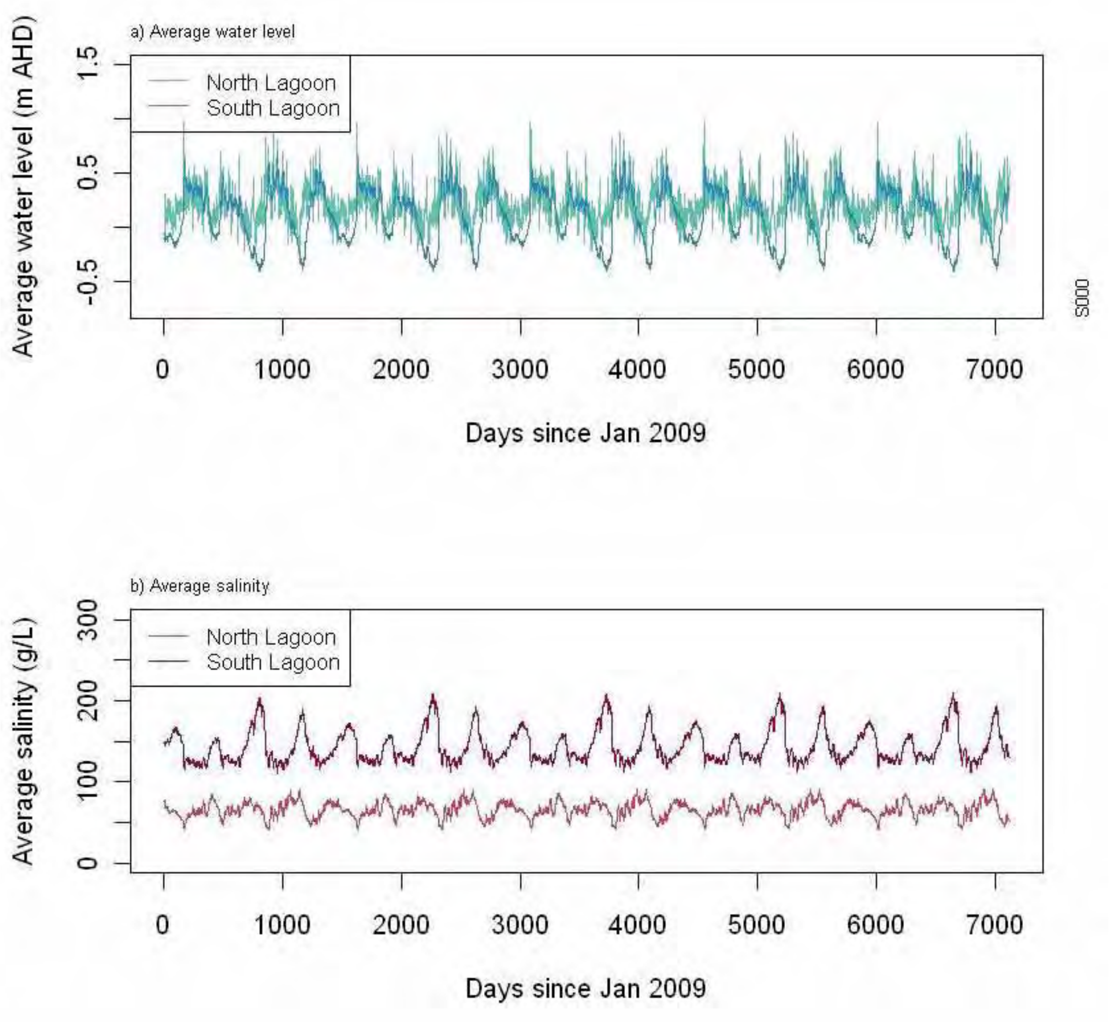

Figure C.1 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 000

In 2008, the South Lagoon of the Coorong was uniformly in the degraded hypersaline state for the length of the lagoon (Figure C.2). There were small improvements in the northern-most site (switching to the average hypersaline state) coinciding with years where meteorological and/or sea level conditions were favourable, but these were short-lived (surviving for two years). Otherwise, the ecology of the South Lagoon remained in the original degraded hypersaline state it began in.

The North Lagoon of the Coorong alternated between the estuarine/marine state and the unhealthy marine state, depending again on the meteorological conditions forcing the system. Except for the last year of the simulation, the North Lagoon was in one of these two states or the other along its entire length.

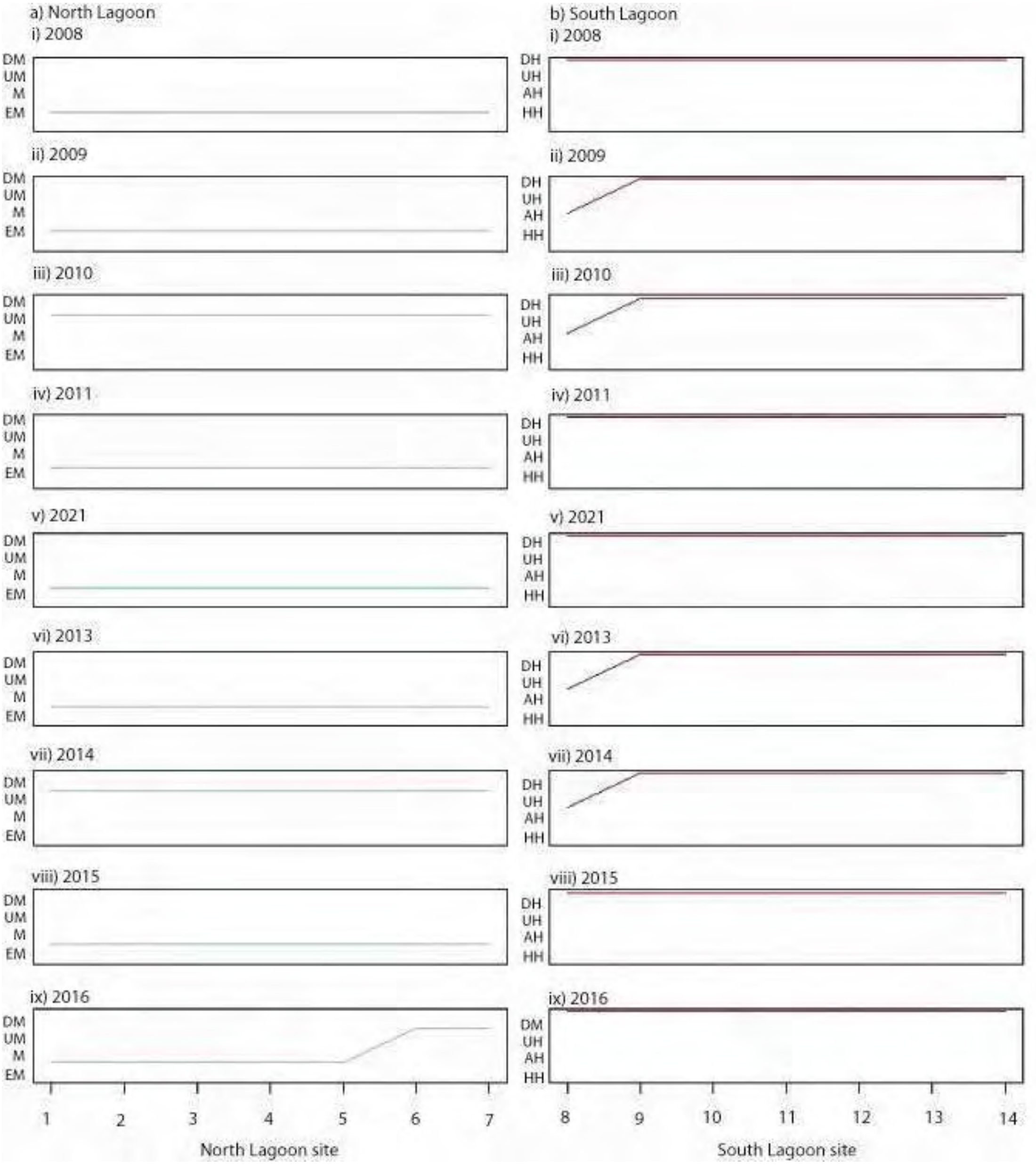

Figure C.2 Distribution of ecosystem states in the North and South Lagoons under Scenario 000

Scenario 302

Scenario 302 investigated the effect of pumping from the South Lagoon at a rate of 150 ML per day for 360 days per annum over three years. Pumping began in winter 2009 and ended in autumn 2012. Also beginning in winter 2009 were works at Parnka channel which maintained the channel at a depth of -0.8 m AHD.

The South Lagoon of the Coorong began in the degraded hypersaline state along its length (Figure C.3). The first year of intervention (2009) saw a slight improvement with one site (near Parnka Point) change to the average hypersaline state. By the second year of intervention (2010) the entire South Lagoon had changed to this average hypersaline state, a condition which was maintained for the remainder of the model run.

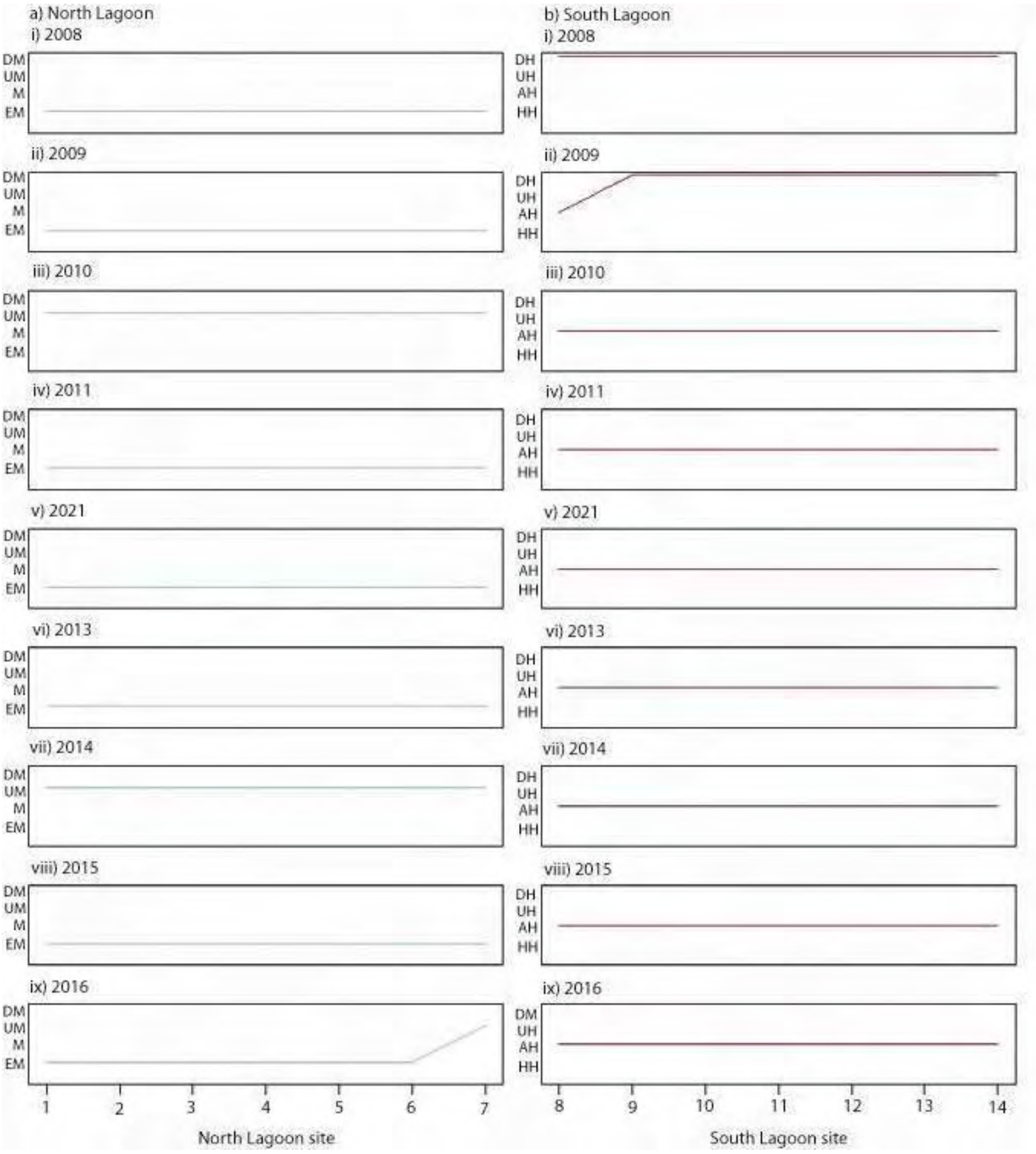

Figure C.3. Distribution of ecosystem states in the North and South Lagoons under Scenario 302

Salinities in the South Lagoon never fell below the identified winter-time target maximum of 60 g L^{-1}, but were below the summer target of 100 g L^{-1} only 50% of the time, largely in the years where pumping was occurring (Figure C.4). For the thresholds identified in the ecological models, the water levels exceeded 0.373 m AHD for 17% of the time and 0.423 m AHD 10% of the time, and maximum salinities exceeded 148.2 g L^{-1} for 5% of the model run.

The North Lagoon of the Coorong was mostly identified as being in the estuarine/marine state, with the exception of 2010 and 2014 when the entire lagoon was unhealthy marine, and also in 2016 when the southern-most site in the North Lagoon changed to unhealthy marine.

