NATIONAL RESEARCH FLAGSHIPS

Water for a Healthy Country

Predicting the future ecological condition of the Coorong

Supplementary output from scenario modelling

Rebecca A. Langley, Rebecca E. Lester, Peter G. Fairweather & Ian T. Webster

DRAFT

April 2009

THE UNIVERSITY OF ADELAIDE AUSTRALIA
SARDI SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE
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The Water for a Healthy Country National Research Flagship is a research partnership between CSIRO, state and Australian governments, private and public industry and other research providers. The Flagship aims to achieve a tenfold increase in the economic, social and environmental benefits from water by 2025.

The Australian Government, through the Collaboration Fund, provides $97M over seven years to the National Research Flagships to further enhance collaboration between CSIRO, Australian universities and other publicly funded research agencies, enabling the skills of the wider research community to be applied to the major national challenges targeted by the Flagships initiative.

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Foreword

The environmental assets of the Coorong, Lower Lakes and Murray Mouth (CLLAMM) region in South Australia are currently under threat as a result of ongoing changes in the hydrological regime of the River Murray, at the end of the Murray-Darling Basin. While a number of initiatives are underway to halt or reverse this environmental decline, rehabilitation efforts are hampered by the lack of knowledge about the links between flows and ecological responses in the system.

The CLLAMM program is a collaborative research effort that aims to produce a decision-support framework for environmental flow management for the CLLAMM region. This involves research to understand the links between the key ecosystem drivers for the region (such as water level and salinity) and key ecological processes (generation of bird habitat, fish recruitment, etc). A second step involves the development of tools to predict how ecological communities will respond to manipulations of the "management levers" for environmental flows in the region. These levers include flow releases from upstream reservoirs, the Lower Lakes barrages, and the Upper South-East Drainage scheme, and dredging of the Murray Mouth. The framework aims to evaluate the environmental trade-offs for different scenarios of manipulation of management levers, as well as different future climate scenarios for the Murray-Darling Basin.

One of the most challenging tasks in the development of the framework is predicting the response of ecological communities to future changes in environmental conditions in the CLLAMM region. The CLLAMMecology Research Cluster is a partnership between CSIRO, the University of Adelaide, Flinders University and SARDI Aquatic Sciences that is supported through CSIRO's Flagship Collaboration Fund. CLLAMMecology brings together a range in skills in theoretical and applied ecology with the aim to produce a new generation of ecological response models for the CLLAMM region.

This report is part of a series summarising the output from the CLLAMMecology Research Cluster. Previous reports and additional information about the program can be found at http://www.csiro.au/partnerships/CLLAMMecologyCluster.html

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Acknowledgements

This research was supported by the CSIRO Flagship Collaboration Fund and represents a collaboration between CSIRO, the University of Adelaide, Flinders University and SARDI Aquatic Sciences.

We also acknowledge the contribution of several other funding agencies to the CLLAMM program and the CLLAMMecology Research Cluster, including Land & Water Australia, the Fisheries Research and Development Corporation, SA Water, the Murray-Darling Basin Commission's (now the Murray-Darling Basin Authority) Living Murray program and the SA Murray-Darling Basin Natural Resources Management Board. Other research partners include Geoscience Australia, the WA Centre for Water Research and the Flinders Research Centre for Coastal and Catchment Environments. The objectives of this program have been endorsed by the SA Department of Environment and Heritage, SA Department of Water, Land and Biodiversity Conservation, SA Murray-Darling Basin NRM Board and Murray-Darling Basin Commission.

We would like to thank the members of the CLLAMMecology Research Cluster for their ongoing contributions to the development of these models and scenarios, and the CLLAMMecology Management Committee for their overall encouragement. The participants of the CLLAMM Futures workshops, and the third workshop in particular, also contributed useful suggestions and criticisms of the model development process. Constructive criticism and suggestions regarding model development, evaluation and verification were also offered by Gene Likens and Peter Petraitis. Participants of the three CLLAMM Futures workshops, along with other managers and stakeholders also provided critical advice regarding the development of the scenario set presented here, with Glynn Ricketts from the SA Murray-Darling Basin NRM Board and Russell Seaman from DEH making significant contributions.

Data and assistance in interpretation of those data were provided by David Paton and Daniel Rogers from the University of Adelaide, Sabine Dittmann and Alec Rolston from Flinders University, Qifeng Ye and Craig Noell from SARDI Aquatic Sciences, Joseph Davis from the Murray-Darling Basin Authority and the Australian Wader Study Group. The generosity of these contributors in sharing their valuable datasets is gratefully acknowledged. The foresight of these scientists in collecting these datasets is exemplary. Funding bodies contributing to the original collection of these data include the South Australian Department for Environment and Heritage, Earthwatch and the Fisheries Research and Development Corporation. Additional data was supplied by the South Australian Department for Environment and Heritage, Primary Industries and Resources South Australia and the Australian Bureau of Meteorology Climate & Consultative Services, the National Tidal Facility and Flinders Ports.

We also gratefully acknowledge the research assistance provided by Stephanie Duong and assistance with map-making from Craig Noell at SARDI Aquatic Sciences.

1. Introduction

The Coorong is a long, shallow, lagoonal system which is separated from the ocean by a narrow sand peninsula and is artificially divided from the freshwater Lakes Alexandrina and Albert to the north by a series of barrages (Figure 1.1). Having its freshwater inflows through these barrages makes the Coorong an inverse estuary rather than the more-usual configuration of fresh inflows at one end and connection to the sea at the other. Environmental conditions thus form a natural gradient from estuarine conditions around the Murray Mouth through to hypersaline conditions in the South Lagoon.

The Coorong is a Ramsar Convention-listed Wetland of International Importance, with the region having substantial cultural, economic, recreation and environmental values. Management of such a large-scale ecosystem is thus complex and objectively assessing likely ecological consequences of management decisions can be difficult. This is heightened with the added uncertainty of climate change and sea level rise.

To assess the likely consequences of 20 possible future scenarios for the Coorong, hydrodynamic and ecosystem state models were used in sequence. 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 were used for a 114-year model run. The ecosystem state model used processed output from the hydrodynamic model and flows over the barrages to predict the mix of ecosystem states along the Coorong over the same model run.

The scenarios investigated included a mixture of climate change, sea level rise and other management options. The effect of current extraction levels, The Living Murray Initiative, dredging at the Murray Mouth and a propose increase in the flow volumes at Salt Creek via the Upper South East Drainage (USED) scheme.

This report presents the additional information for each of the scenarios investigated. For comparisons between scenarios, discussion and management implications, refer to Lester and Fairweather (2009).

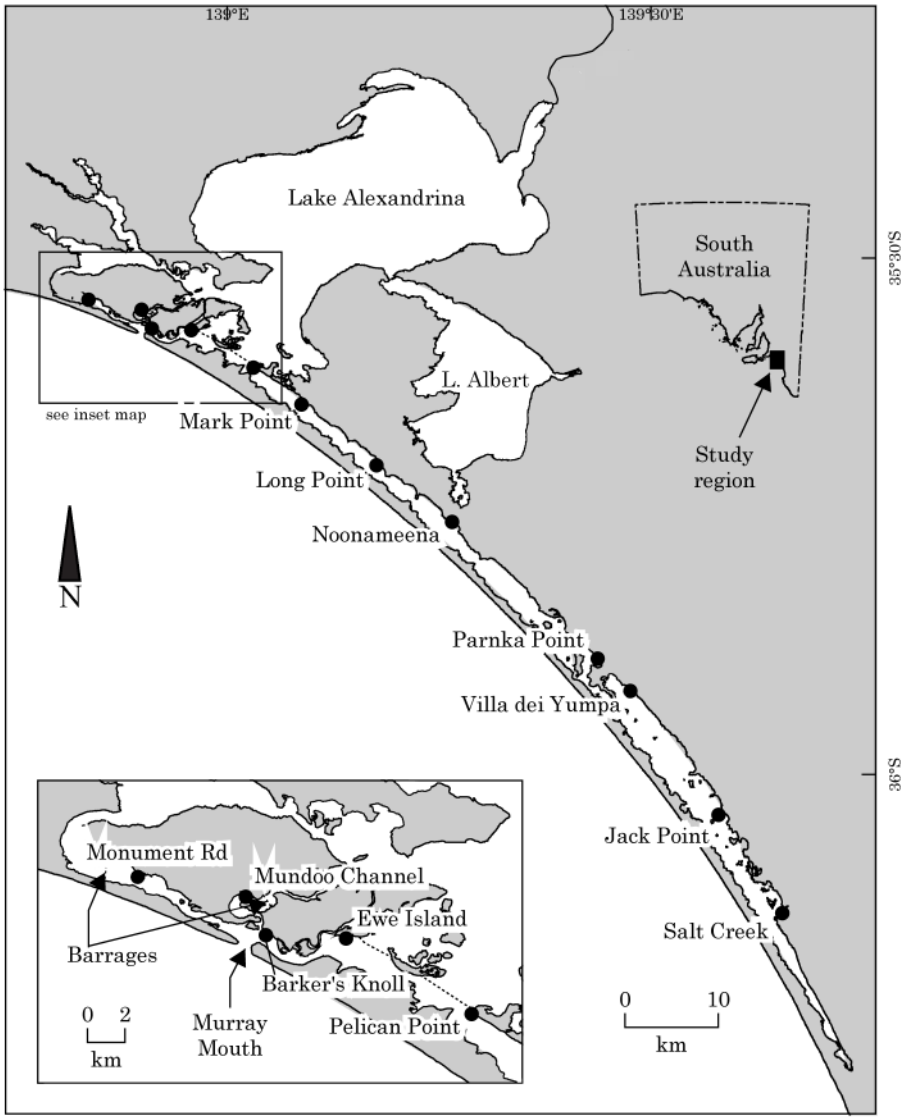

Figure 1.1. Map of the Coorong showing the twelve study sites used as focal locations during CLLAMMecology and forming the basis of our ecosystem response modelling

(Source: Craig Noell, SARDI Aquatic Sciences, South Australia)

2. Additional detail for each scenario

2.1. Baseline

The Baseline scenario investigates the historical climate of the Coorong, with current extraction levels from the Murray-Darling Basin, actual inflows from the USED scheme through Salt Creek and no intervention through dredging. It provides a point of comparison for all other scenarios investigated.

Figure 2.1 shows the distributions of each of the variables driving the ecosystem states of the Coorong under the Baseline conditions. Median water level (shown by the bar within the box; see Appendix A for further detail on how to read the figures presented) was 0.30 m AHD falling between 0.24 m AHD and 0.34 m AHD for 50% of the time (Figure 2.1). Median water depth under baseline conditions along the length of the Coorong was 1.41 m, falling between 1.2 m and 1.6 m for 50% of the time. Median salinity was around that of seawater along the length of the Coorong over the 114-year model run, at 35.5 g L^{-1}, although there were a number of outliers at extremely high salinities. The median for the maximum number of days since flow over the barrages (MaxDSF) for the Baseline scenario was 135 days, while the median tidal range was small, at only 0.10 m.

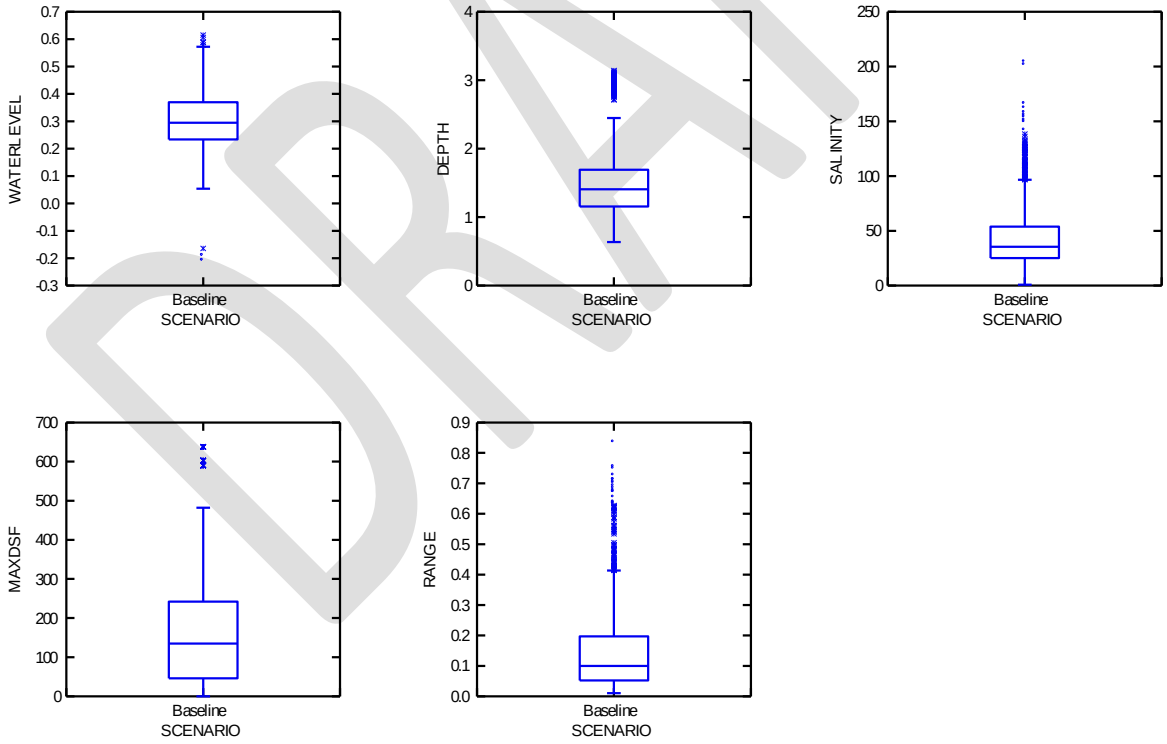

Figure 2.1. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Baseline scenario.