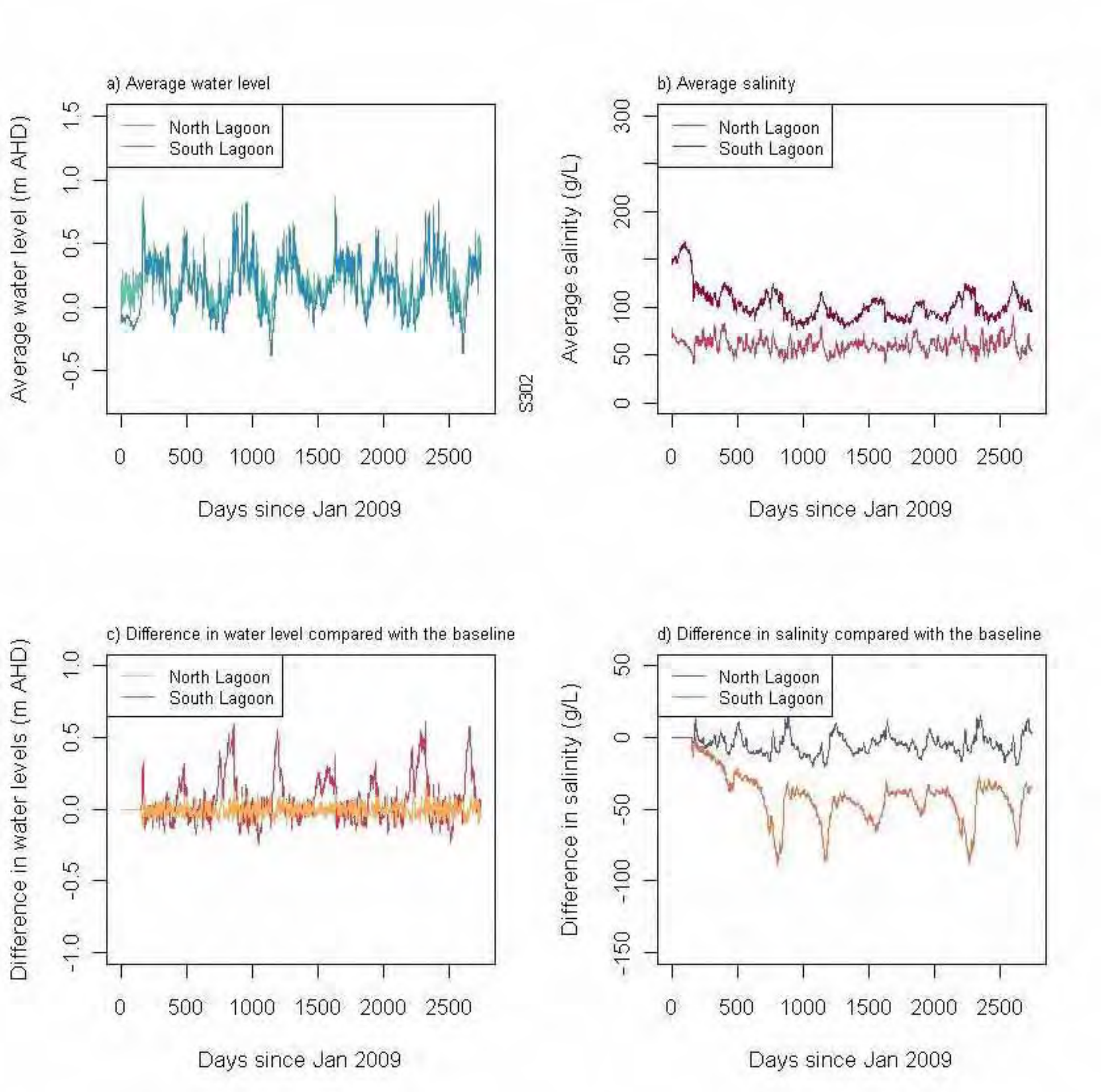

Figure C.4 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 302

Scenario 304

Scenario 304 examined the result of pumping from the South Lagoon at a rate of 150 ML per day for 360 days per annum over three years. Pumping began in spring 2009 and ended in winter 2012. Works at Parnka channel began in winter 2009, keeping the channel depth at -0.8 m AHD.

The total length of the South Lagoon of the Coorong began in the degraded hypersaline state (Figure C.5). After the first year of intervention there was no improvement with all sites remaining in the degraded hypersaline state. By the second year of intervention (2010), the majority of the South Lagoon (excluding one site) had changed to the average hypersaline state. The third year of intervention

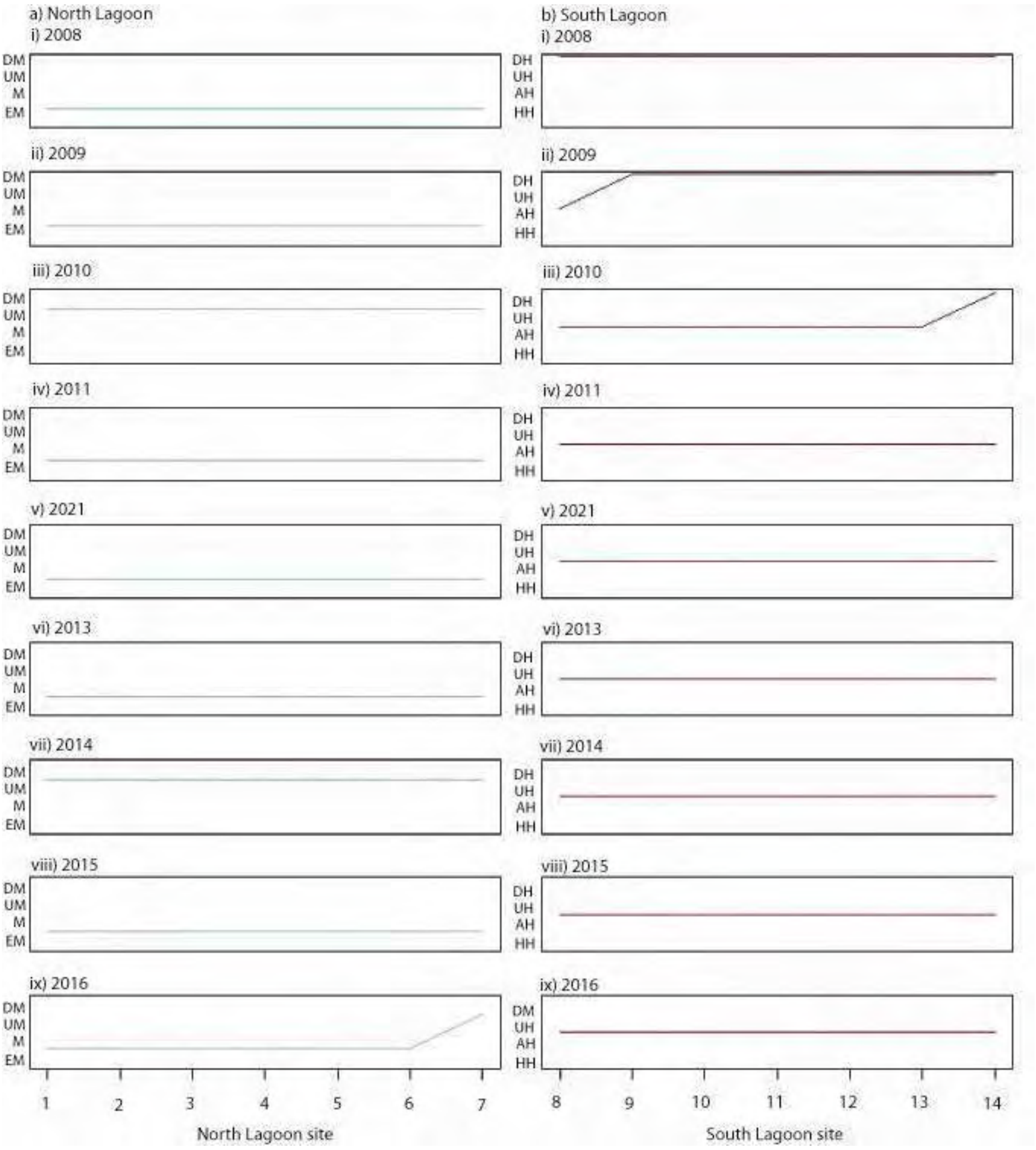

Figure C.5. Distribution of ecosystem states in the North and South Lagoons under Scenario 304

(2011) saw the improvement of the remaining site changing to the average hypersaline state, a condition that the length of the South Lagoon maintained for the remainder of the model run.

Salinities in the South Lagoon were always greater than the identified winter-time target maximum of 60 g L^{-1} (Figure C.6). Salinities fell below the summer target of 100 g L^{-1} 48% of the time, largely during autumn and winter during pumping years. Water levels exceeded 0.373 m AHD for 17% and 0.423 m AHD 9% of the time, for the ecological model thresholds. Maximum salinities in the South Lagoon exceeded the 148.2 g L^{-1} for 5% of the model run.

The North Lagoon of the Coorong was predominantly identified as being in the estuarine/marine state, with only the years 2010 and 2014 showing the entire lagoon as being in the unhealthy marine state. In 2016 the southern-most site in the North Lagoon was also identified as being in the unhealthy marine state.

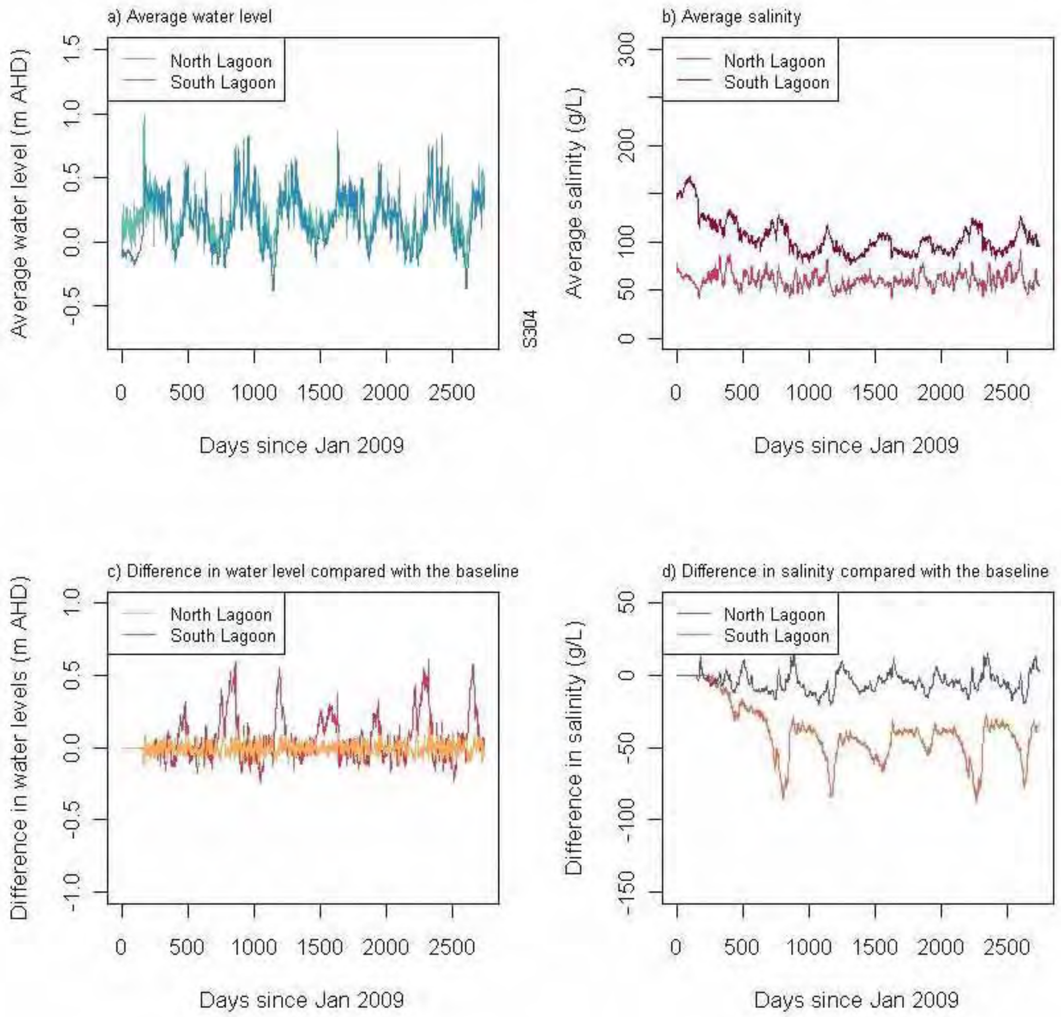

Figure C.6 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 304

Scenario 306

Scenario 306 considered the effect of pumping the South Lagoon for 360 days per annum over three years at a rate of 150 ML per day. Pumping began in winter 2009 and finished in autumn 2012. Works at Parnka channel also began in autumn 2010, which maintained the channel at a depth of -0.8 m AHD.

Before intervention (2008) the South Lagoon was in the degraded hypersaline state along its length (Figure C.7). The first year of intervention (2009) saw a minor improvement in one site (near Parnka Point) through a change to the average hypersaline state. By the second year of intervention (2010), the northern half (4 sites) of the South Lagoon had changed to the average hypersaline, with the three southern sites remaining in the degraded hypersaline state. By the third year of

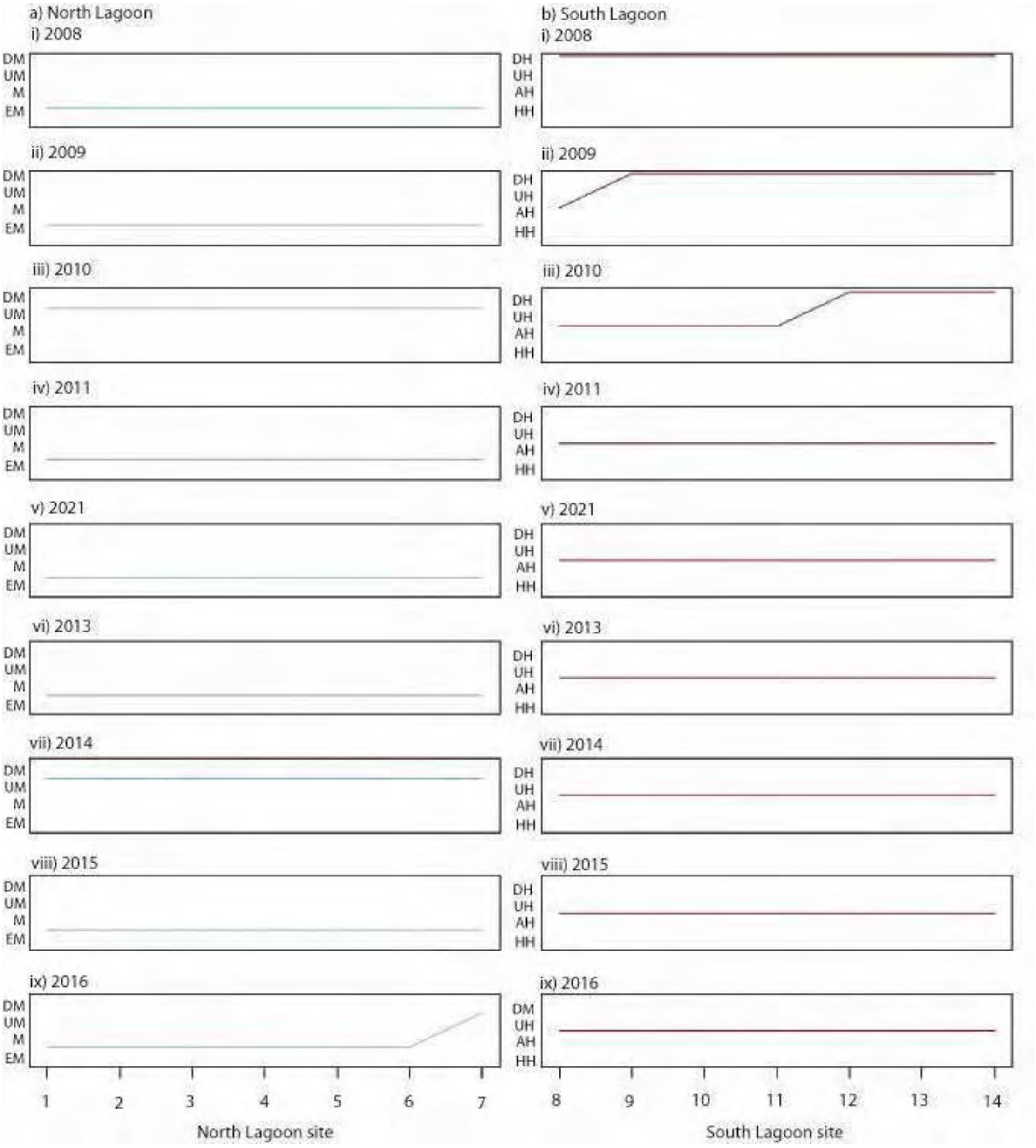

Figure C.7. Distribution of ecosystem states in the North and South Lagoons under Scenario 306

intervention (2011), the southern three sites had slightly improved to the average hypersaline state. This condition continued for the remainder of the model run.

Salinities in the South Lagoon were never lower than the identified winter-time target maximum of 60 g L^{-1} (Figure C.8), but were lower than the summer target of 100 g L^{-1} 46% of the time, particularly after the second year of intervention. Compared to the thresholds identified in the ecological models, water levels exceeded 0.373 m AHD 16% of the time and 0.423 m AHD 9% of the time. In the model run, maximum salinities exceeded 148.2 g L^{-1} 5% of the time.

Only during 2010 and 2014 was the length North Lagoon identified as being in the unhealthy marine state, with it being in the estuarine/marine state for the remainder of the years. In 2016 the southern-most site of the North Lagoon was also in the unhealthy marine state.

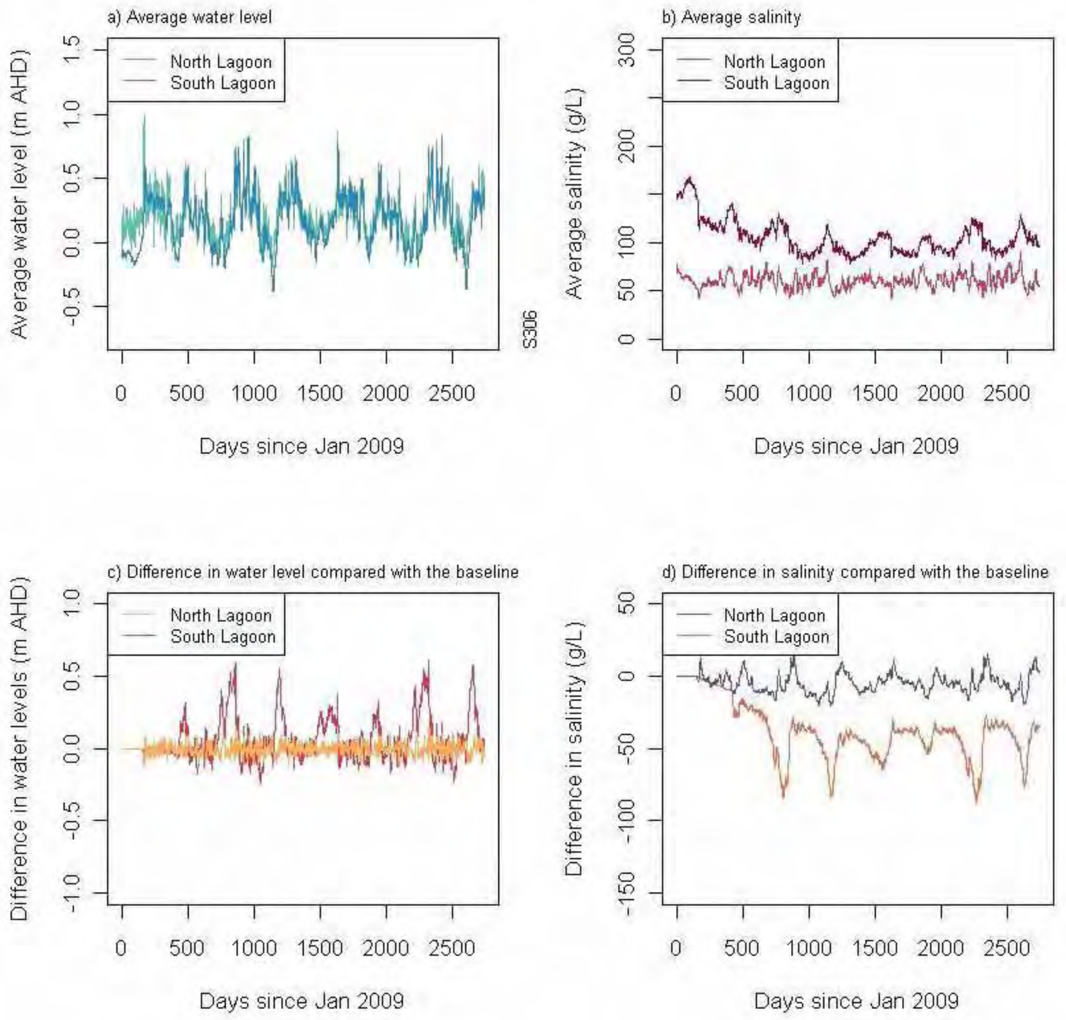

Figure C.8 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 306

Scenario 308

The consequence of pumping the South Lagoon at a rate of 150 ML per day for 360 days per annum over three years was investigated in Scenario 308. Pumping began in spring 2009 and finished in winter 2012. In autumn 2010 works at Parnka channel began, which kept the channel at a depth of -0.8 m AHD.

The South Lagoon of the Coorong began in the degraded hypersaline state along its length (Figure C.9). The first year of intervention (2009) saw a small improvement with one site (near Parnka Point) changing to the average hypersaline state. By the second year of intervention (2010) the three northern sites of the South Lagoon had changed to the average hypersaline with the southern end remaining in the degraded hypersaline state. By 2011 only the two most southern sites remained in

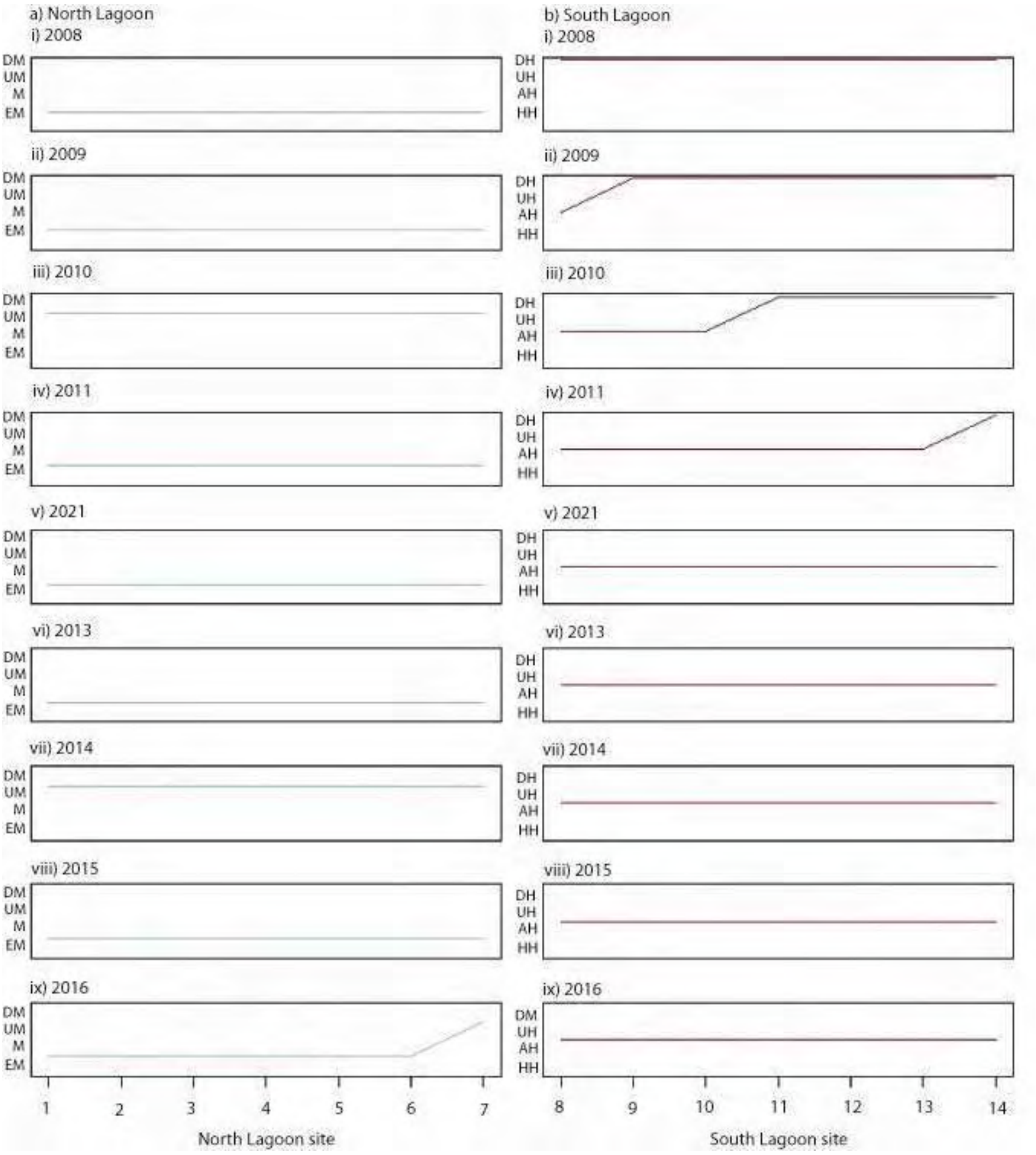

Figure C.9. Distribution of ecosystem states in the North and South Lagoons under Scenario 308

the degraded hypersaline state, only changing to the average hypersaline state by 2012, a condition maintained for the remainder of the model run.

Salinities for the South Lagoon were never lower than the identified winter-time target maximum of 60 g L^{-1} but were below the summer target of 100 g L^{-1} 45% of the time (Figure C.10). South Lagoon water levels exceeded 0.373 m AHD 16% of the time and 0.423 m AHD 9% of the time, for the thresholds identified in the ecological models. Maximum salinities exceeded 148.2 g L^{-1} for 5% of the model run.

The length of the North Lagoon of the Coorong was mostly identified as being in the estuarine/marine state, with the exception of 2010 and 2014 where the entire lagoon was unhealthy marine. In 2016 the southern-most site in the North Lagoon changed to unhealthy marine.

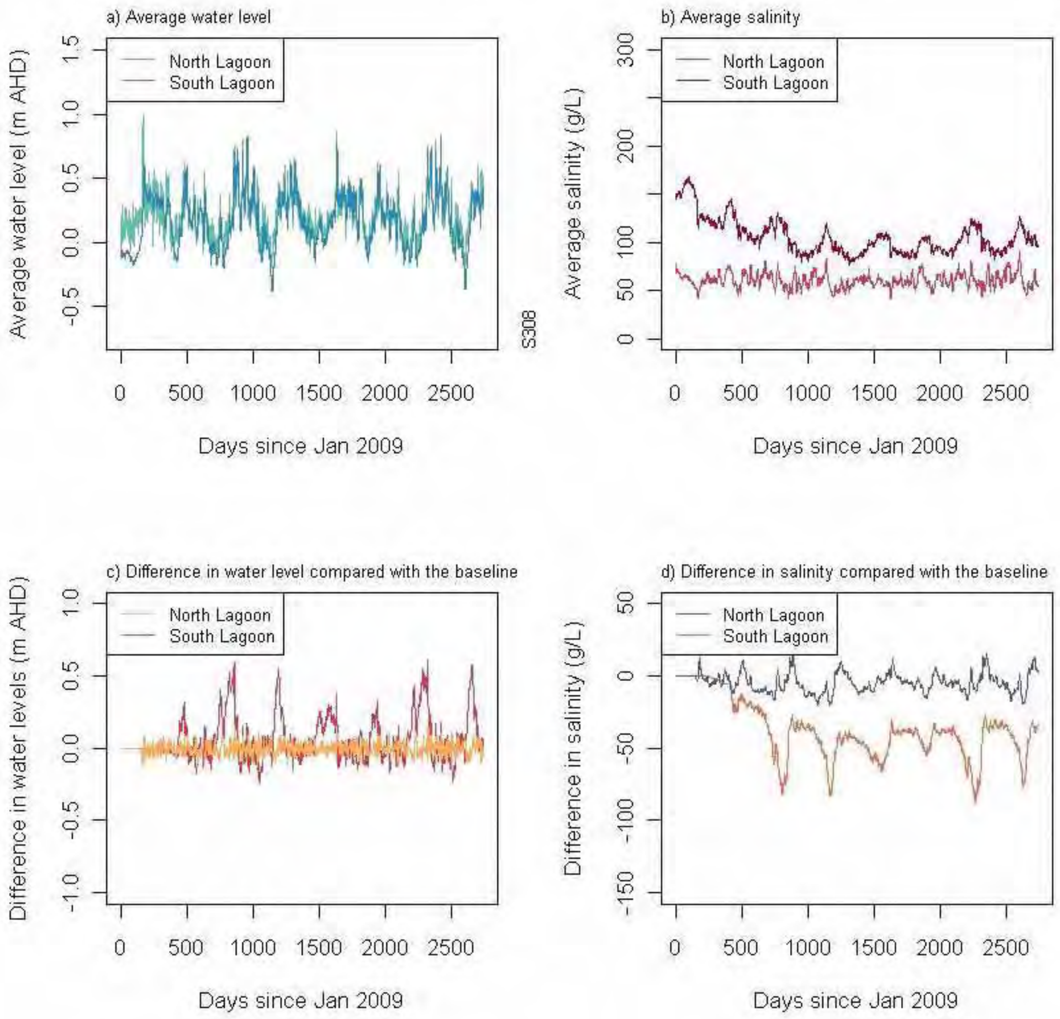

Figure C.10 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 308

Scenario 310

Scenario 310 examined the effect of pumping from the South Lagoon for 360 days per annum over three years, at a rate of 150 ML per day. Pumping began in winter 2009 and ended in autumn 2012. In winter 2009 channel works also began at Parnka Point, maintaining the channel depth at -0.4 m AHD.