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g L^{-1}), d) maximum number of days since flow (MaxDSF, days) and e) tidal range (m).

All sites north of Noonameena exceeded the threshold for tidal range for all site-years, as did the Parnka Point site. The remainder of the North Lagoon sites exceeded the threshold for an average of 13.8 years with a return time of 2.6 years. South Lagoon sites exceeded the threshold for 4.6 years on average, returning every 20.5 years.

The threshold for the maximum number of days without flow over the barrages was exceeded for an average of 1.8 years at a return interval of 34.3 years.

The water level threshold of 0.37 m AHD was exceeded for an average of between one and two years across the various sites along the Coorong. For the Murray Mouth region, the return time for exceeding this threshold was 8.2 years. This dropped to 5.0 years for the North Lagoon sites, but was 10.2 years for the South Lagoon. The second water level threshold of -0.09 m AHD was always exceeded for all sites, except for the South Lagoon sites in 2008, the last year of simulation.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point every 15.0 years for 1.7 years, on average.

In the North Lagoon, Long Point was the only site to cross the salinity threshold more than once. This occurred in two separate years, with a return time of 62 years. In the South Lagoon, the salinity threshold was exceeded for an average of 7.3 years with a return time of 10.3 years. Expert opinion has suggested that the maximum salinity of 100 g L^{-1} is important for key biota in the Coorong. Under the Baseline scenario conditions 6% of site-years were greater than this salinity threshold. In the alternative model, maximum salinity was greater than 100 g L^{-1} in 14% of the site-years.

The Gini coefficient was calculated for each variable driving ecosystem states. For the Baseline scenario, depth and water level were the most evenly distributed variables (Gini = 0.04 and 0.07, respectively). This suggests that they were relatively likely to occupy any value within their range, rather than being skewed to either end of the distribution. Tidal range and salinity were moderately-well dispersed (Gini = 0.16 and 0.21, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with occasional large deviations towards the high end of the spectrum (Gini = 0.46).

For the Baseline Scenario, eight out of the eight states were observed during the 114-year by 12-site (1368 site-years) model run. Over the Baseline scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (70%) and the Average Hypersaline state (20%; Figure 2.2). Together, these two accounted for 90% of the site-years modelled. Healthy Hypersaline (3%), Unhealthy Hypersaline (2%), Unhealthy Marine (2%) and Marine (1%) were all uncommon and the two most-degraded states, Degraded Marine and Degraded Hypersaline appeared in less than 1% of site-years each.

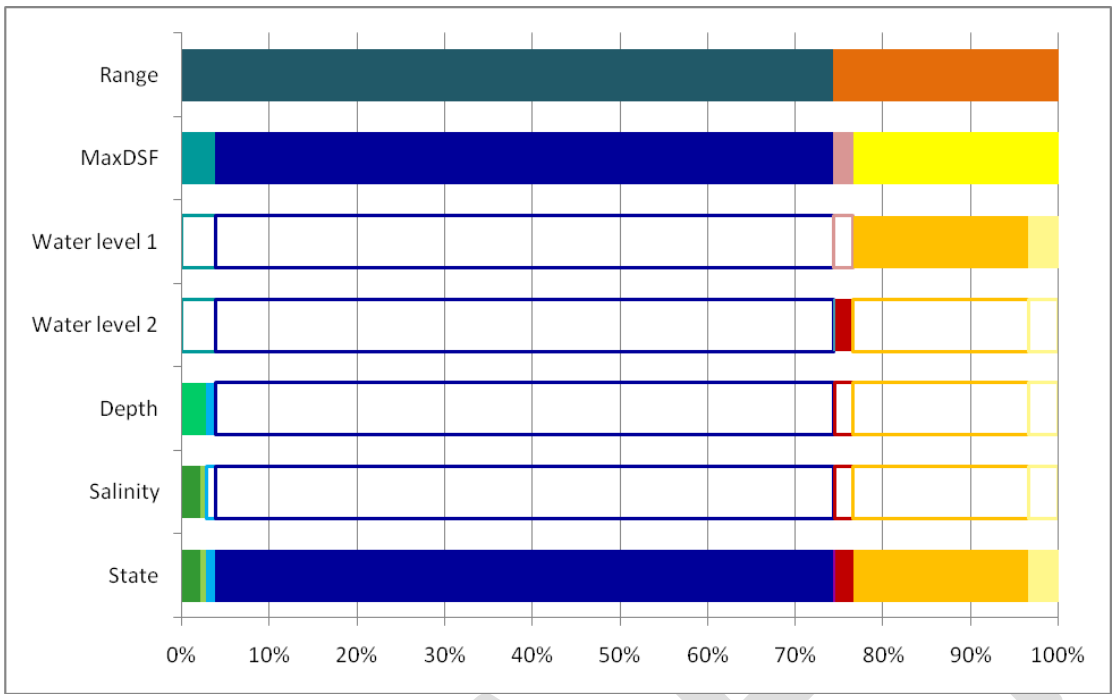

Figure 2.2. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Baseline scenario

Each of the upper six bars shows one threshold for a variable driving ecosystem states in the Coorong. The two solid blocks represent the proportion of site-years that fall below (on the left) and above (on the right) the threshold. Going from top to bottom, each bar builds on the previous until the bottom bar illustrates the distribution of ecosystem states for this scenario. The final bar shows the states with dark green representing the Degraded Marine state, light green is Unhealthy Marine, light blue is Marine, dark blue is Estuarine/Marine, purple is Degraded Hypersaline, red is Unhealthy Hypersaline, orange is Average Hypersaline and yellow is Healthy Hypersaline.

Transitions occurred between states for 14% of site-years (Figure 2.3). This means that the state inertia (i.e. the proportion of site-years where the state did not change) in the system for the Baseline scenario was 86%. The sequence in which the states appear at each site across the 114 years is significantly different from a random distribution (Z_u ranged between 3.909 and 7.743 for the 12 sites, $p < 0.0001$ for all sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 4% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 6% of the time and to a less-degraded state 4% of the time.

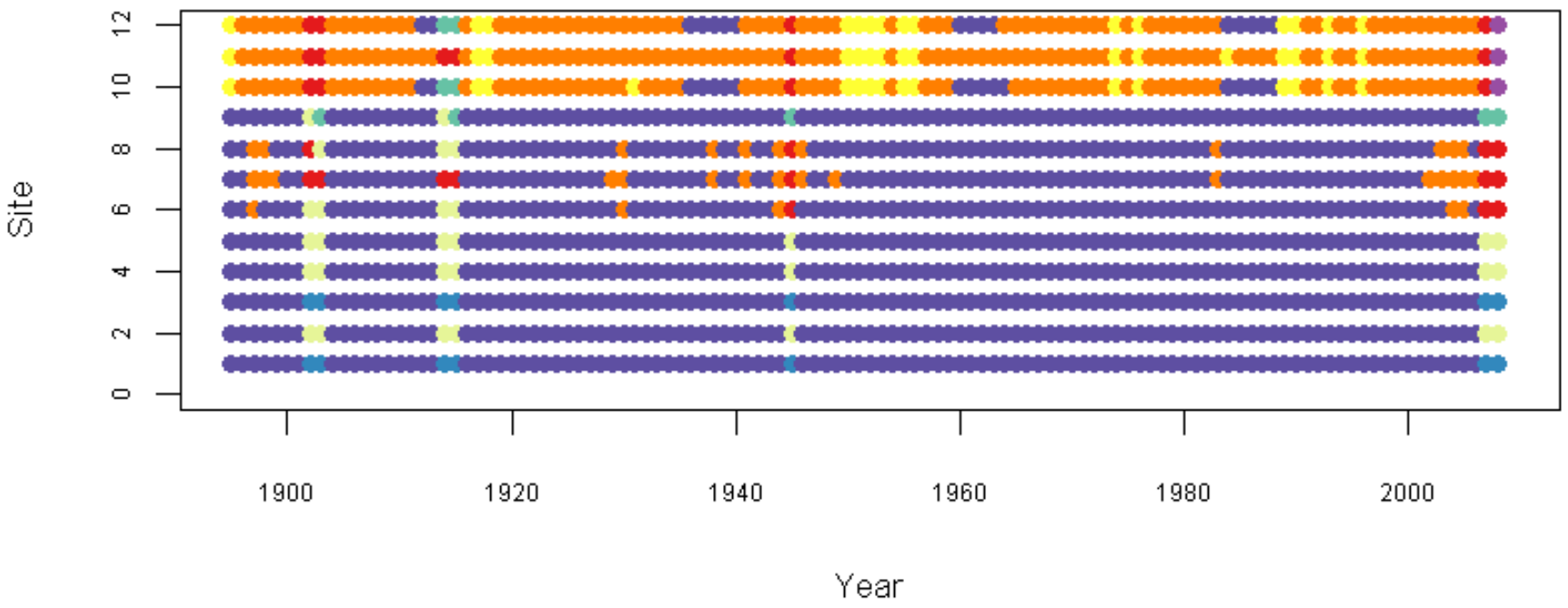

Figure 2.3. Distribution of states for each site-year under the Baseline scenario

Each bar shows the distribution of the states within each site across the 114-year model run. Sites are numbered from north to south (e.g. Monument Road = Site 1 and Salt Creek = Site 12). The changes in the bar colours represent the transitions between states. For each bar, colours represent the following states: dark blue = Estuarine/Marine, light blue = Marine, light green = Unhealthy Marine, dark green = Degraded Marine, yellow = Healthy Hypersaline, orange =Average Hypersaline, red = Unhealthy Hypersaline and purple = Degraded Hypersaline.

For a number of seminal years, we have mapped the distribution of ecosystem states within the Coorong (Figure 2.4). These years include two dry periods (the Federation Drought, represented by 1902 and during the current drought, represented by 2005 and 2008), two wet periods (the 1956 and 1972 floods) and the year of Ramsar-listing, which is taken as the baseline for ecological character under that treaty (1985).

During the seminal years 1956, 1974, 1985 and 2005, the Murray Mouth region was classified as being in the Estuarine/Marine state. For the remainder of the years (1902 and 2008), this region showed a greater distribution of states with the Marine and Unhealthy Marine states in 1902 and the Estuarine/Marine, Marine and Unhealthy Marine states in 2008. The North Lagoon of the Coorong under the Baseline scenario was in the Marine state for the years of 1956, 1974 and 1985. During 1902 the northern and most-southern parts of the North Lagoon were in the Unhealthy Marine state, while the middle section was shown to be in the Unhealthy Hypersaline state. By 2005 the North Lagoon was in a combination of the Estuarine/Marine and Average Hypersaline states and by 2008 the length (excluding Parnka Point which was in the Degraded Marine state) was classified as the Unhealthy Hypersaline state. The South Lagoon across the earlier seminal years (i.e. 1902, 1956 and 1974) showed a distribution of the Healthy Hypersaline and Unhealthy Hypersaline states. By the later years (i.e. 1985, 2005 and 2008), the South Lagoon progressively degraded from the Estuarine/Marine state to the Average Hypersaline and Degraded Hypersaline states.

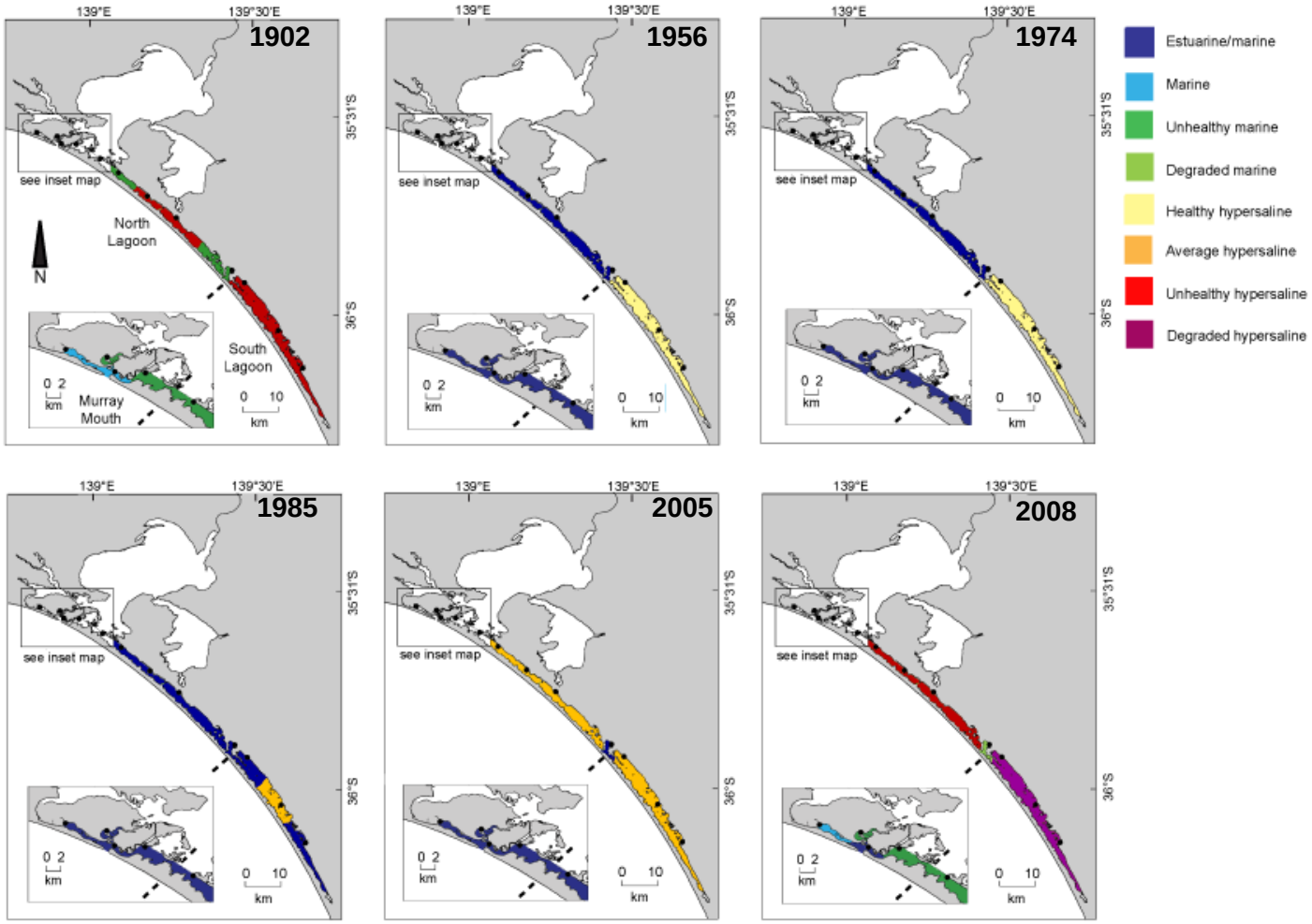

Figure 2.4. Mapping the distribution of states for seminal years under the Baseline scenario

The dotted lines indicate boundaries between the three regions. Dots indicate the locations of the focal sites. Names of regions are only listed in the 1902 panel, but apply to all other panels as well. Each colour represents a different state (with corresponding states and colours shown in the legend).