The length of the South Lagoon of the Coorong began in the degraded hypersaline state, but shifted between the degraded hypersaline and average hypersaline states over the model run (Figure C.11). The first year of intervention (2009) showed a slight improvement with one site (near Parnka Point) changing to the average hypersaline condition. By the second (2010) and third year of intervention (2011) five and four sites changed to the average hypersaline state, respectively. Following

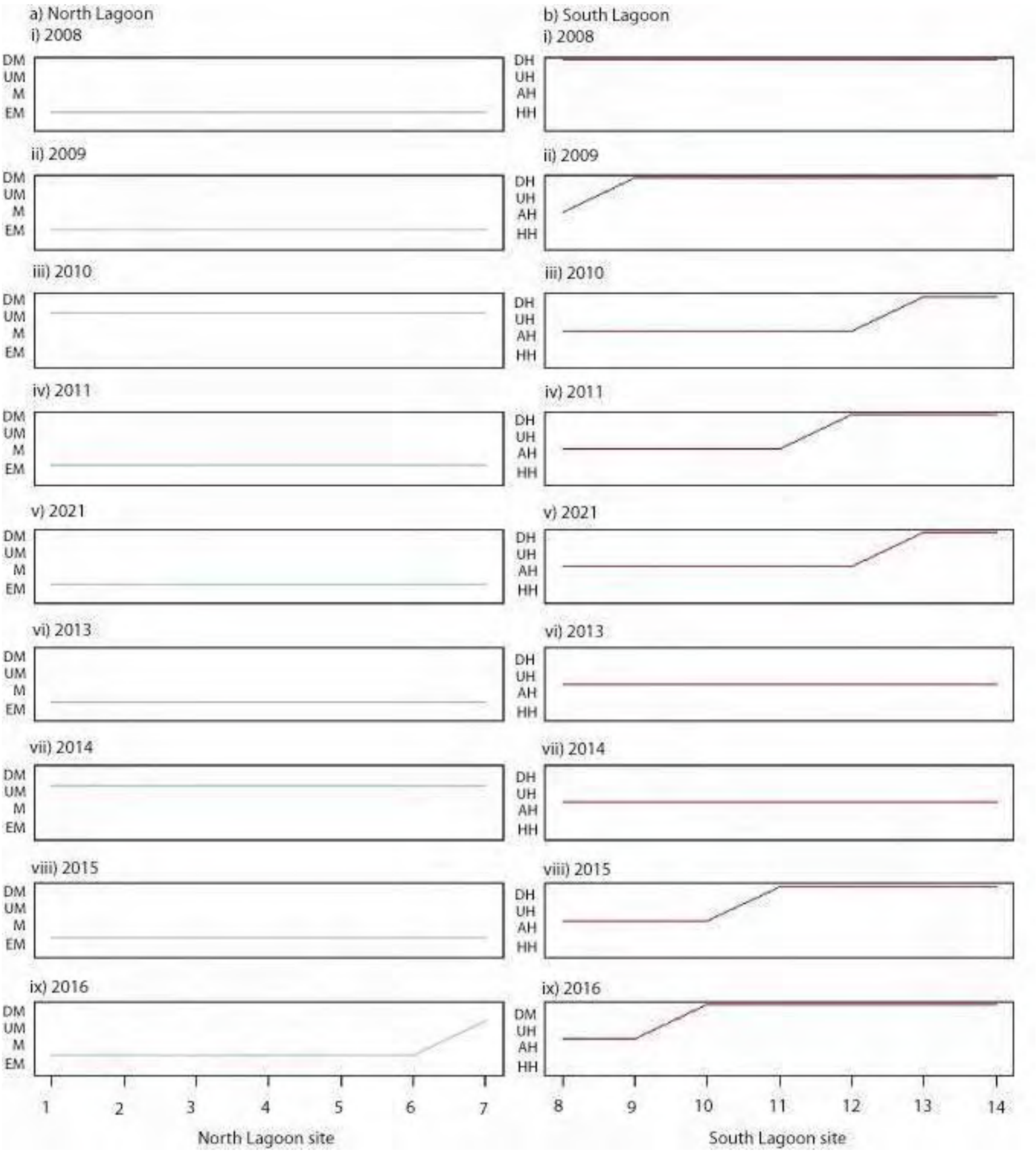

Figure C.11. Distribution of ecosystem states in the North and South Lagoons under Scenario 310

intervention the South Lagoon shifted from the entire length being in the average hypersaline state in two years (2013 and 2014), to sites (typically between 8 and 12) changing between the degraded and average hypersaline states for the remainder of the run.

Salinities in the South Lagoon were always greater than the winter-time target maximum of 60 g L^{-1} and were below the summer-time target of 100 g L^{-1} 24% of the time (Figure C.12). For the identified thresholds in the ecological models, water levels exceeded 0.373 m AHD for 15% and 0.423 m AHD for 9% of the time. The maximum salinity threshold (148.2 g L^{-1}) was exceeded for 5% of the model run.

The identification of states in the North Lagoon was predominantly the estuarine/marine state, with only the years 2010 and 2014 and the southern-most site in 2016 being different, in the unhealthy marine state.

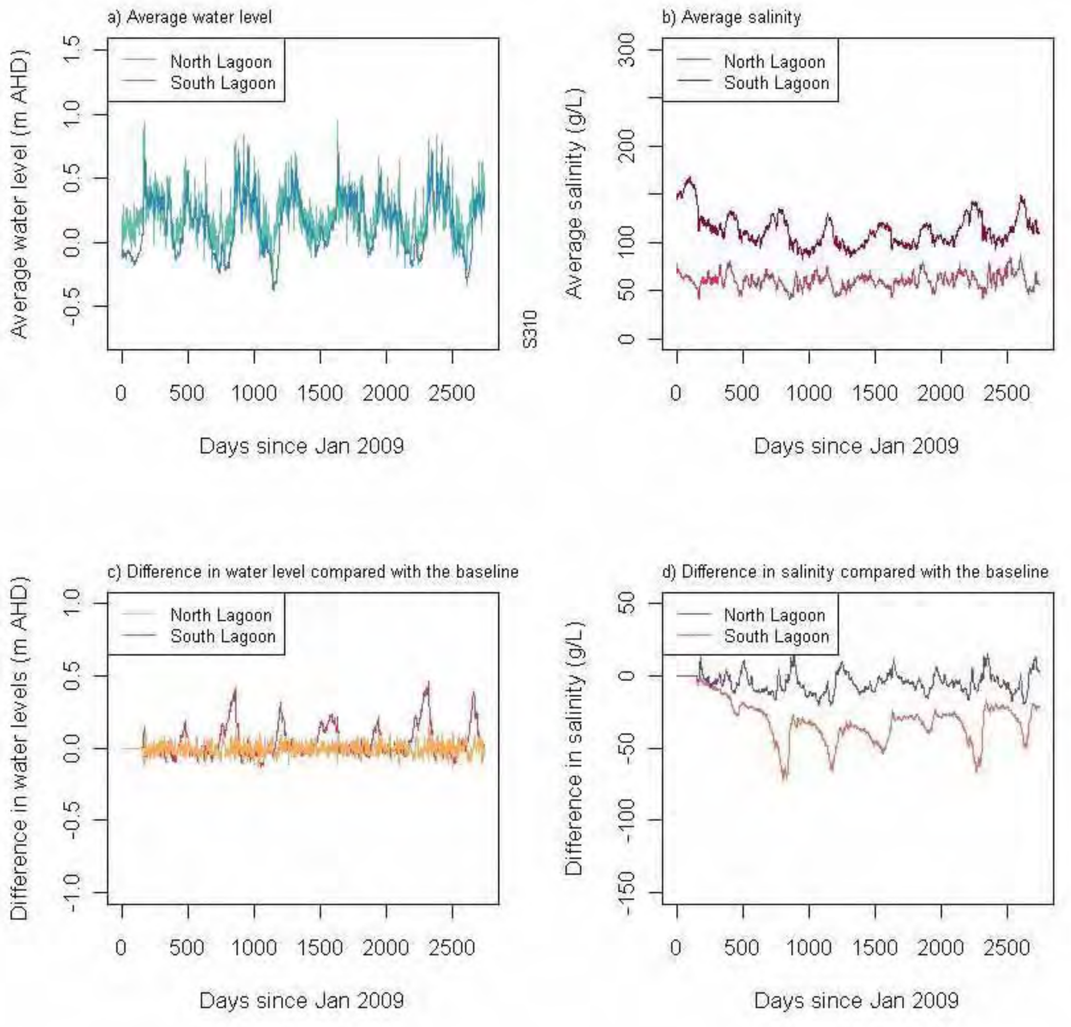

Figure C.12 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 310

Scenario 311

Scenario 311 investigated the result of pumping from the South Lagoon for 360 days per annum over three years, at a rate of 150 ML per day. Pumping began in winter 2009 and ended in autumn 2012. The works at Parnka channel began in autumn 2010 and kept the channel depth at -0.4 m AHD.

The whole of the South Lagoon of the Coorong was originally in the degraded hypersaline state, but shifted between the degraded and average hypersaline states (Figure C.13). During the years of intervention (2009-2012), the South Lagoon slightly improved progressively south from degraded to average hypersaline conditions. Upon intervention completion (2013 and 2014) the length of the South

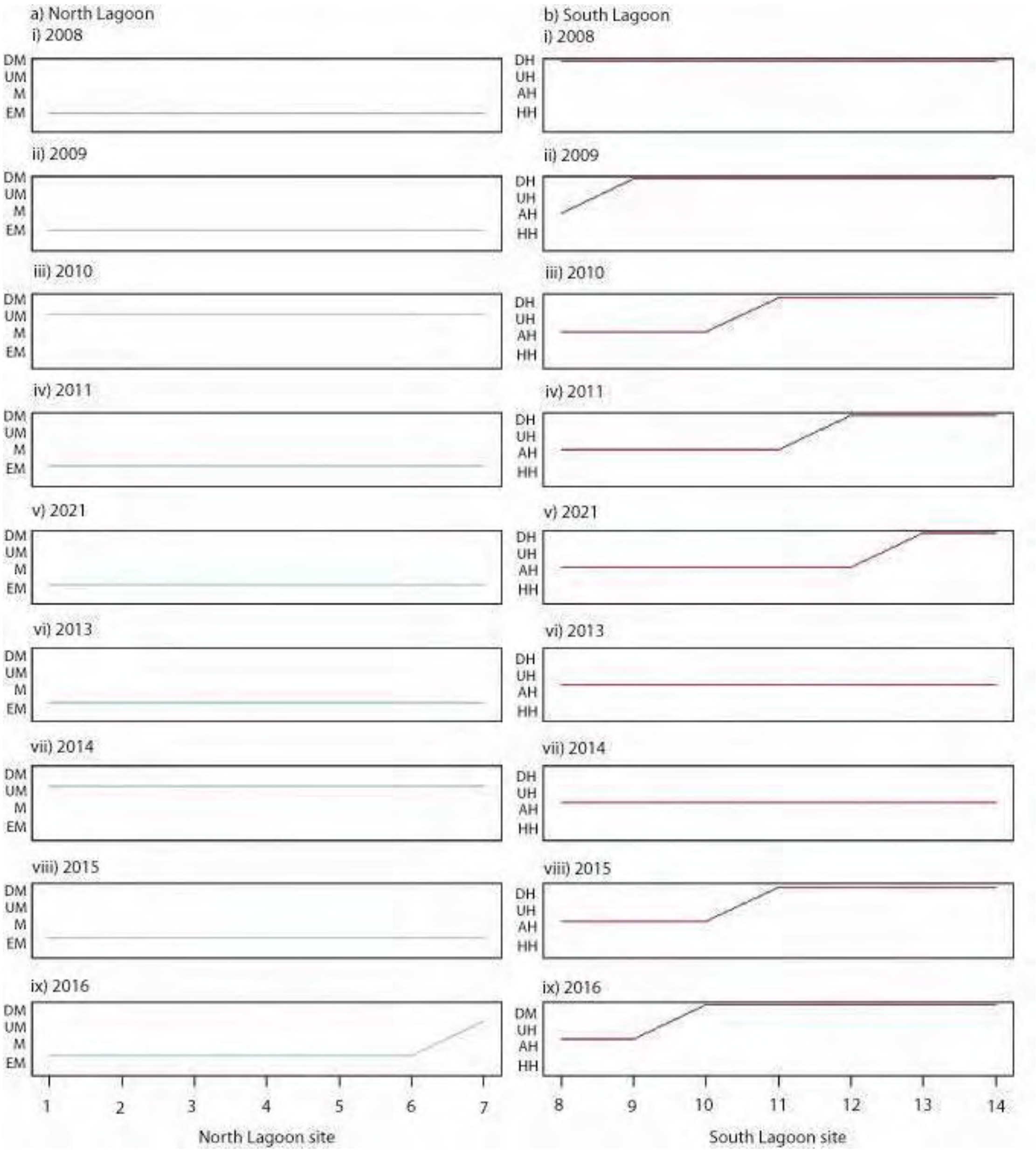

Figure C.13. Distribution of ecosystem states in the North and South Lagoons under Scenario 311

Lagoon slightly improved to the average hypersaline state, but for the remainder of the model run the southern end of the South Lagoon returned to the original degraded hypersaline state.

As for the preceding scenarios, South Lagoon salinities were never lower than the identified winter-time target maximum of 60 g L^{-1} (Figure C.14). Salinities fell below the summer-time target of 100 g L^{-1} 22% of the time. Water levels in the South Lagoon exceeded the ecological model water level thresholds of 0.373 m AHD for 14% of the time and 0.423 m AHD 9% of the time and maximum salinity threshold of 148.2 g L^{-1} for 5 % of the model run.