2.2. Historic Natural

The Historical Natural scenario investigates flows as they would have occurred without any infrastructure or extractions within the Murray-Darling Basin under a historic climate. No dredging is modelled, but average flows from the USED scheme are included.

Figure 2.5 shows the distributions of each of the environmental variables driving the ecosystem states of the Coorong under the Historical Natural conditions. Median water level was 0.40 m AHD, falling between 0.34 m AHD and 0.45 m AHD for 50% of the time. Under Historical Natural conditions, the median water depth along the length of the Coorong was 1.52 m, falling between 1.24 m and 1.77 m for 50% of the time. Median salinity was much lower than that of seawater over the 114-year model run, at 11.55 g L^{-1}, although there was a number of high salinity outliers present in the later years in the more southern sites of the Coorong. The median for the maximum number of days since flow (MaxDSF) for the historic natural scenario was zero, with some years (e.g. blocks in early 1900s and late 2000s) having higher numbers of days since flow. The median tidal range was also small, at 0.12m.

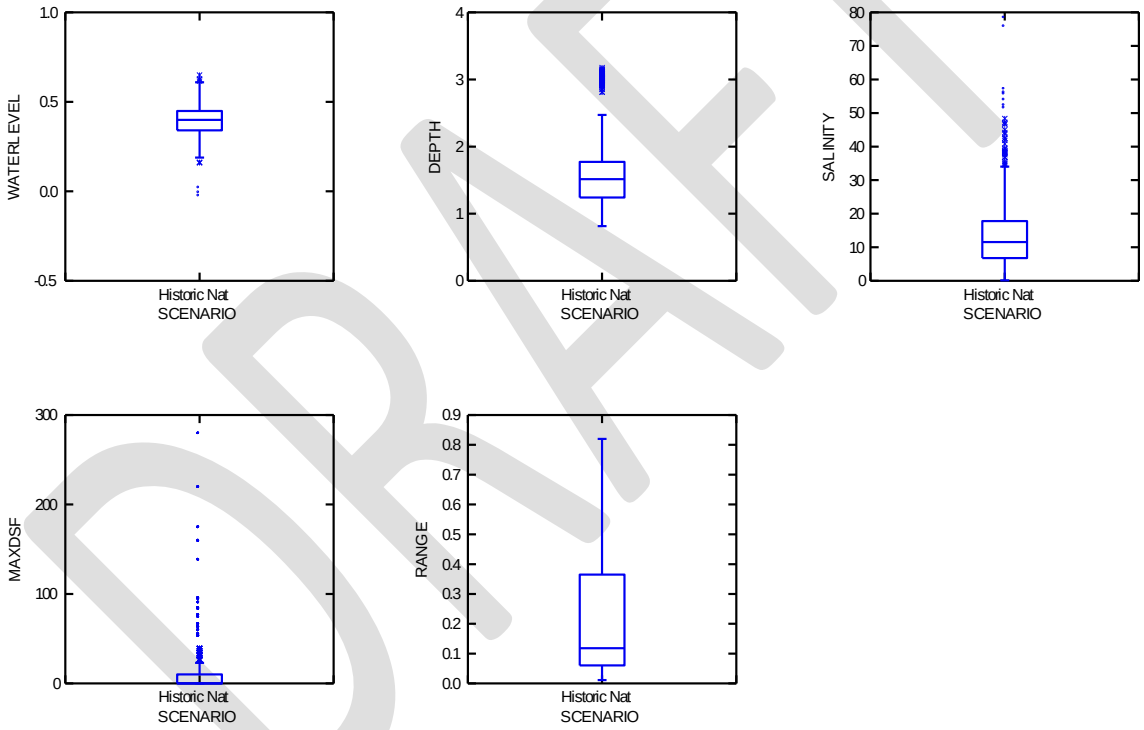

Figure 2.5. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Historic Natural scenario

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g L^{-1}), d) maximum number of days since flow (MaxDSF, days) and e) tidal range (m).

All sites in the Murray Mouth and North Lagoon regions exceeded the threshold for tidal range. In the South Lagoon, this was exceeded on average for 3.4 years, at a return interval of 21.3 years.

The threshold for the maximum number of days without flow over the barrages was never exceeded under the Historic Natural flow scenario.

The water level threshold of 0.37 m AHD was exceeded for an average of 8.2 years in the Murray Mouth region with a return time of 4.4 years. In the North Lagoon, this decreased to a duration of 5.3 years every 2.8 years. The South Lagoon sites exceeded the threshold for an average of 2.8 years with a return time of 2.7 years. The second water level threshold at -0.09 m AHD was always exceeded for all sites.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for an average of 1.6 years with a return interval of 4.2 years.

The salinity threshold was only exceeded at the two southern-most sites in the final year of simulation. All other site-years were below the threshold. Salinity under historical natural conditions was never greater than the 100 g L^{-1} over the site-years.

For each environmental variable driving the ecosystem states, the Gini coefficient was calculated. For the Historic Natural scenario, depth, water level and tidal range were the most evenly distributed variables (Gini = 0.03, 0.05 and 0.08, respectively). Salinity was moderately-well dispersed (Gini = 0.30), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with some years showing much longer periods without flow (Gini = 0.84).

For the Historic Natural scenario, three out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the Historic Natural model run, only the three states of Estuarine/Marine, Average and Healthy Hypersaline were observed (Fig. 2.6). The Estuarine/Marine state was the most common (77%) with Average Hypersaline and Healthy Hypersaline states accounting for 8% and 15%, respectively.

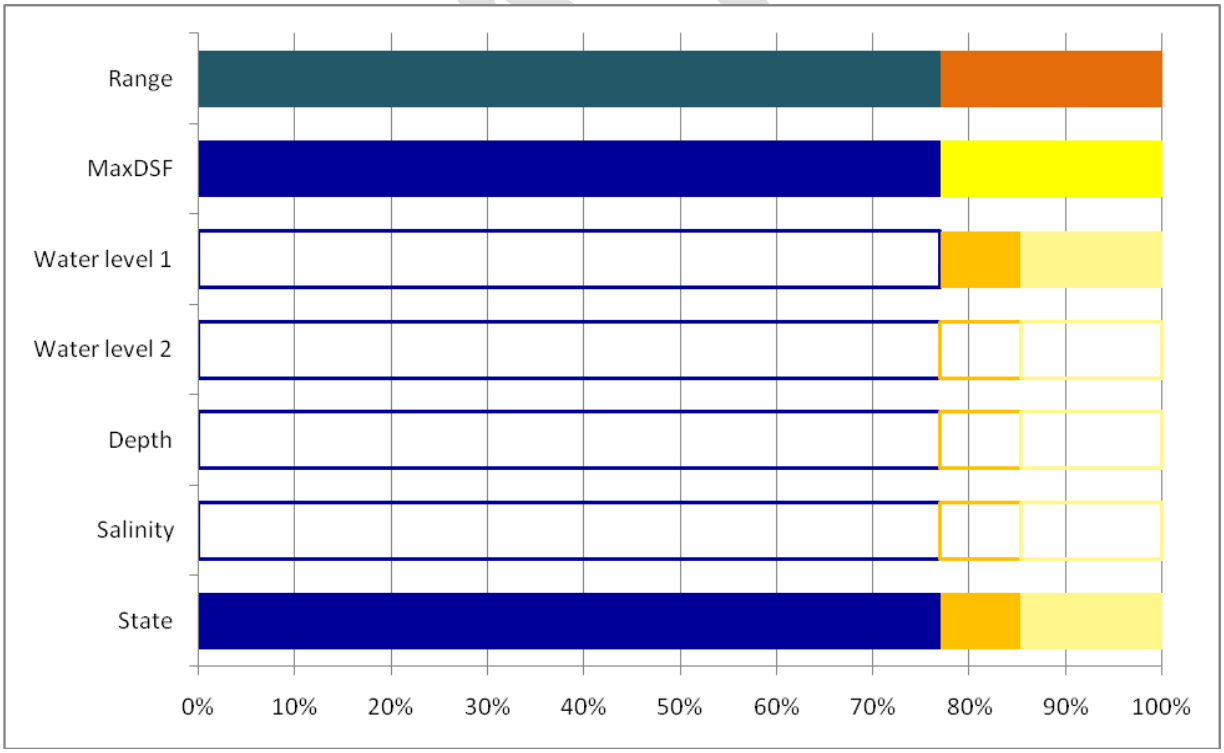

Figure 2.6. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Historic Natural scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 11% of site-years (Figure 2.7). The proportion of site-years where the state did not change in the system for the Historic Natural scenario was 89%. Two sites (Villa dei Yumpa and Salt Creek) showed sequences of states across the 114 years that were significantly different from the random distribution. Jack Point was the only other state to show a change in states across the 114 years but the sequence of states was not significantly different from random. When transitions did occur, sites changed basin only 1% of site-years, shifting from a marine state to a hypersaline state or vice versa (i.e. both directions). When sites changed within the same basin, they shifted to a more degraded state 5% of the time and to a less-degraded state 4% of the time.

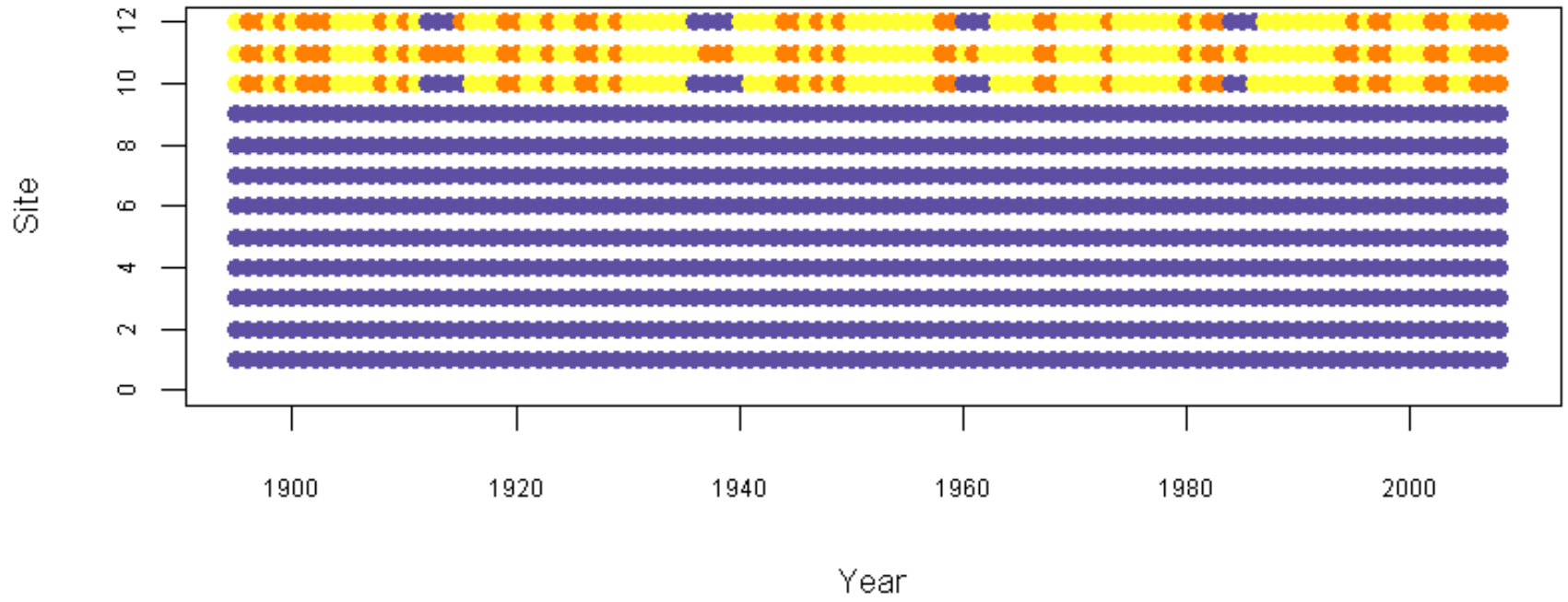

Figure 2.7. Distribution of states for each site-year under the Historic Natural scenario

See Figure 2.3 for further explanation of the figure.

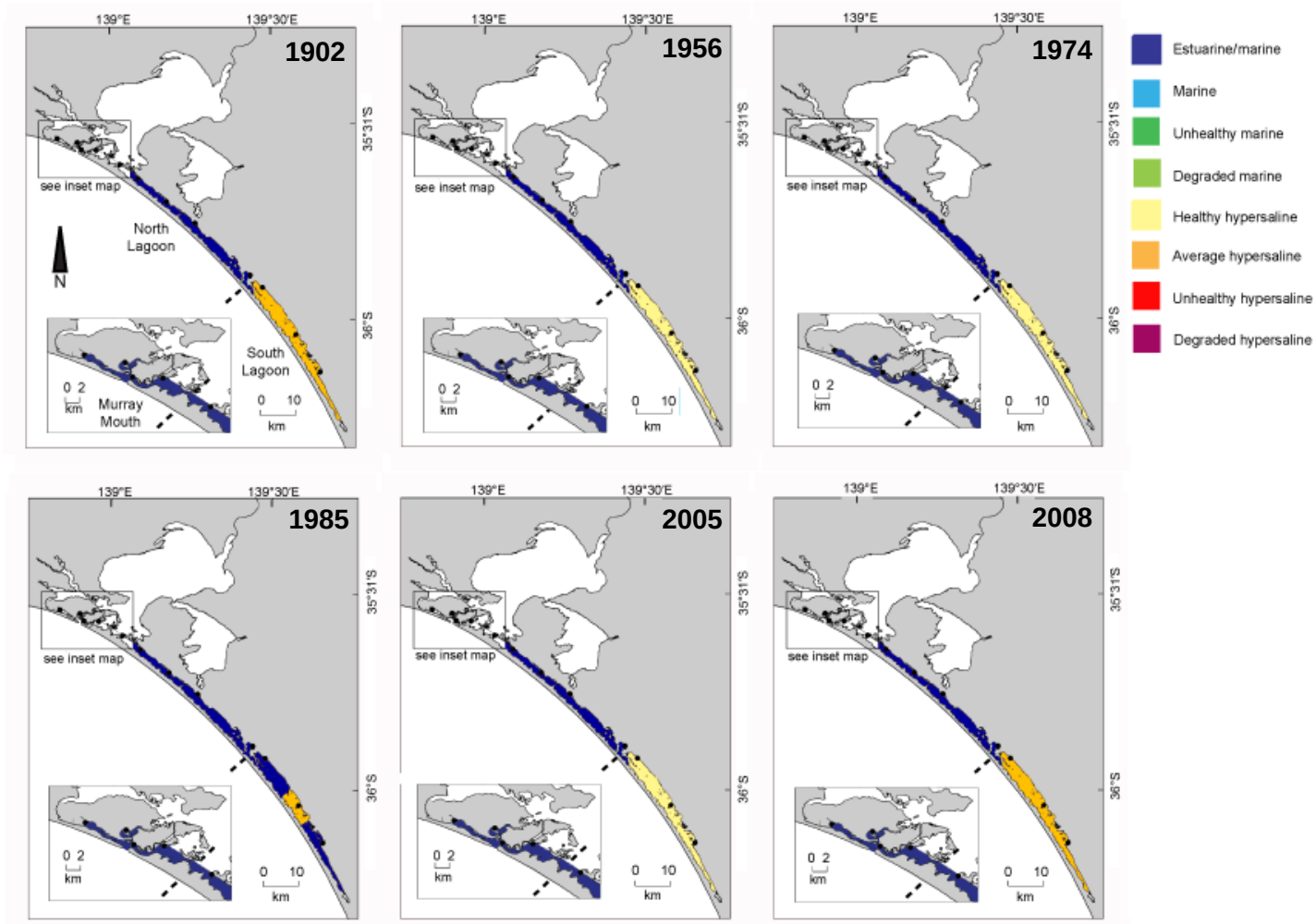

Figure 2.8. Mapping the distribution of states for seminal years under the Historic Natural scenario

See Figure 2.4 for further explanation of the figure.

2.3. Median Future

The Median Future scenario modelled current levels of extraction within the Murray-Darling Basin with a Median Future climate scenario, no dredging and average USED scheme inflows.

The distributions of each of the variables driving the ecosystem states of the Coorong under the Median Future scenario are shown in Figure 2.9. Median water level was 0.27 m AHD, although there were a few outliers at extremely low water levels (around the minimum of -0.24 m AHD). Median water depth under median future conditions along the length of the Coorong was 1.38 m, falling between 1.14 m and 1.68 m for 50% of the time. Median salinity was slightly higher than seawater at 40.45 g L^{-1}, although there were a number of outliers at extremely high salinities. The median maximum number of days since flow over the barrages (MaxDSF) for the Median Future scenario was 186, falling between 70 and 272 days for 50% of the time. Median tidal range was small at 0.09 m.

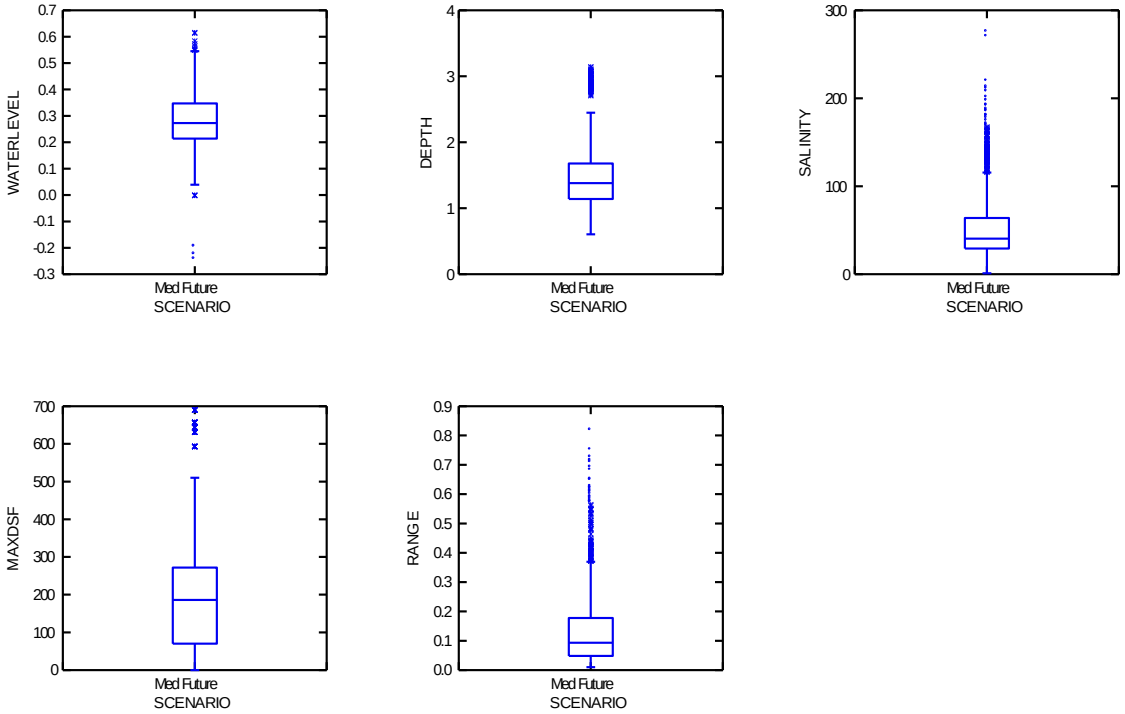

Figure 2.9. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Median Future scenario

The tidal threshold was not exceeded north of Pelican Point. For sites further south in the North Lagoon, the threshold was exceeded for 9.9 years on average, with a return interval of 2.8 years. In the South Lagoon, the sites exceeded the threshold for 4.1 years on average, with a return time of 18.2 years.

On average, the threshold for the maximum number of days without flow over the barrages was exceeded for 1.8 years with a return interval of 17.5 years.

The water level threshold at 0.37 m AHD was exceeded for between one and two years for all sites, on average. The return times varied between regions, with the Murray Mouth

region having a return time of 10.9 years, but 7.1 years and 15.4 years for the North and South Lagoon regions, respectively.

The second water level threshold (-0.09 m AHD) was exceeded for all sites except for the South Lagoon sites in the last year of simulation (2008).

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point every 17.8 years for 1.2 years, on average.

The salinity threshold was not exceeded in the Murray Mouth region. In the North Lagoon, it was exceeded for an average of 2.1 years with a return time of 34.9 years, and in the South Lagoon, it was crossed for 23.3 years at a time every 4.8 years. Salinity under median future conditions was greater than 100 g L^{-1} in 13% of site-years.

For the Median Future scenario, depth and water level were the most evenly distributed variables (Gini = 0.04 and 0.07, respectively). Tidal range and salinity were moderately-well dispersed (Gini = 0.18 and 0.20, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, occasionally deviating to high number of days (Gini = 0.43).

For the Median Future scenario, eight of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the length of the Coorong, the two most common states over the Median Future scenario model run were the Estuarine/Marine (66%) and Average Hypersaline states (20%; Figure 2.10). The remaining 14% of the site-years modelled consisted of Unhealthy Hypersaline (5%), Unhealthy Marine (3%), Marine (2%) and Healthy Hypersaline (2%) states. The most-degraded states of Degraded Marine and Degraded Hypersaline were observed in less than 1% during the Median Future scenario model run.

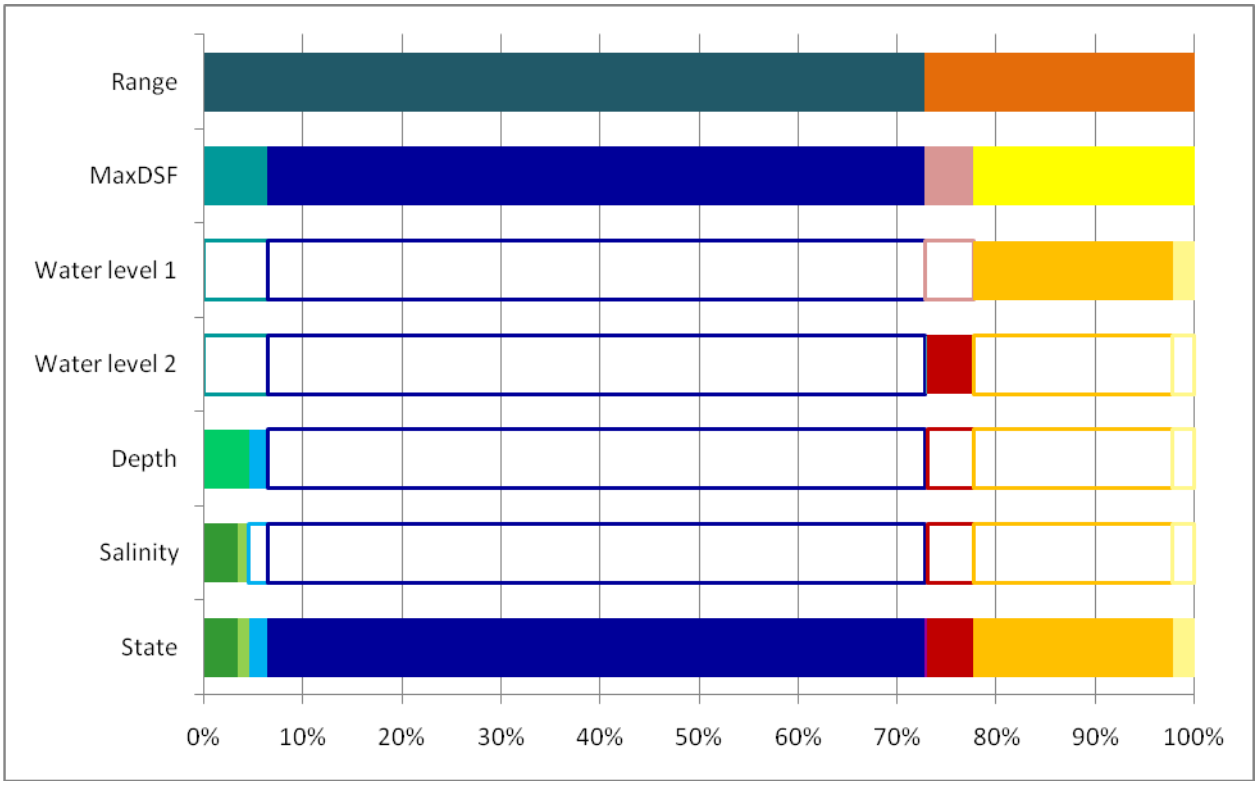

Figure 2.10. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Median Future scenario

See Figure 2.2 for further explanation of the figure.

For 18% of site-years, transitions occurred between states (Figure 2.11). This means that the proportion of site-years where the state did not change in the sytsem for the Median Future scenario was 82%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 4.73 and 8.64 for 12 sites). Sites transitioned between basins (i.e. went from a marine state to a hypersaline state or vice versa) in 6% of site-years, indicating a shift in the penetration of tidal prism. When sites changed within the same basin, they shifted to a more degraded state 7% of the time but to a less-degraded state only 4% of the time.