The North Lagoon of the Coorong was mostly identified as estuarine/marine, with the exception of 2010 and 2014 when the length of the North Lagoon was unhealthy marine and also in 2016 when the southern-most site changed to unhealthy marine.

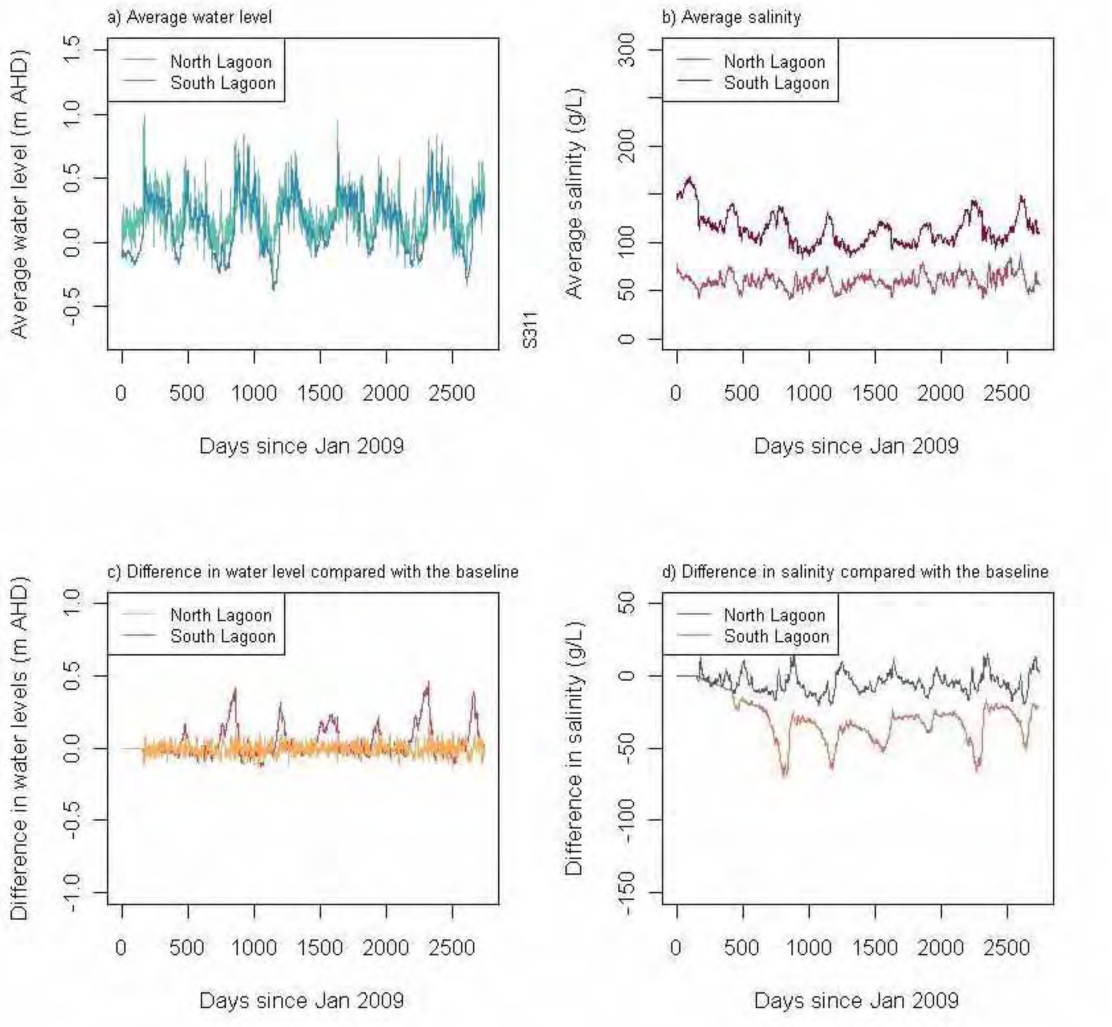

Figure C.14 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 311

Scenario 312

The effect of pumping from the South Lagoon for 360 days per annum over three years at a rate of 150 ML per day was examined in Scenario 312. Pumping commenced in spring 2009 and was completed in winter 2012. Works at Parnka channel also began in autumn 2010 and maintained the channel depth at -0.4 m AHD.

In 2008 the length of the South Lagoon of the Coorong was in the degraded hypersaline state (Figure C.15). Throughout the years when intervention was occurring (2009-2012), the South Lagoon progressively showed slight improvement changing from the degraded to average hypersaline state, except for the southern-most sites. After intervention (years 2013 and 2014), the southern-most sites

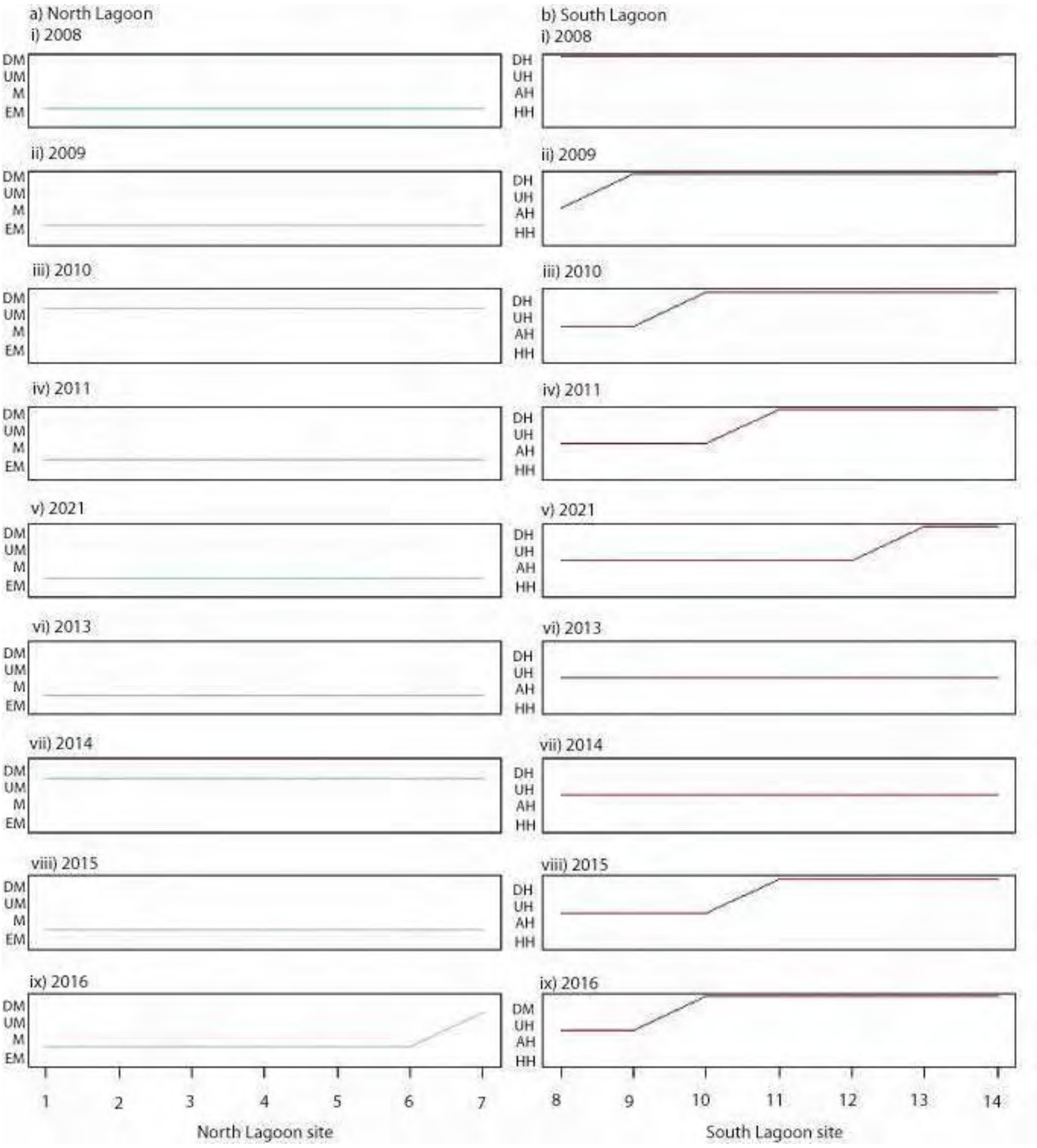

Figure C.15. Distribution of ecosystem states in the North and South Lagoons under Scenario 312

changed to the same average hypersaline state shown in the northern parts of the South Lagoon. Subsequently, and for the remainder of the model run, the southern-most sites returned to the original degraded hypersaline state.

Salinities in the South Lagoon were never lower than the winter-time target maximum of 60 g L^{-1} and were lower than the summer-time target of 100 g L^{-1} for 23% of the time (Figure C.16). For the thresholds identified in the ecological models, the water levels exceeded 0.373 m AHD for 15% of the time, 0.423 m AHD for 8% of the time, and maximum salinities exceeded 148.2 g L^{-1} for 5% of the model run.

The length of the North Lagoon was mostly identified as being in the estuarine/marine state, but in the years 2010 and 2014 it was in the unhealthy marine state. In 2016 there was also a slight change in states, with the southern-most site changing to the unhealthy marine condition.

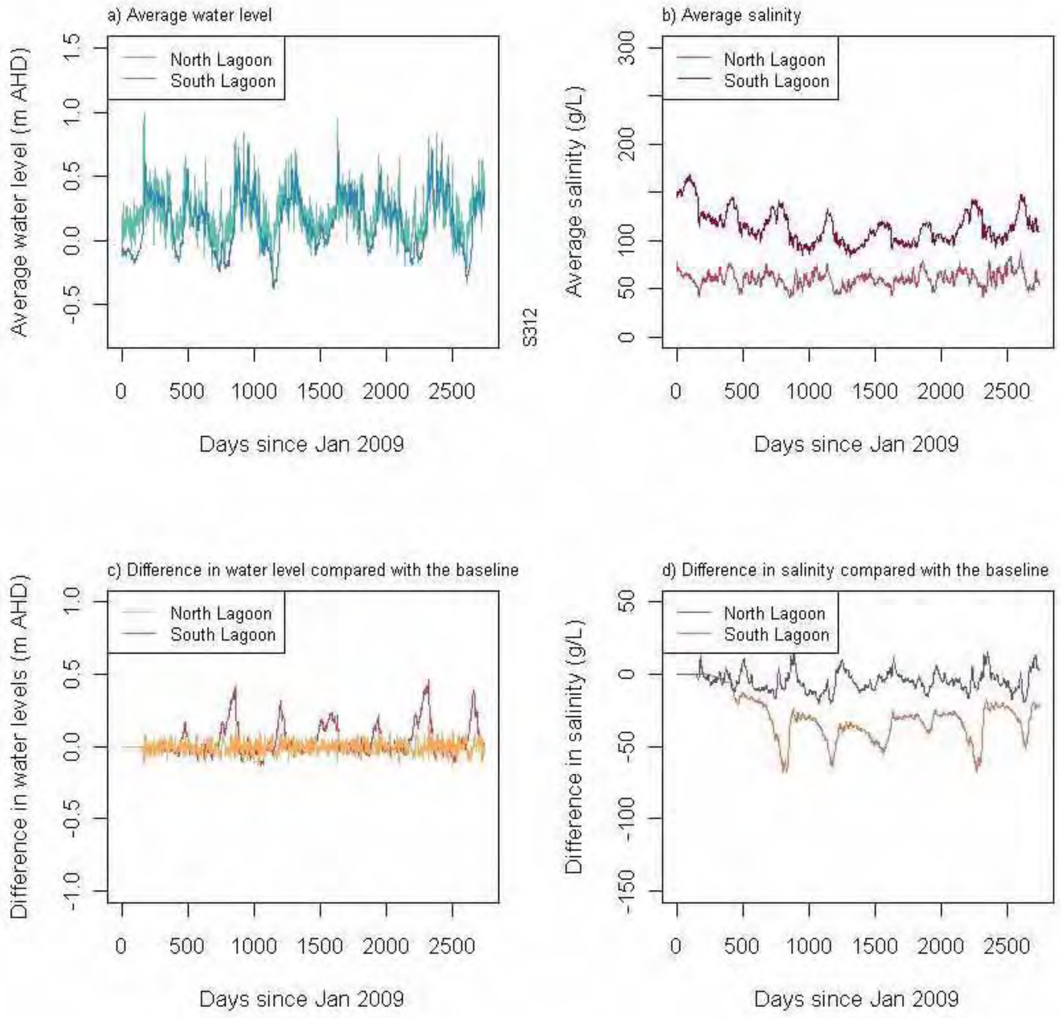

Figure C.16 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 312

Scenario 313

Scenario 313 considered the effect of pumping from the South Lagoon for 360 days per annum over three years at a rate of 150 ML per day. Pumping began in spring 2009 and finished in winter 2012. The works at Parnka channel began in winter 2009, keeping the channel at a depth of -0.8 m AHD. In addition, a flow of 150 ML per day was augmented through Salt Creek.

All sites in the South Lagoon began in the degraded hypersaline state (Figure C.17). By the end of the first year of pumping (2009) the South Lagoon showed minimal improvement with only one site (near Parnka Point) changing to the average hypersaline state. The second year of intervention (2010) showed a greater improvement with the remainder of sites changing to the average hypersaline state.

Figure C.17. Distribution of ecosystem states in the North and South Lagoons under Scenario 313

For the rest of the model run, the length of the South Lagoon stayed in the average hypersaline state.

Salinities in the South Lagoon never fell below the winter-time target maximum of 60 g L^{-1}, but were below the summer-time target of 100 g L^{-1} for 59% of the time, particularly in years following the first year of intervention (Figure C.18). Salinity was greater than the maximum of 148.2 g L^{-1} for 5% of the model run. South Lagoon water levels exceeded model thresholds of 0.373 m AHD 17% and 0.423 m AHD 10% of the time.

All sites of the North Lagoon were predominantly in the estuarine/marine state, but for the years 2010 and 2014 sites had changed to the unhealthy marine state. In 2016, the southern-most site had also changed to the unhealthy marine state, with the remainder identified as being estuarine/marine.