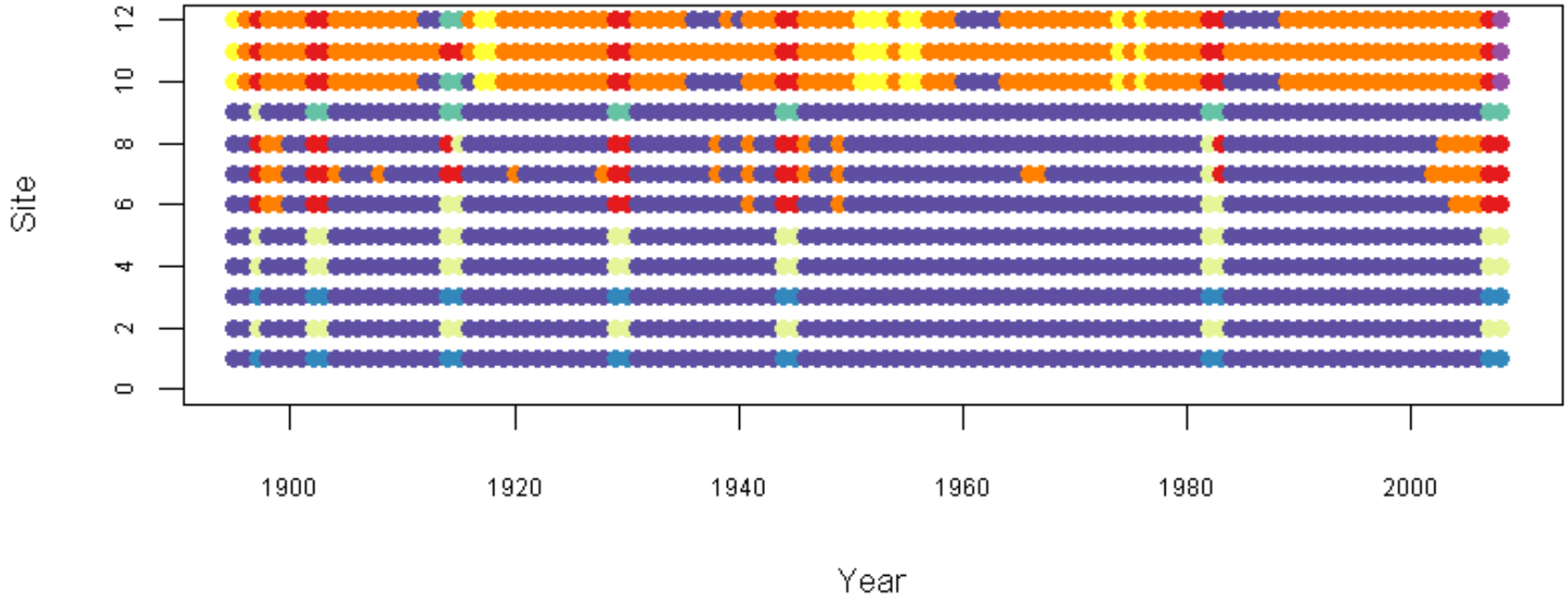

Figure 2.11. Distribution of states for each site-year under the Median Future scenario

See Figure 2.3 for further explanation of the figure.

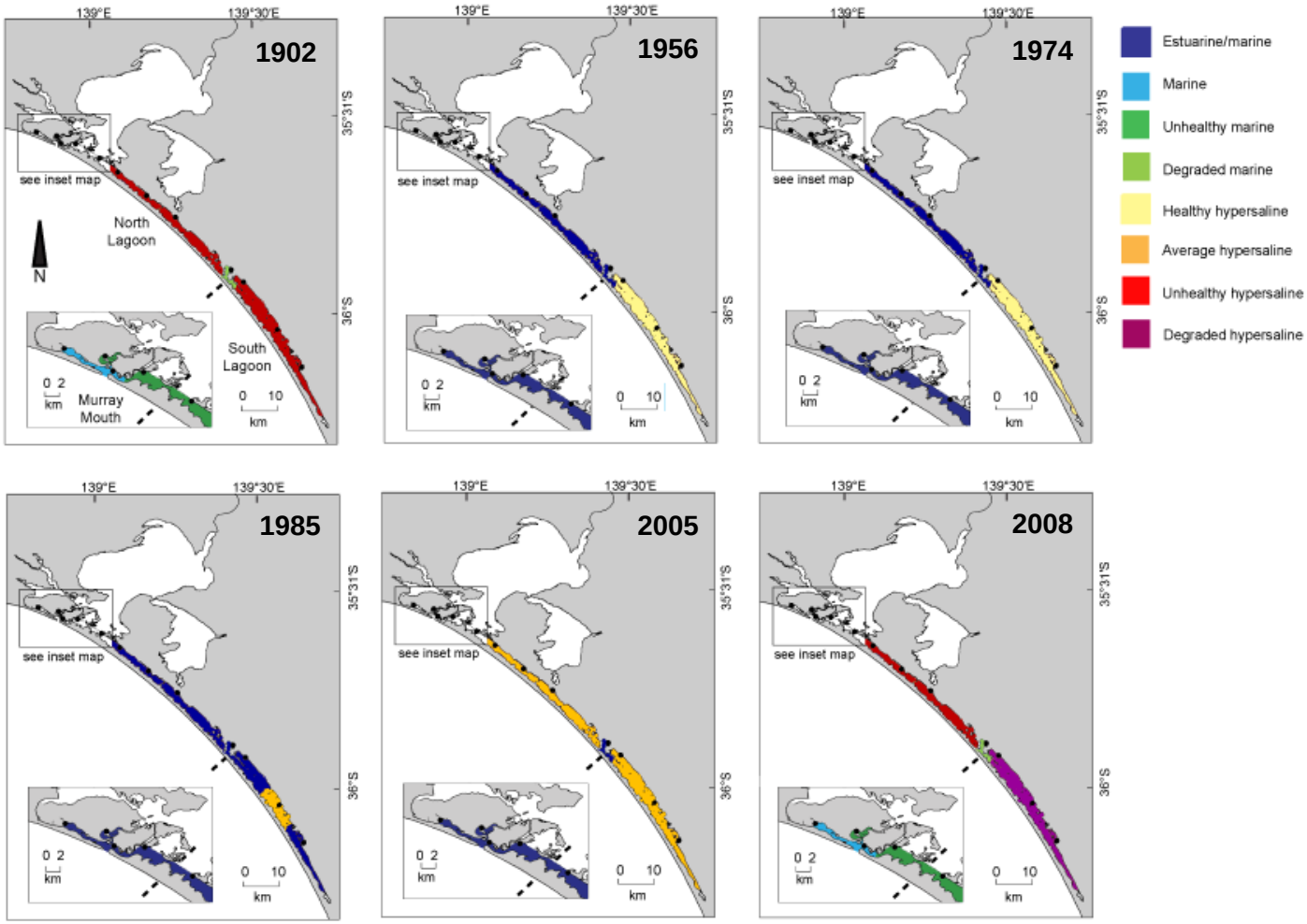

Figure 2.12. Mapping the distribution of states for seminal years under the Median Future scenario

See Figure 2.4 for further explanation of the figure.

2.4. Dry Future

The Dry Future scenario investigated the impact of a dry future climate with current extraction levels from the Murray-Darling Basin. It included average flows from the USED scheme, but not the current dredging operation.

Figure 2.13 shows the distribution of each of the variables driving the ecosystem states of the Coorong under the Dry Future conditions. Median water level was 0.58 m AHD, but there were a number of outliers at lower water levels (i.e. below half of the median water level observed). Median water depth under the dry future conditions along the length of the Coorong was 1.33 m, falling between 1.07 m and 1.66 m for 50% of the time. Median salinity was much higher than seawater along the length of the Coorong over the 114-year model run, at 59.49 g L^{-1}, although there were a number of outliers at extremely high salinities. The median maximum number of days without flow over the barrages (MaxDSF) for the Dry Future scenario was 321 days, but there were numerous outliers at extremely high maximum number of days (with maximum of 2778 days). Median tidal range was 0.07 m, but there were outliers of extremely higher tidal ranges observed.

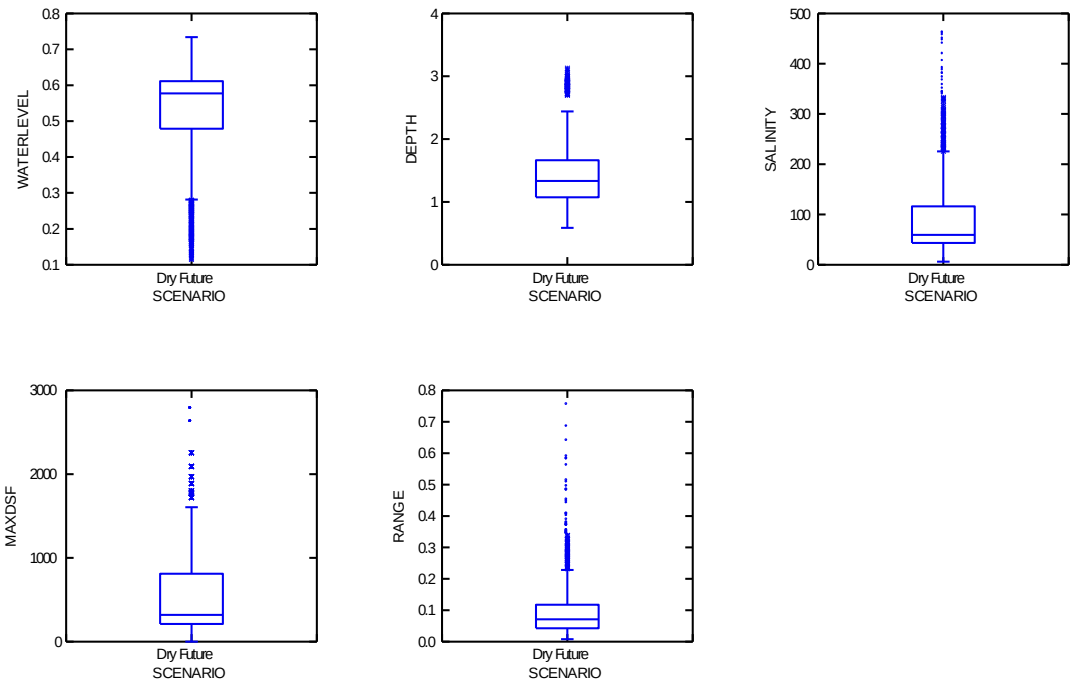

Figure 2.13. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Dry Future scenario

Barkers Knoll was the only Murray Mouth site to fall below the tidal range threshold. It remained above the threshold for an average of 25.5 years, recurring every two years. North Lagoon sites were over the threshold for 8.0 years at a time, with a return interval of 3.1 years, and in the South Lagoon, the threshold was exceeded for 3.8 years at a return interval of 18.0 years.

Under the Dry Future scenario, the threshold for the maximum number of days without barrage flows was exceeded every 7.7 years for an average of 4.8 years at a time.

The first water level threshold (0.37 m AHD) was exceeded for an average of between 1 and 1.3 years across the three regions. In the Murray Mouth region, the return time was 13.8

years. This extended to 18.0 and 39.0 years for the North and South Lagoons, respectively. The second water level threshold (-0.09 m AHD) was exceeded only for the South Lagoon sites in 2008.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for two single years with an average return time of 28.5 years.

The salinity threshold was exceeded in the Murray Mouth region for an average of 1.5 years at a return interval of 31.1 years. The North Lagoon had a return time of 11.7 years, and exceeded the threshold for 7.5 years on average, while Villa dei Yumpa exceeded the threshold for 61 years at a return interval of 2.0 years. The other South Lagoon sites always exceeded the threshold except for the first year of simulation. Under Dry Future conditions, salinity was greater than 100 g L^{-1} in 29% of site-years.

For the Dry Future scenario, depth and water level were the most evenly distributed variables (Gini = 0.03 for both). This suggests that they were relatively likely to occupy any value within their range, rather than being skewed to either end of the distribution. Tidal range and salinity were moderately-well dispersed (Gini = 0.2 and 0.17, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with the occasional large deviations towards the higher end of the spectrum (Gini = 0.51).

For the Dry Future scenario, eight out of the eight states were observed during the 114-year model run by 12 sites (1368 site-years) model run. Over the Dry Future scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (39%) and the Unhealthy Hypersaline state (20%; Figure 2.14). The Average Hypersaline and Unhealthy Marine states accounted for the following 26% (with 14% and 12%, respectively). Together, these accounted for 85% of the site-years modelled. The remaining 15% consisted of the less common Marine and Degraded Marine states (8% and 7%, respectively).

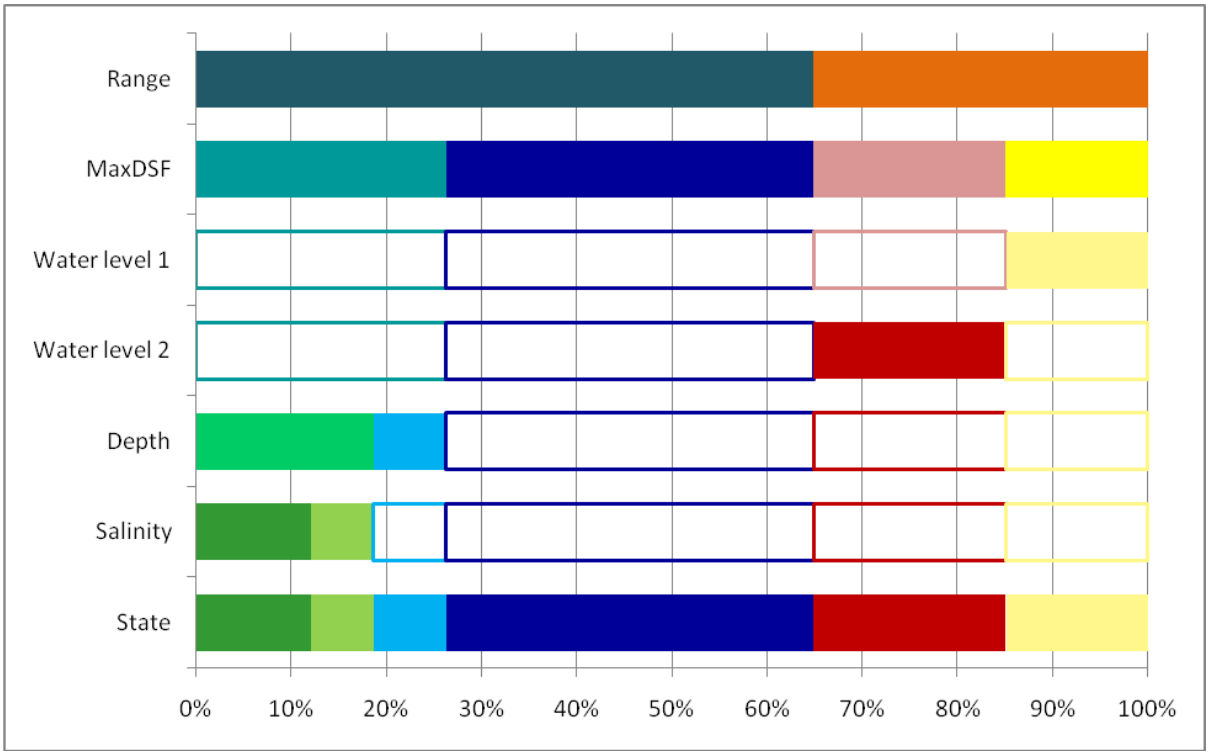

Figure 2.14. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Dry Future scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 26% of site-years (Figure 2.15). The proportions of site-years where the state did not change (state inertia) for the Dry Future scenario was 74%. The sequence in which states appeared at each site across the 144 years was significantly different from a random distribution (Z_u ranged between 6.73 and 9.69; $p <$ 0.001 for all sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 10% of site-years. When sites changed within the same basin, they shifted to a more degraded state 9% of the time and to a less degraded state 7% of the time.