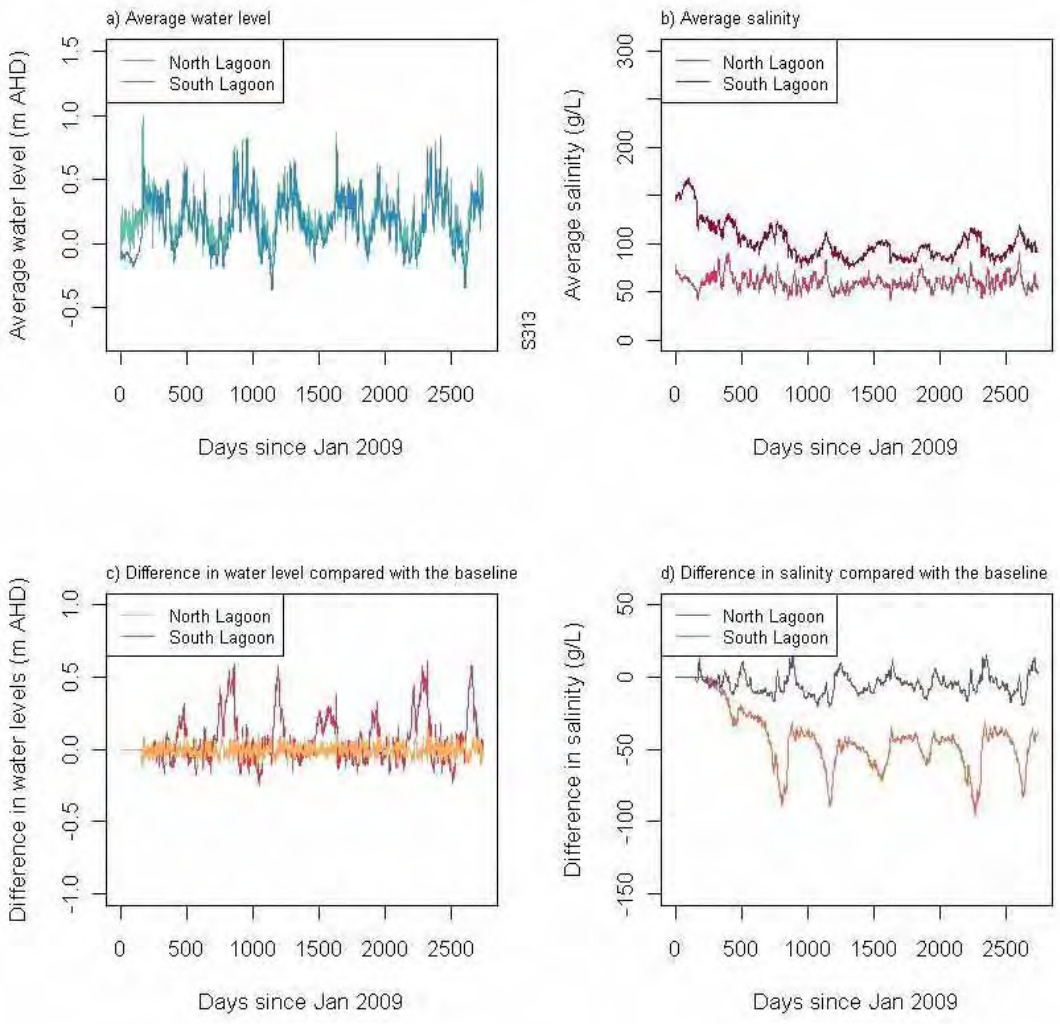

Figure C.18 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 313

Scenario 315

The effect of pumping for 360 days per annum over three years at a rate of 150 ML per day was examined for Scenario 315. Pumping began in winter 2009 and was completed in autumn 2012, with no additional intervention strategies in place.

The length of the South Lagoon was originally in the degraded hypersaline, but shifted between the degraded and average hypersaline states throughout the model run (Figure C.19). By the first year of intervention on the northern-most site (near Parnka Point) had improved to the average hypersaline state. By the second year of intervention (2010) another site had also changed to the average hypersaline state. For the remainder of the years, the northern-most sites typically shifted between the

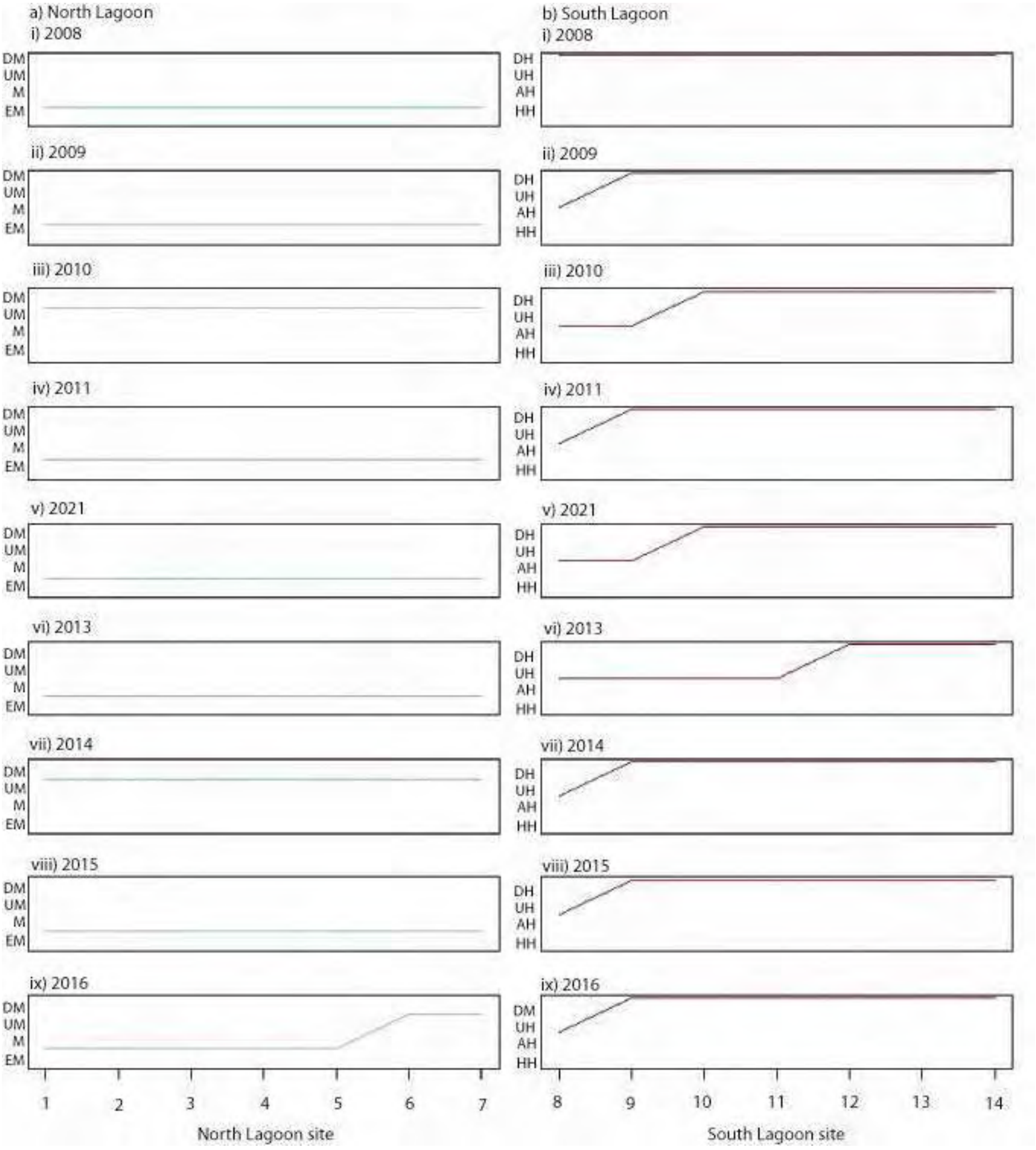

Figure C.19. Distribution of ecosystem states in the North and South Lagoons under Scenario 315

degraded and average hypersaline states. Sites further south in the South Lagoon remained in the degraded hypersaline state for the entire model run. South Lagoon salinities were always higher than the winter-time target maximum of 60 g L^{-1}, but were below the summer-time target of 100 g L^{-1} for 11% of the time (Figure C.20). Salinities were also higher than the maximum of 148.2 g L^{-1} for 16% of the time. Water levels exceeded the thresholds of 0.323 m AHD for 11%, and 0.423 m AHD for 6%, of the model run.

The North Lagoon of the Coorong was mostly identified as being in the estuarine/marine state, except in 2010 and 2014 where the total length and also in 2016 when the two most southern sites were in the unhealthy marine condition.

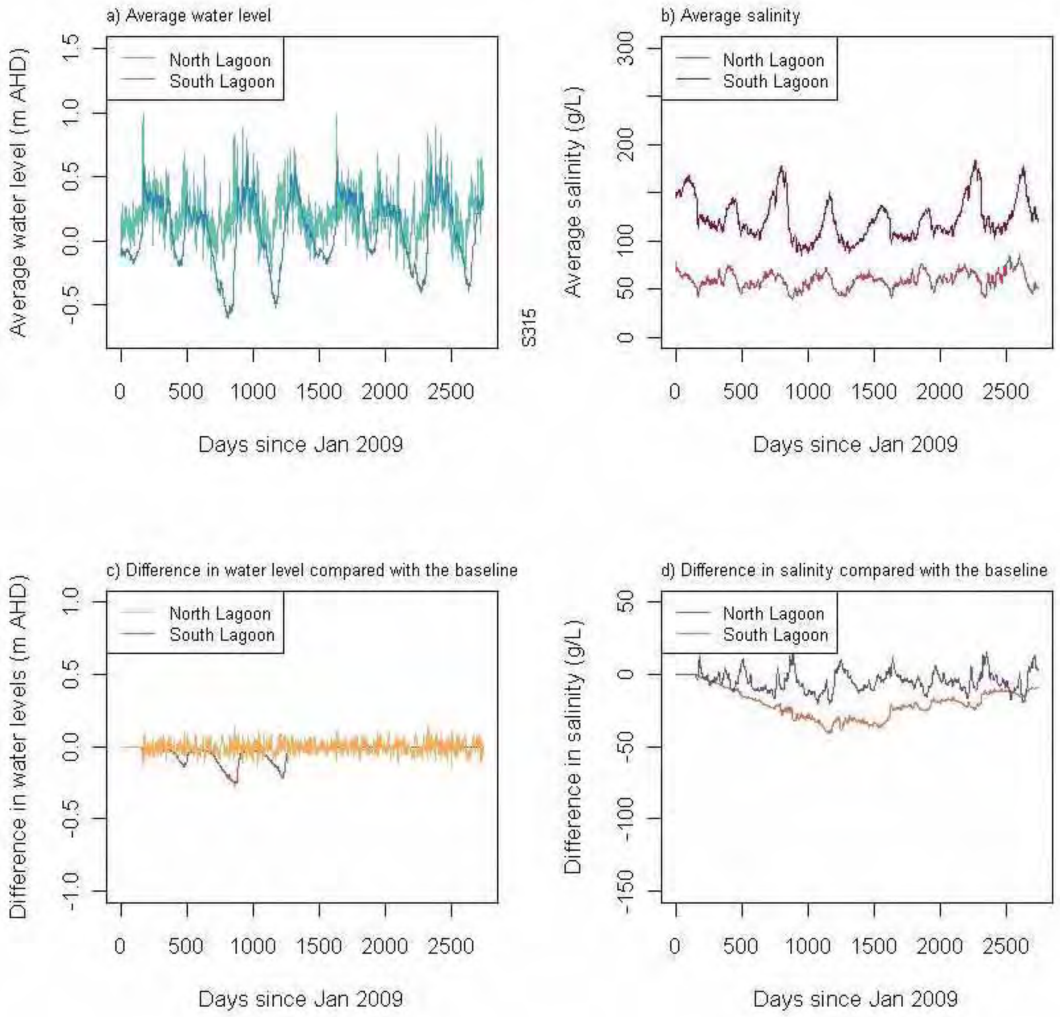

Figure C.20 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 315

Scenario 317

Scenario 317 investigated the effect of pumping for 360 days per annum over three years at a rate of 150 ML per day. Pumping commenced in spring 2009 and ended in winter 2012, with no other intervention occurring.

The South Lagoon began in the degraded hypersaline state and continually changed between this and the average hypersaline condition in following years (Figure C.21). During the years of intervention the most northern site (near Parnka Point) changed from the degraded state and remained in the average hypersaline for the rest of the model run. The southern-most sites did not show any improvement with no change from their original degraded hypersaline condition.