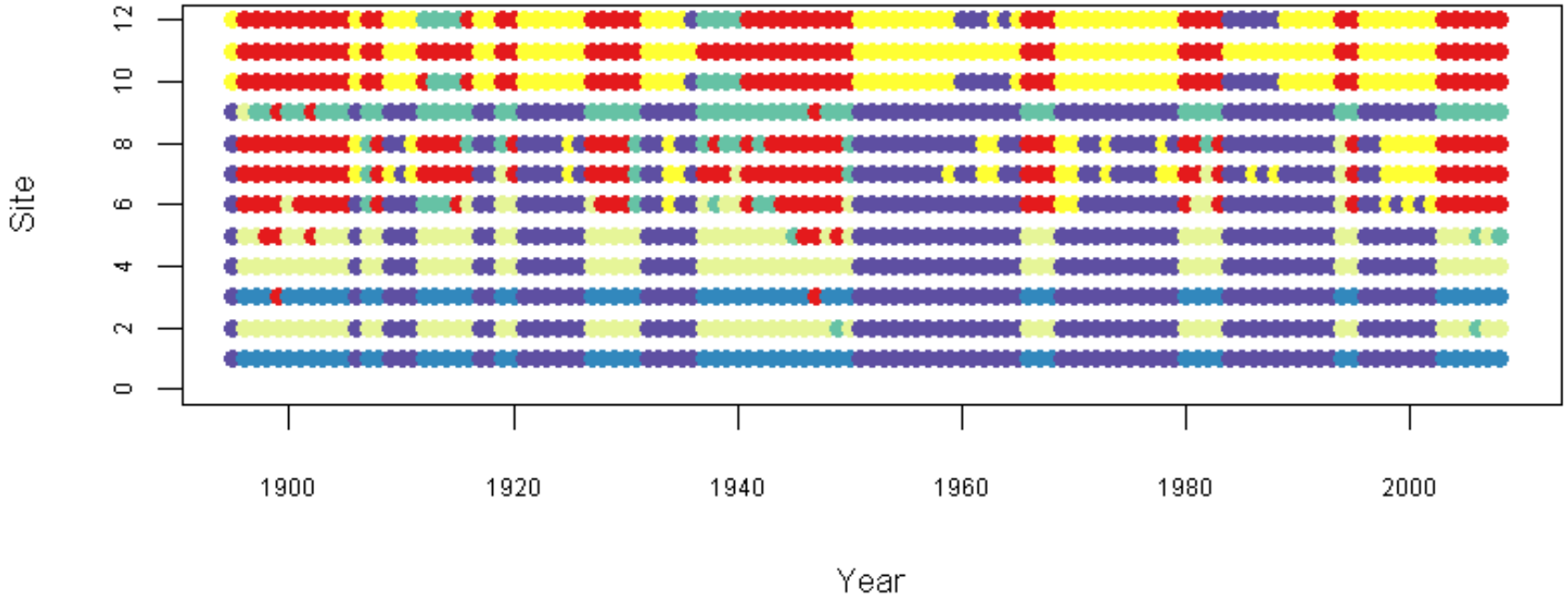

Figure 2.15. Distribution of states for each site-year under the Dry Future scenario

See Figure 2.3 for further explanation of the figure.

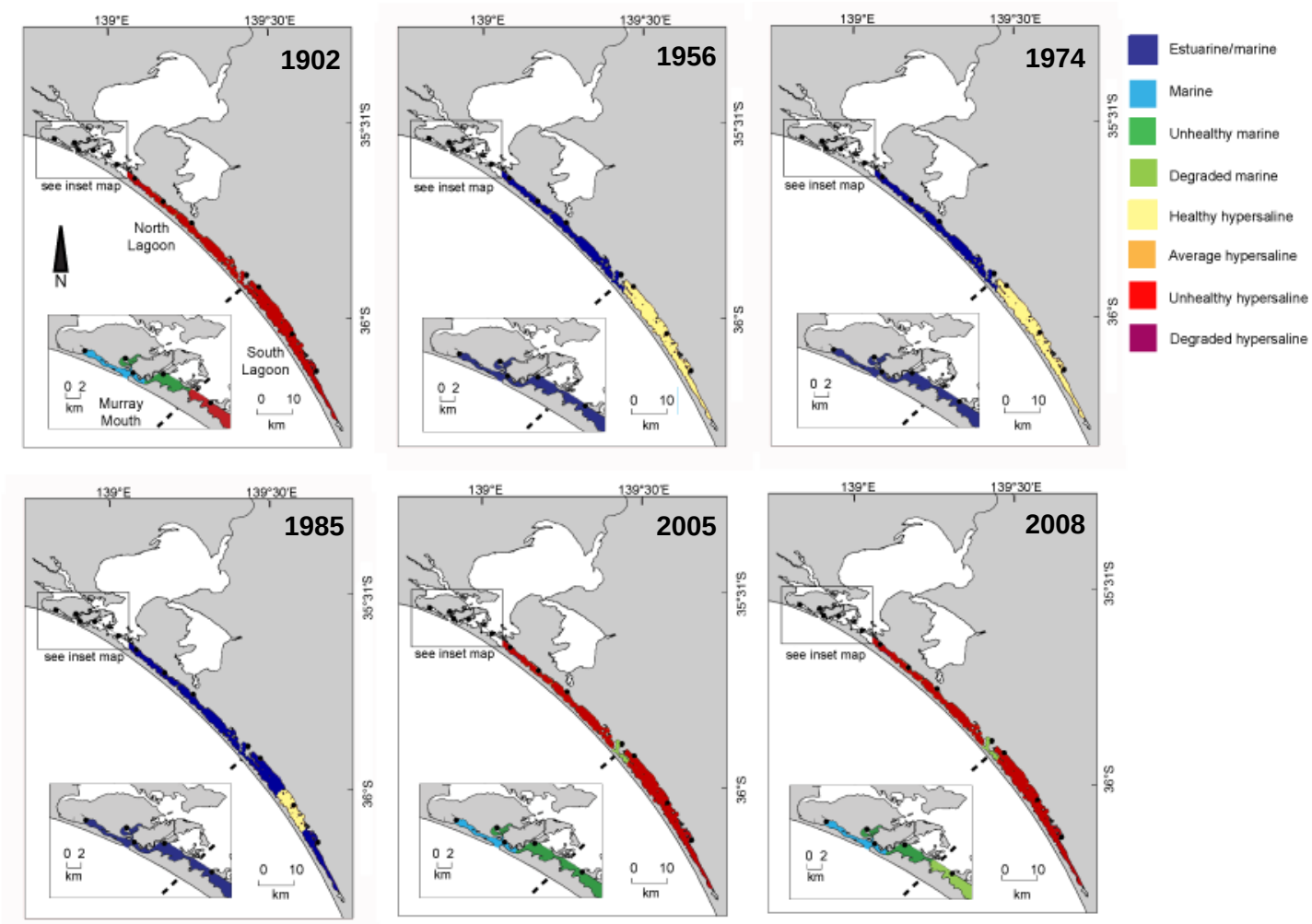

Figure 2.16. Mapping the distribution of states for seminal years under the Dry Future scenario

See Figure 2.4 for further explanation of the figure.

2.5. Median Natural

The Median Natural scenario investigates a median future climate with no extractions and no infrastructure within the Murray-Darling Basin (except for the barrages). Average flows from the USED scheme were modelled.

The distributions of each of the variables driving the ecosystem states of the Coorong under the Median Natural conditions are shown in Figure 2.17. Median water level was 0.39 m AHD, falling between 0.33 m AHD and 0.44 m AHD for 50% of the time. Median water depth under Median Natural conditions along the length of the Coorong was 1.50 m, although there were some outliers with depths of approximately double the median value observed. Median salinity was lower than that of seawater at 13.78 g L^{1}, but there were a number of outliers at higher salinities, with a few even at extreme salinities (with a maximum of 90.95 g L^{-1}). The median maximum number of days without flow (MaxDSF) for the Median Natural scenario was zero days, falling between zero and 43 days for 50% of the time. The median tidal range was small at 0.12 m, but there were much higher values in the upper range of values observed (e.g. a maximum of 0.83 m).

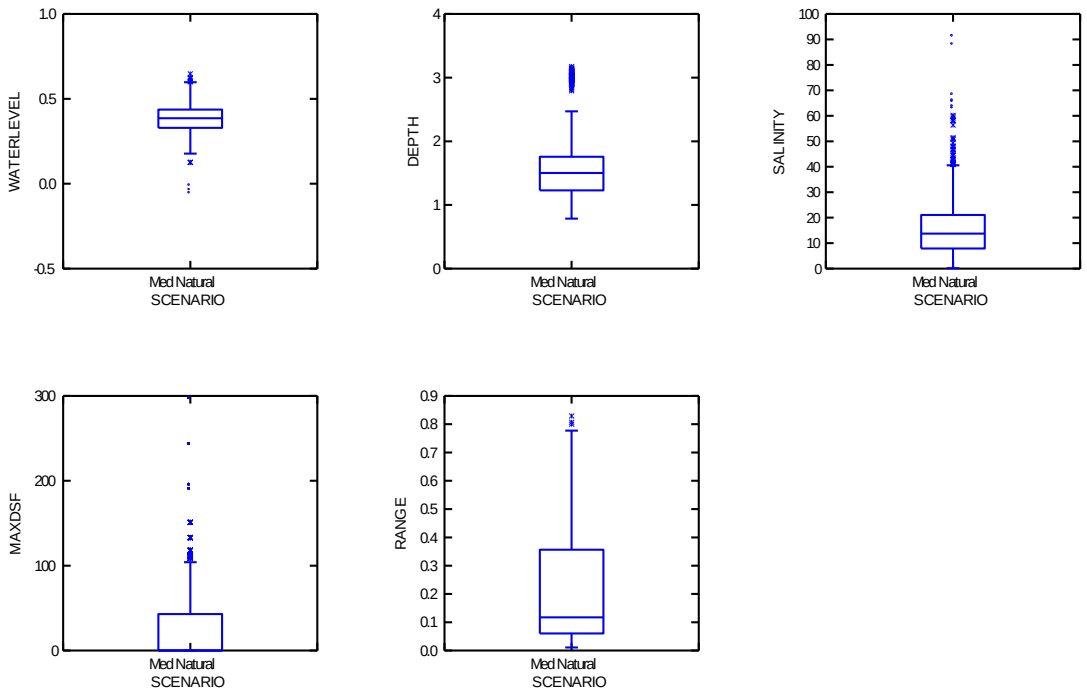

Figure 2.17. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Median Natural scenario

All North Lagoon and Murray Mouth sites exceeded the tidal range threshold, with the exception of Long Point for the final year of the simulation. In the South Lagoon, sites exceeded the threshold for an average of 3.0 years, at a return interval of 19.3 years.

The threshold for the maximum number of days since flow passed over the barrages was not exceeded under the Median Natural scenario.

The water level threshold of 0.37 m AHD was exceeded for an average of 6.0 years with a return time of 4.4 years in the Murray Mouth region. In the North Lagoon, these figures were 3.4 and 2.8 years respectively. In the South Lagoon, the average length of time the

threshold was exceeded decreased to 2.0 years, with a return time of 3.0 years. The water level threshold of -0.09 m AHD was always exceeded under this scenario.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for an average of 1.6 years, recurring every 4.9 years.

The salinity threshold was exceeded in the South Lagoon sites in two years for a year at a time. The return interval was 105 years. Salinity under median natural conditions was never greater than 100 g L^{-1} for the site-years modelled.

For the Median Natural scenario, depth, water level and tidal range were the most evenly distributed variables (Gini = 0.03, 0.05 and 0.08, respectively). Salinity was moderately-well dispersed (Gini = 0.30), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with occasional large deviations towards the high end of the spectrum (Gini = 0.78).

For the Median Natural scenario, three out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Figure 2.18 shows that only the three states of Estuarine/Marine, Average Hypersaline and Healthy Hypersaline are observed under the Median Natural conditions along the length of the Coorong. The Estuarine/Marine state was the most common (77%), then the Average Hypersaline (12%) and finally Healthy Hypersaline states accounting for the remaining 11%.