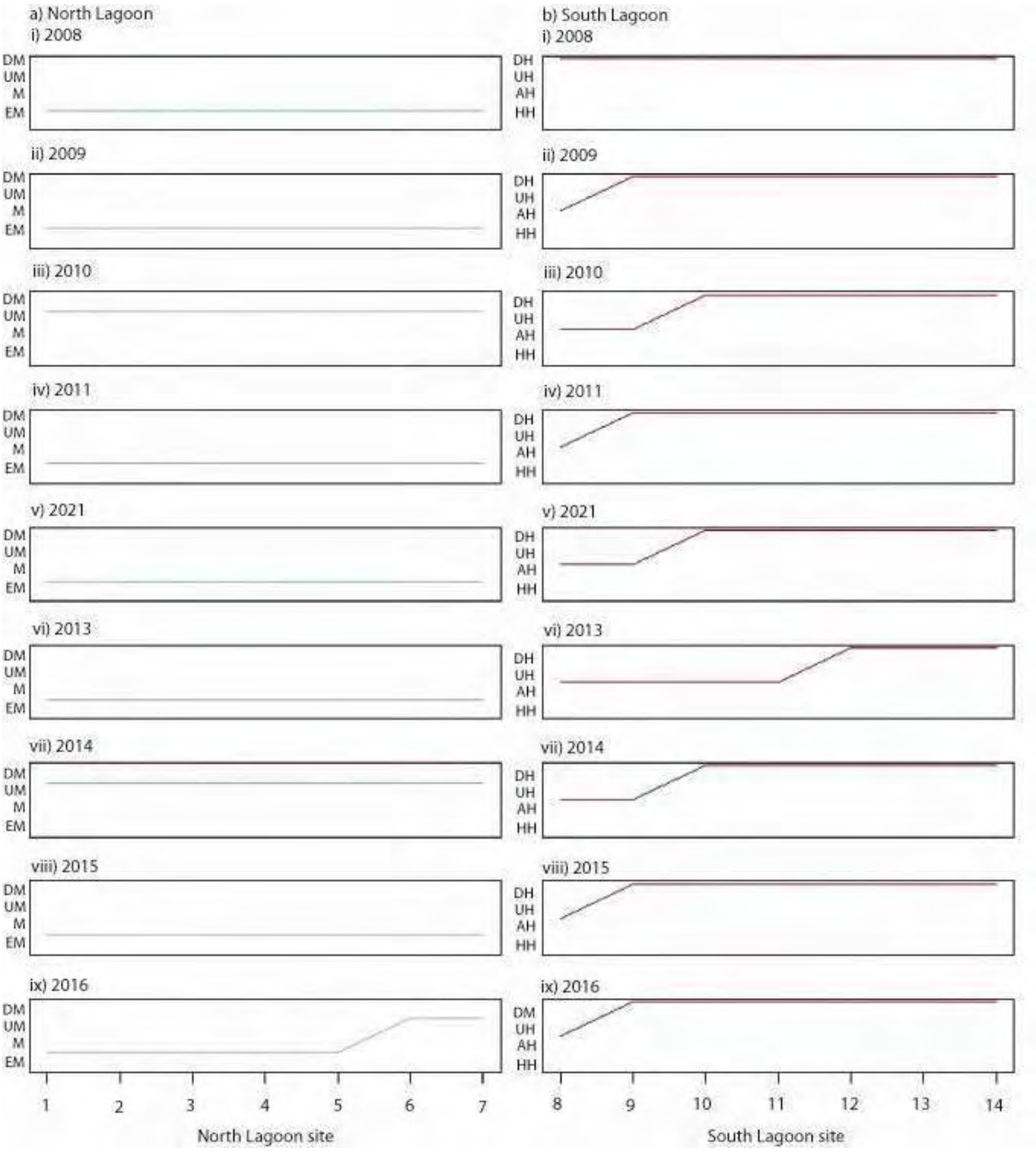

Figure C.21. Distribution of ecosystem states in the North and South Lagoons under Scenario 317

Salinities in the South Lagoon were never lower than the winter-time target maximum of 60 g L^{-1} and were below the summer-time target of 100 g L^{-1} for 12 % of the time (Figure C.22). The maximum salinity of 148.2 g L^{-1} was exceeded for 16% of the model run. Thresholds for water level of 0.323 m AHD and 0.423 m AHD were exceeded for 11% and 6%, respectively.

All sites in the North Lagoon began and remained in the estuarine/marine state, with the exception of 2010 and 2014 where all sites and also in 2016 when the two southern-most sites changed to the unhealthy marine condition.

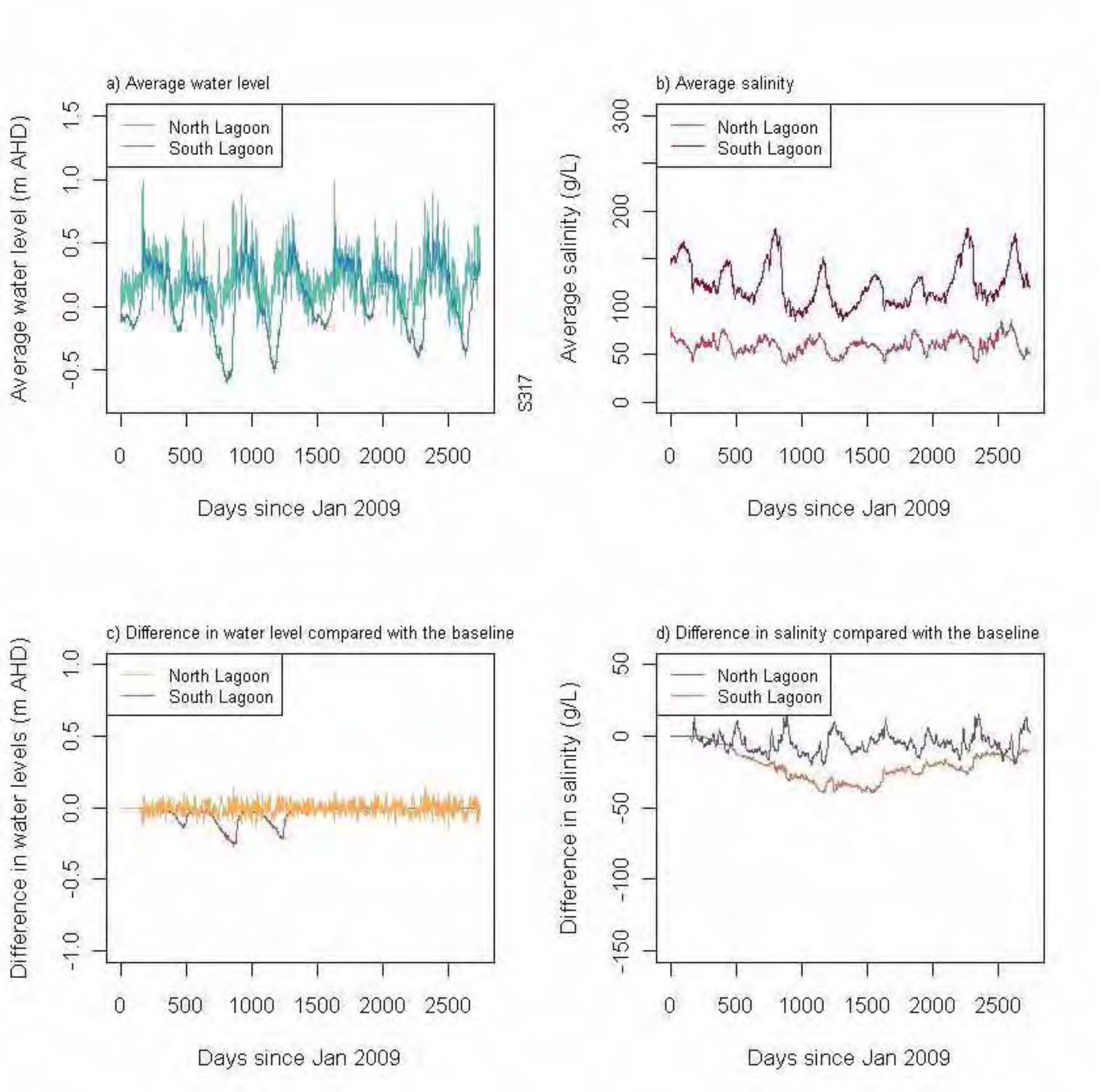

Figure C.22 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 317

Scenario 318

Scenario 318 considered the effect of returning median barrage flows into the system. Flows began in June 2009 and were continuously implemented for the remainder of the model run.

All sites in the South Lagoon began, in 2008, in the degraded hypersaline state (Figure C.23). The first year of intervention saw a vast improvement with all sites changing to the healthy hypersaline state, a condition that was maintained until 2015. In the final year of the model run (2016) the length of the South Lagoon had deteriorated to the unhealthy hypersaline condition.

Figure C.23. Distribution of ecosystem states in the North and South Lagoons under Scenario 318

Salinities in the South Lagoon were lower than the winter-time target maximum of 60 g L^{-1}, largely in the years following the initial return of barrage flows (2009) (Figure C.24). Salinities also fell below the summer-time target of 100 g L^{-1} 92% of the time, with salinities greater than the threshold of 148.2 g L^{-1} observed only in 5% of the model run. Water-level thresholds of 0.373 m AHD and 0.423 m AHD were exceeded 60% and 56% of the time, respectively.

The estuarine/marine state was observed at all sites of the North Lagoon throughout the whole of the model run.

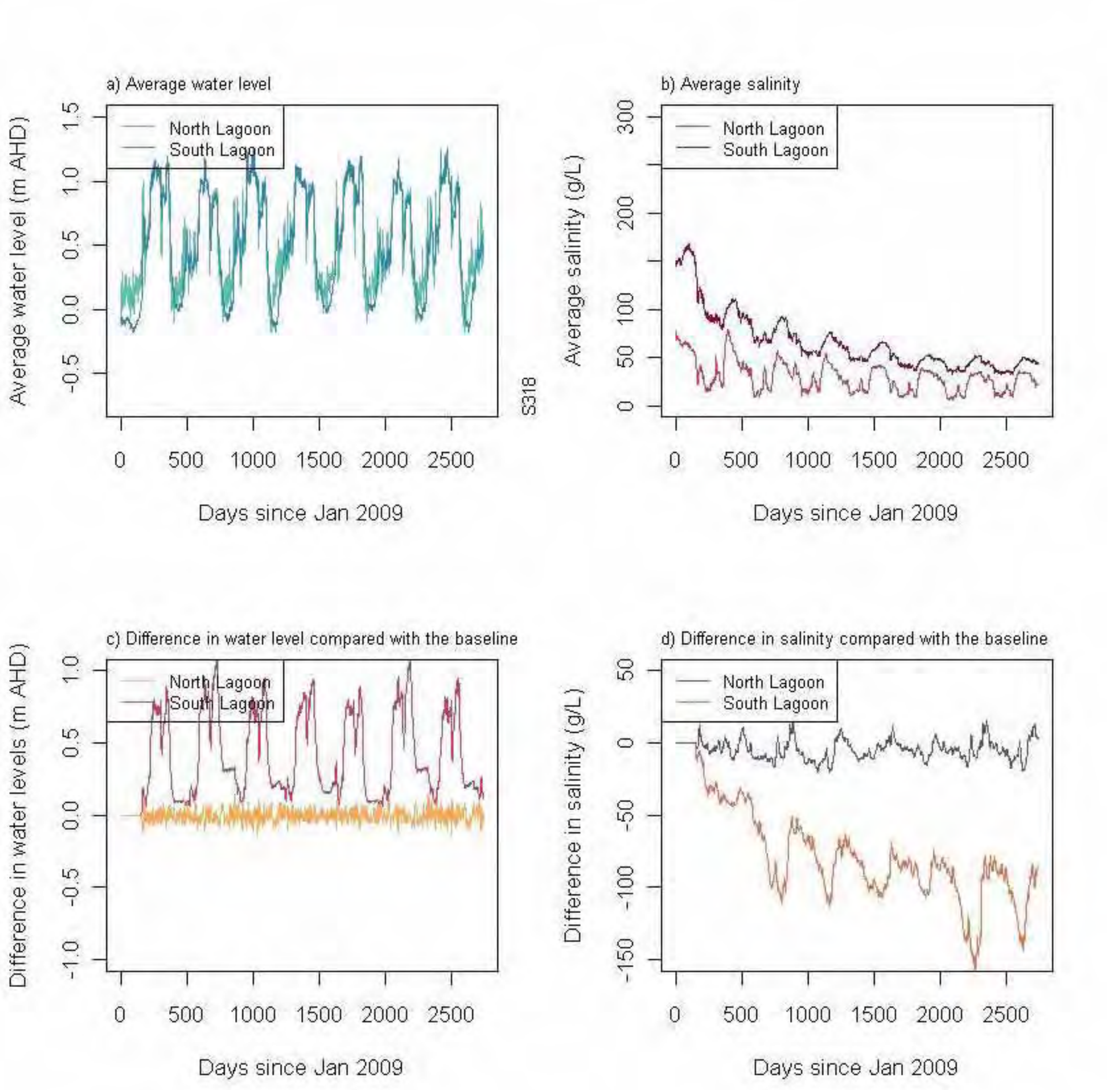

Figure C.24 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 318

Scenario 319

The effect of continuously returning median barrage flows into the system, beginning in June 2009 was examined in Scenario 319. Ongoing works at Parnka channel, also starting in June 2009, maintained the channel depth at -0.8 m AHD.

The South Lagoon of the Coorong began in the degraded hypersaline state along its length (Figure C.25). The first year of intervention saw a great improvement, with all sites changing to the healthy hypersaline state, a condition that was maintained in 2015. The final year of the model run, 2016, saw sites degrade again into the unhealthy hypersaline state.

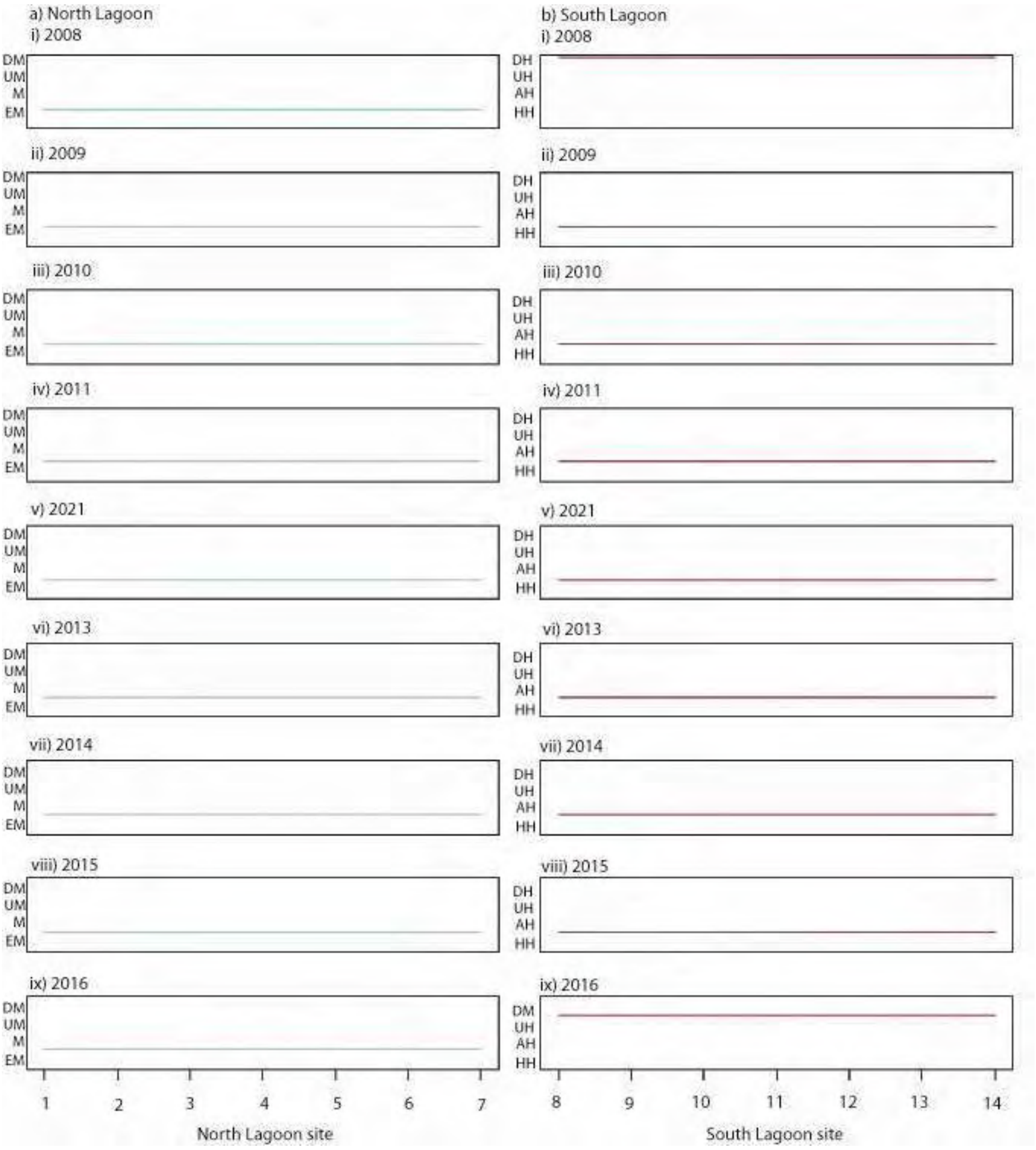

Figure C.25. Distribution of ecosystem states in the North and South Lagoons under Scenario 319

South Lagoon salinities fell below the winter-time target maximum of 60 g L^{-1}, particularly in later years, 2015 and 2016, of the model run (Figure C.26). Salinities also fell below the summer-time target of 100 g L^{-1} for 89% of the time. For the thresholds identified in the ecological models, water levels exceeded 0.373 m AHD for 61% and 0.423 m AHD for 57%, of the model run and maximum salinities exceeded 148.2 g L^{-1} for 5% of the time.