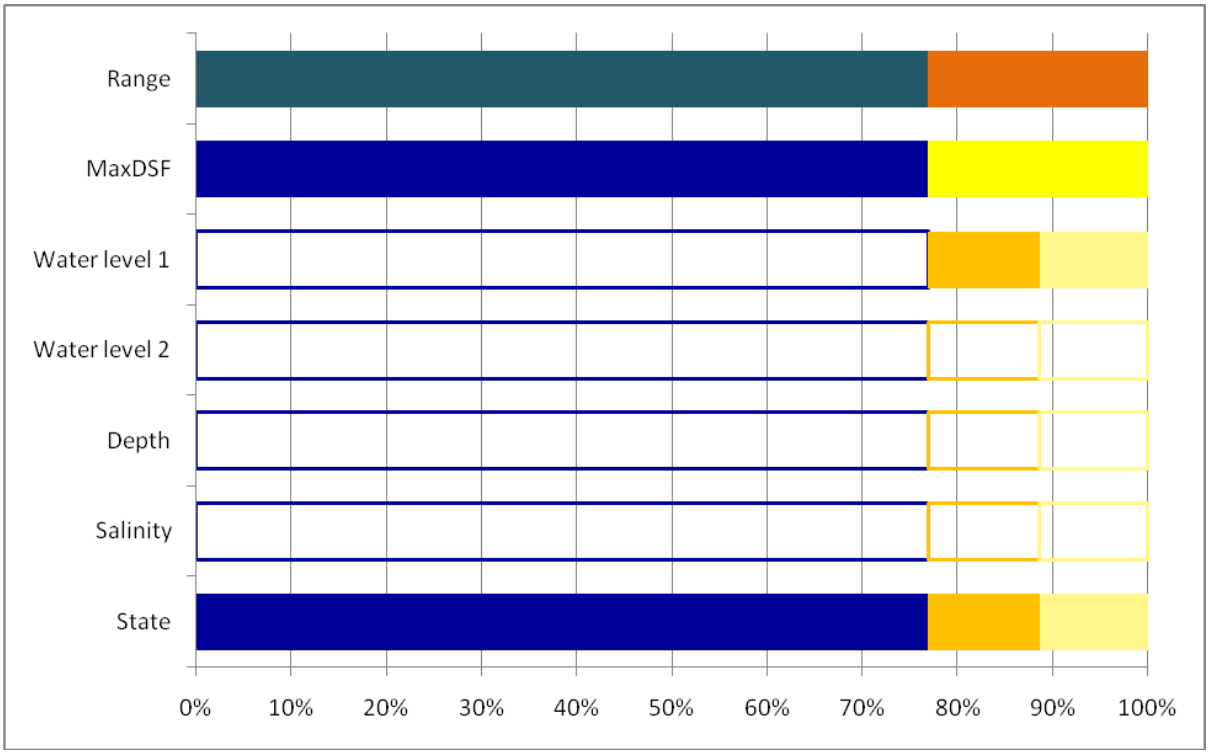

Figure 2.18. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Median Natural scenario

See Figure 2.2 for further explanation of the figure.

For 12% of the site-years, transitions occurred between states (Figure 2.19). This means that the state inertia (i.e. the proportion of site-years where the state did not change) in the system for the Median Natural scenario was 88%. Three of the 12 sites (Long Point, Villa dei Yumpa and Salt Creek) showed sequences of states which were significantly different from a random distribution (Z_u was 7.48, 2.64 and 2.64, respectively). When transitions did occur, sites changed from a marine state to a hypersaline state, or vice versa (i.e. both directions) in 1% of site-years. When sites changed within the same basin, they shifted to a more degraded state 6% of the time and to a less-degraded state 5% of the time.

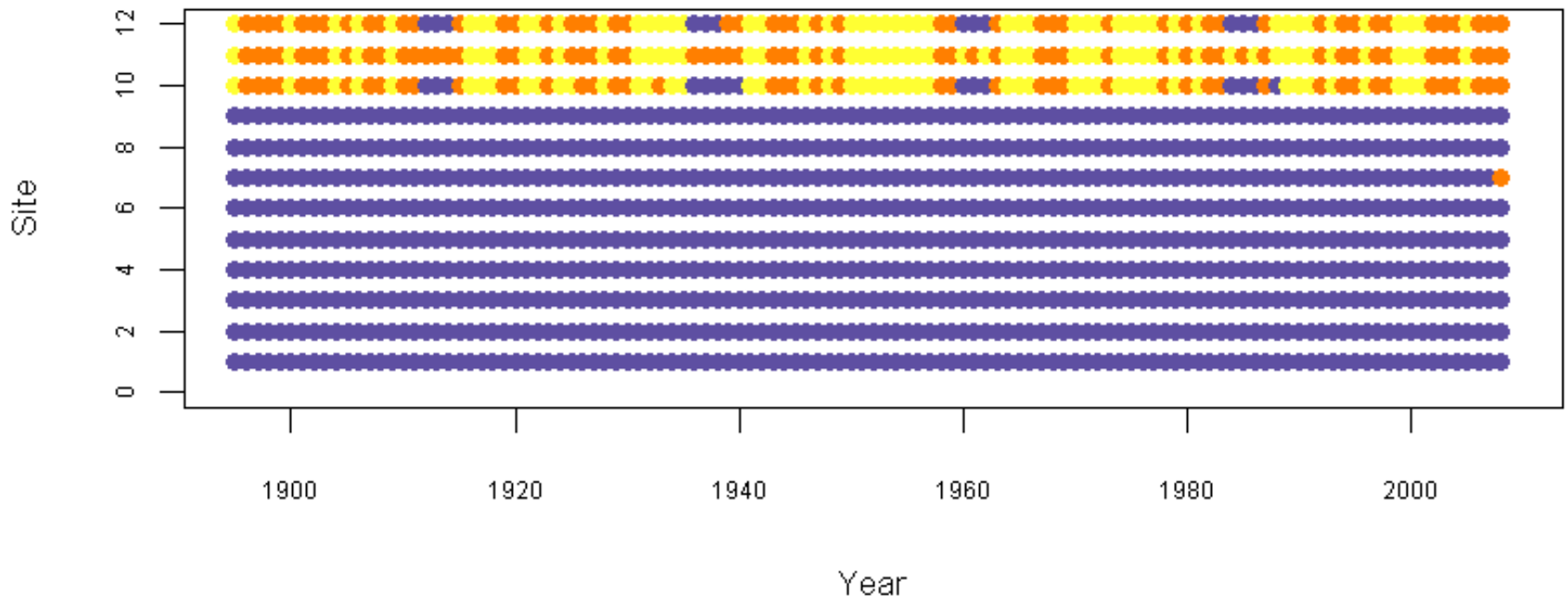

Figure 2.19. Distribution of states for each site-year under the Median Natural scenario

See Figure 2.3 for further explanation of the figure.

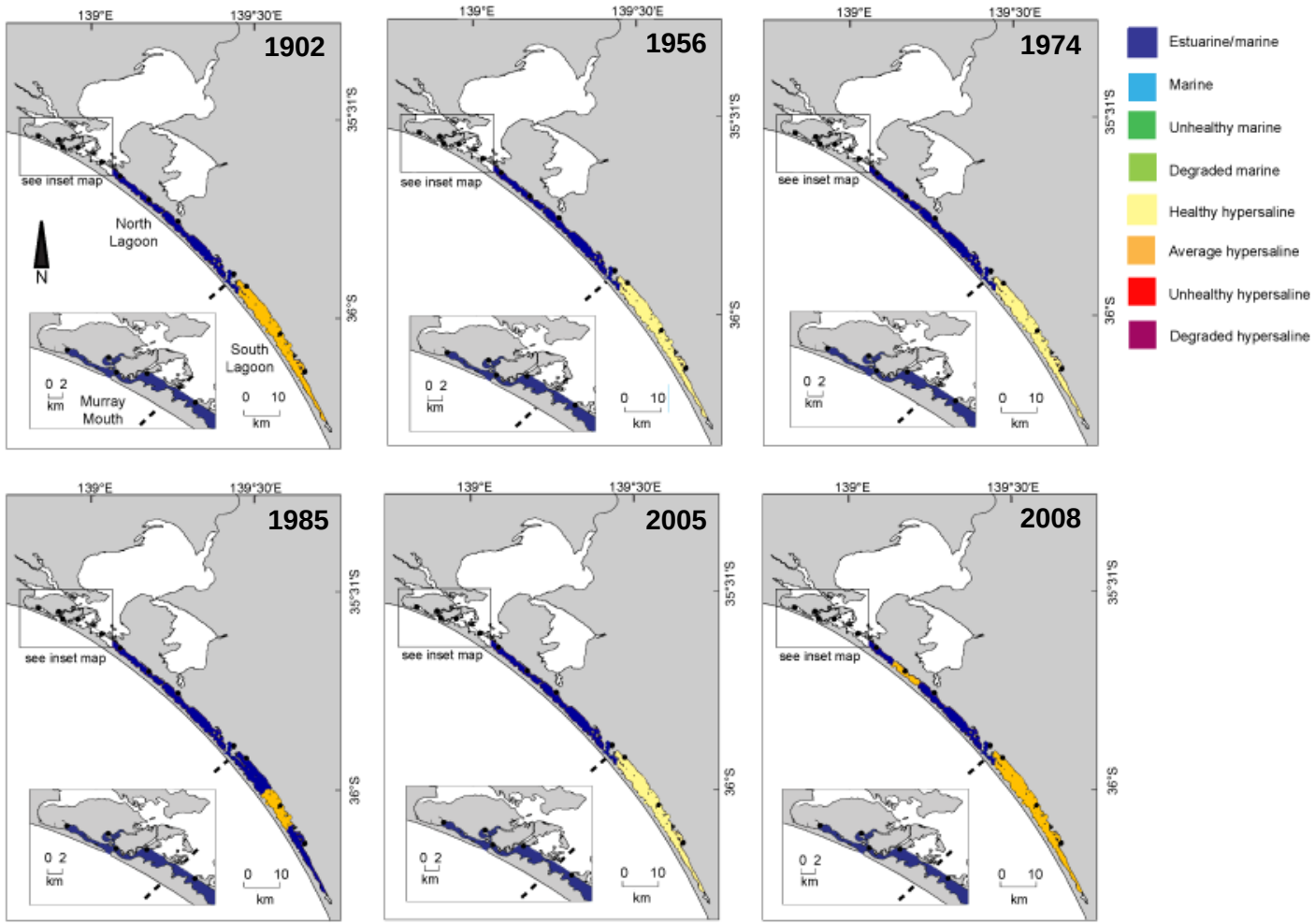

Figure 2.20. Mapping the distribution of states for seminal years under the Median Natural scenario

See Figure 2.4 for further explanation of the figure.

2.6. Dry Natural

The Dry Natural scenario modelled the effects of a dry future climate without extractions or infrastructure in the Murray-Darling Basin. It included USED flows but no dredging effort.

The distributions of each of the variables driving the ecosystem states of the Coorong under Dry Natural conditions are shown in Figure 2.21. Median water level was 0.35 m AHD, although there are some outliers at extremely low water levels (minimum of -0.31 m AHD). Median water depth under Dry Natural conditions along the length of the Coorong was 1.46 m, falling between 1.20 m and 1.72 m for 50% of the time. Median salinity was lower than seawater along the length of the Coorong over 114-year model run, at 21.07 g L^{-1}, although there were a number of outliers at extremely high salinities. The median for the maximum number of days since flow over the barrages (MaxDSF) for the Dry Natural scenario was 50 days, falling between zero and 126 days for 50% of the time. Median tidal range was small at 0.11 m, but there were some outliers at much higher tidal ranges (maximum 0.84 m).

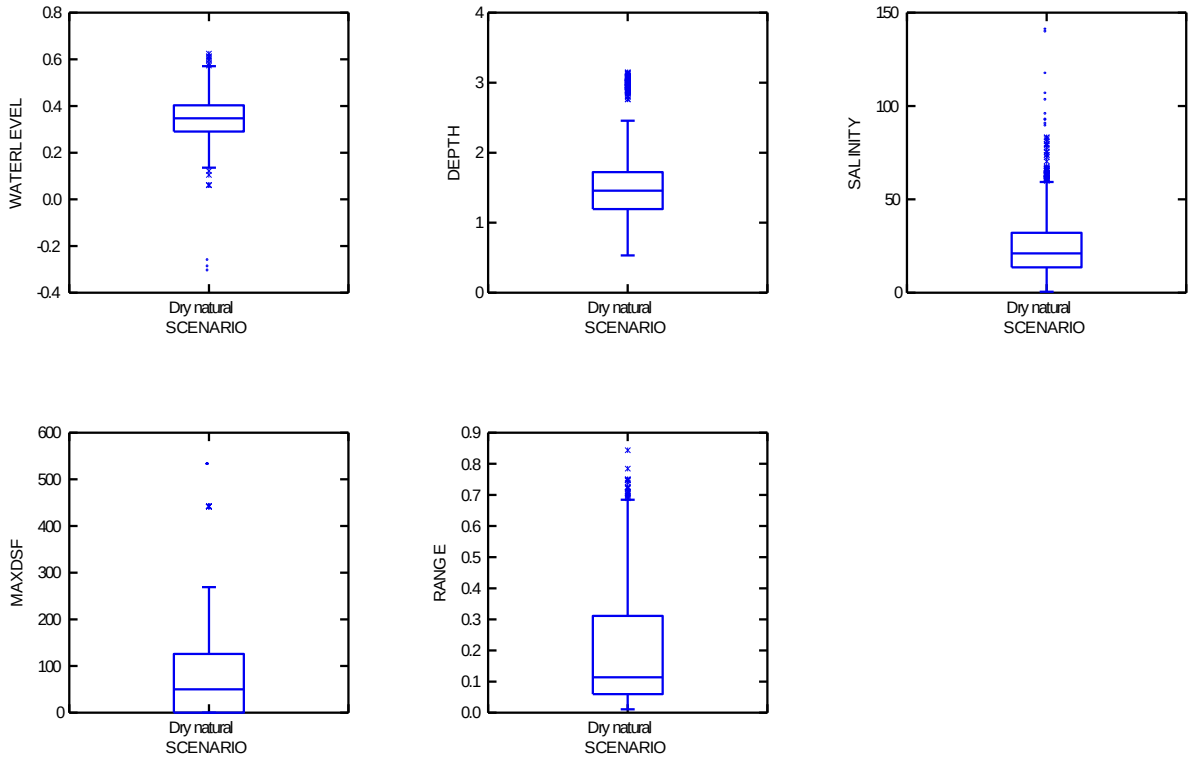

Figure 2.21. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Dry Natural scenario

North Lagoon sites south of Mark Point exceeded the tidal range threshold for all years bar 2008. All sites further north were always over the threshold. In the South Lagoon, the average exceedance was 3.4 years, at an interval of 15.9 years.