The North Lagoon was identified as being in the estuarine/marine state for the whole model run.

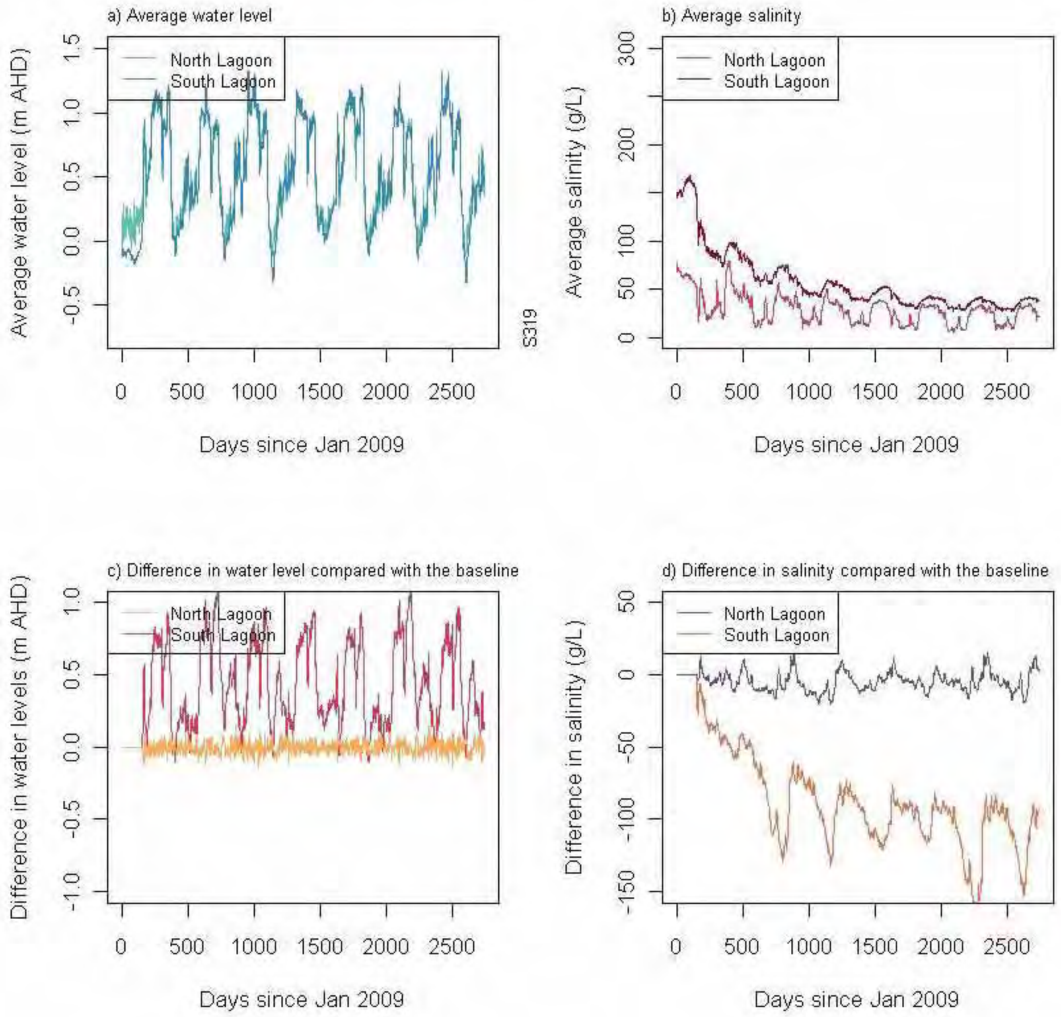

Figure C.26 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 319

Scenario 320

Scenario 320 investigated the effect of returning median barrage flows for one year, with no additional intervention occurring. Barrage flows began in June 2009 and ended in June 2010.

The length of the South Lagoon began in the degraded hypersaline state (Figure C.27). By the first year of intervention (2009) all sites had greatly improved, changing to the healthy hypersaline condition. Immediately after the completion of intervention (2010), the South Lagoon had deteriorated again to the unhealthy hypersaline state. Following intervention, in later years, the northern-most sites progressively improved to an average hypersaline state, with the rest of the sites

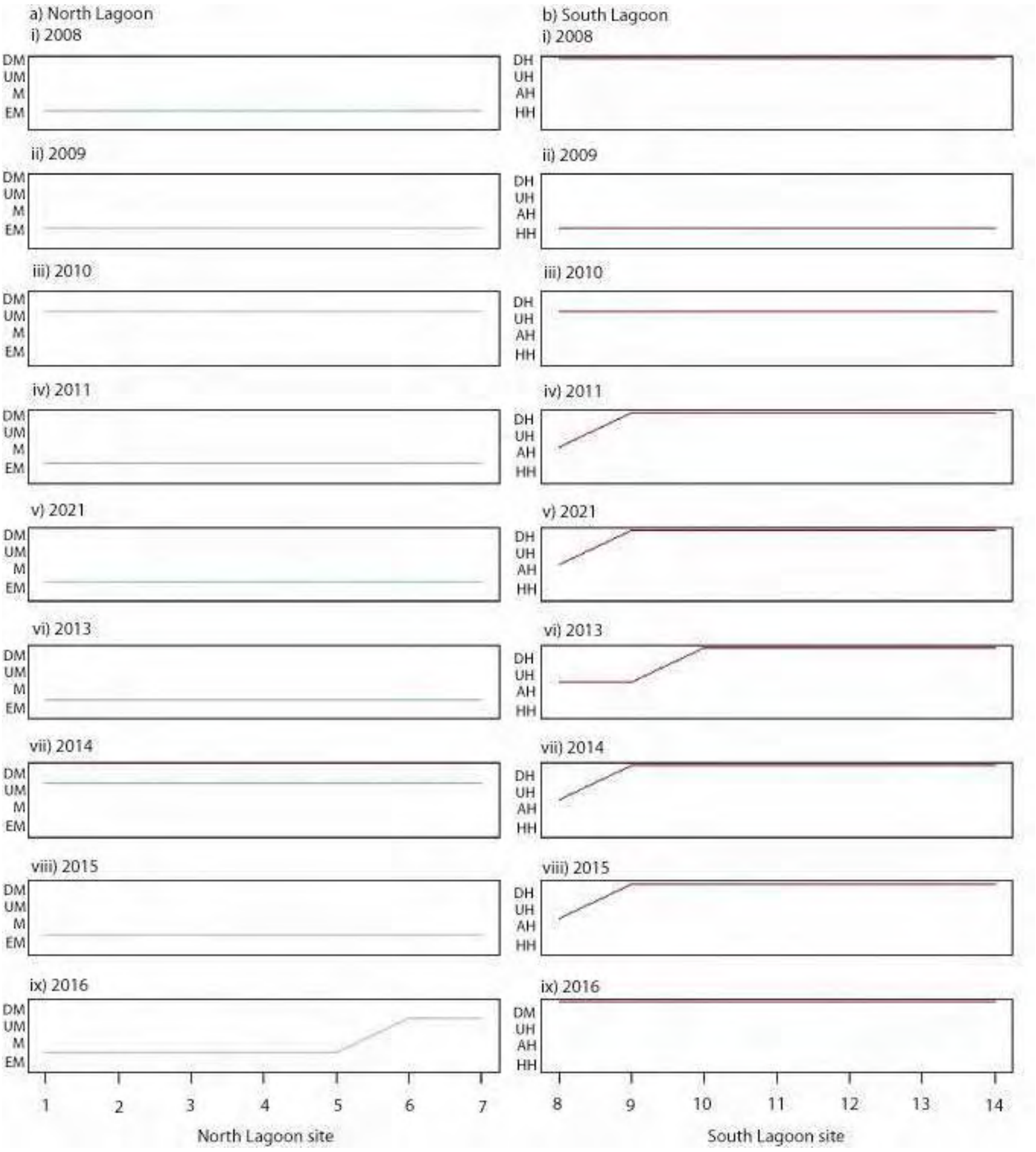

Figure C.27. Distribution of ecosystem states in the North and South Lagoons under Scenario 320

returning to their original degraded hypersaline condition. By the final year of the model run (2016) all of the sites had returned to the degraded hypersaline state. Salinities in the South Lagoon never fell below the winter-time target maximum of 60 g L^{-1}, but were below the summer-time target of 100 g L^{-1} for 14% of the time (Figure C.28). Water level thresholds of 0.373 m AHD and 0.423 m AHD were exceeded for 19% and 15%, respectively and maximum salinity of 148.2 g L^{-1} for 19% of the model run.

The North Lagoon of the Coorong was mostly identified as being in the estuarine/marine state, except in 2010 and 2014 where the total length and during 2016 where the two most southern sites were in the unhealthy marine condition.

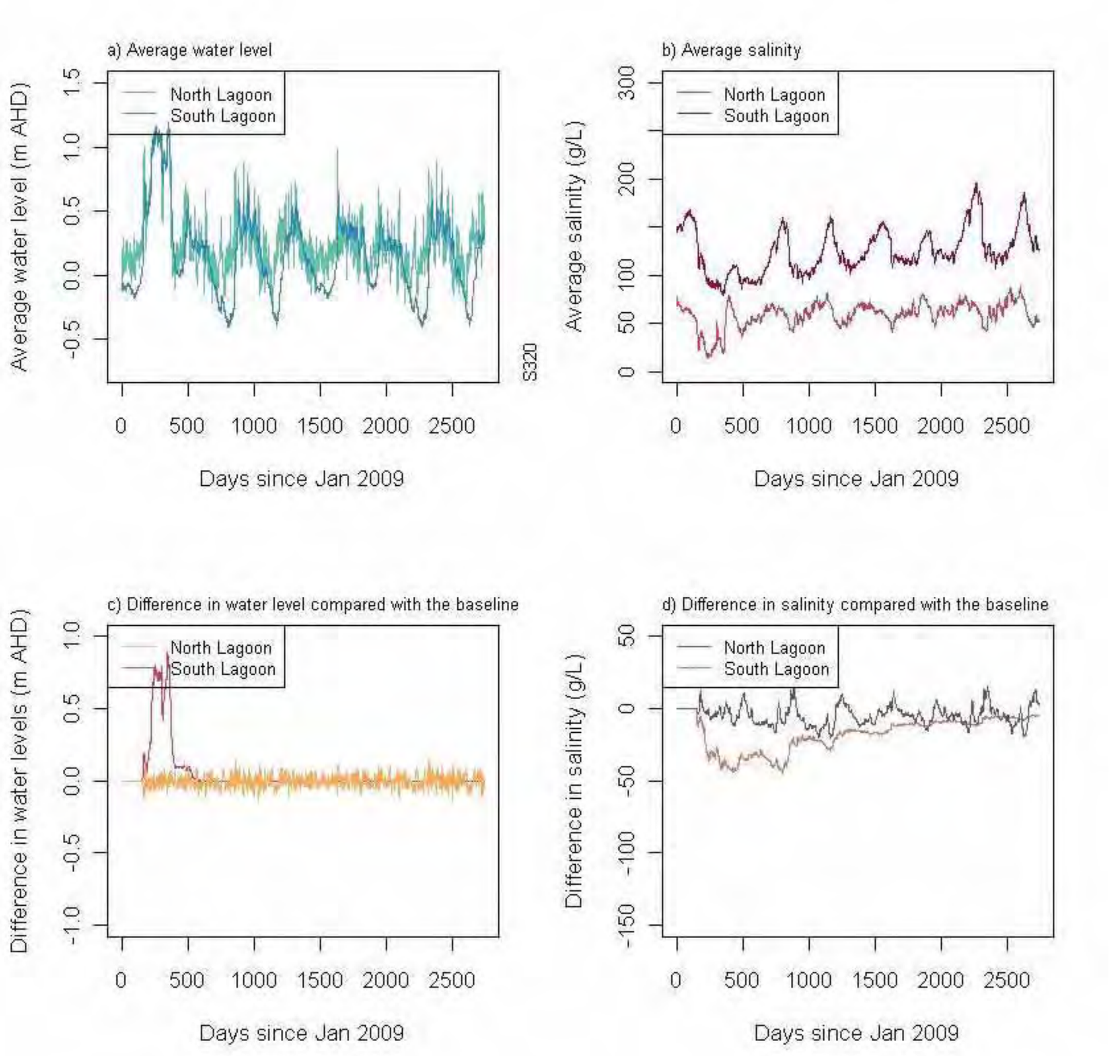

Figure C.28 Average water levels and salinities for the North and South Lagoon of the Coorong under Scenario 320