Under the Dry Natural scenario, the threshold for the maximum number of days without flow over the barrages was exceeded once, during the 113th year of the simulation, and was also over the threshold in the 114th year.

The higher water level threshold, of 0.37 m AHD was exceeded for an average of 2.7 years at a return interval of 6.5 years in the Murray Mouth region. For the North Lagoon, the length of time the threshold was exceeded fell to 1.7 years, occurring every 3.2 years. The

South Lagoon sites exceeded the threshold for 1.6 years every 5.5 years. The water level threshold at -0.09 m AHD was exceeded only for the South Lagoon sites in the final year of simulation.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point on a regular basis, with a return time of 9.0 years and an average duration of 1.5 years.

The Murray Mouth sites never exceeded the salinity threshold, and the three southern-most North Lagoon sites only did for the last year of simulation. The South Lagoon sites exceeded the threshold for an average of 1.7 years at a return time of 22.8 years. Under Dry Natural conditions salinity was never greater than 100 g L^{-1} for the site-years modelled.

For the Dry Natural scenario, depth, water level and tidal range were the most evenly distributed variables (Gini = 0.03, 0.06 and 0.09, respectively). Salinity was moderately well-dispersed (Gini = 0.25), but the maximum number of days without flow was unevenly dispersed, tending to remain high on most occasions, but with occasional large deviations towards the lower end of the spectrum (Gini = 0.60).

For the Dry Natural scenario, five out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the Dry Natural scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (76%) and the Average Hypersaline state (16%; Figure 2.22). Together, these two states accounted for 92% of the site-years modelled. The Healthy Hypersaline (6%), Unhealthy Marine (1%) and Unhealthy Hypersaline (1%) states were all uncommon. Under Dry Natural conditions there was an absence of the two most degraded states (the Degraded Marine and Degraded Hypersaline states) and the Marine state over the model run.

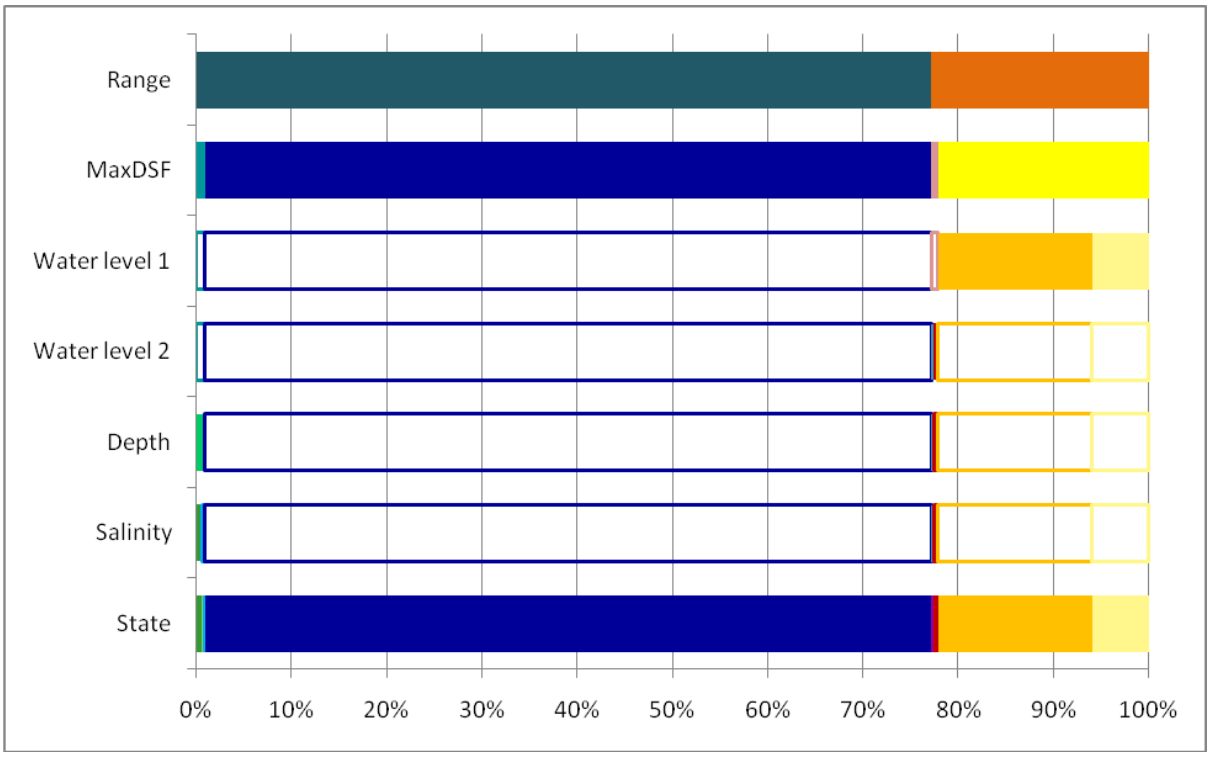

Figure 2.22. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Dry Natural scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 10% of site-years (Figure 2.23). The proportion of site-years where the state did not change in the system for the Dry Natural scenario was 90%. The sequence in which states appeared at each of the sites across the 114 years was significantly different from a random distribution (Z_u ranged between 2.28 and 9.18 for 12 sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 2% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 5% of the time and to a less-degraded state only 3% of the time.

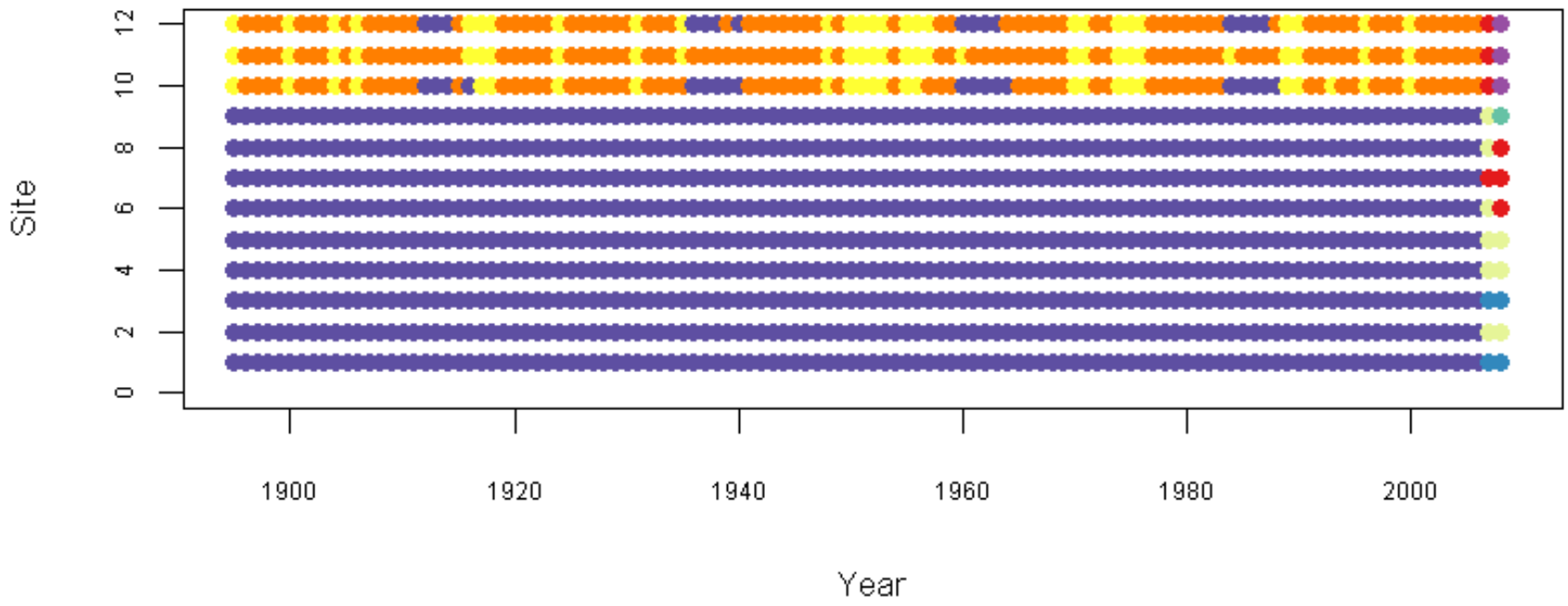

Figure 2.23. Distribution of states for each site-year under the Dry Natural scenario

See Figure 2.3 for further explanation of the figure.

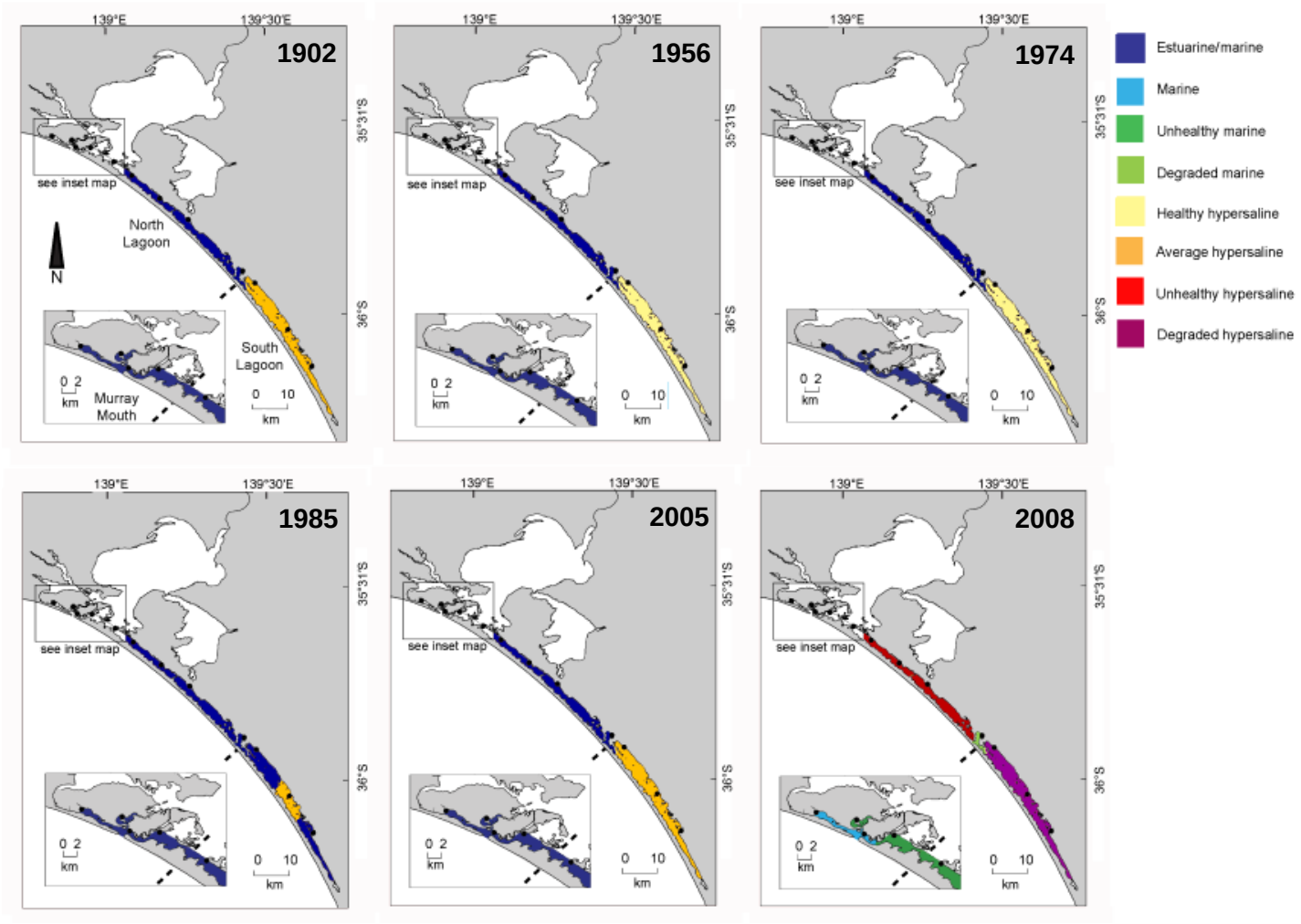

Figure 2.24. Mapping the distribution of states for seminal years under the Dry Natural scenario

See Figure 2.4 for further explanation on the figure.

2.7. Median Future, -10 cm SLR

The Median Future, -10 cm SLR scenario investigated the effect of a 10 cm decrease in sea level under a median future climate. Other parameters remained the same as for the Median Future scenario.

Figure 2.25 shows the distributions of each of the variables driving the ecosystem states of the Coorong under the Median Future, -10 cm SLR conditions. Median water level was 0.17 m AHD, falling between 0.11 m AHD and 0.25 m AHD for 50% of the time. Median water depth under Median Future -10 cm SLR conditions along the length of the Coorong was 1.27 m, with some outliers at higher depths (maximum 0.49 m). Median salinity was slightly higher than seawater, at 40.08 g L^{-1}, falling between 29.08 g L^{-1} and 66.14 g L^{-1} for 50% of the time. The median for the maximum number of days without flow (MaxDSF) for the Median Future, -10 cm SLR scenario was 186 days, although there were a number of outliers with greater numbers of days without flow (maximum 690 days). The median tidal range was small at 0.09 m, falling between 0.05 m and 0.18 m for 50% of the time.

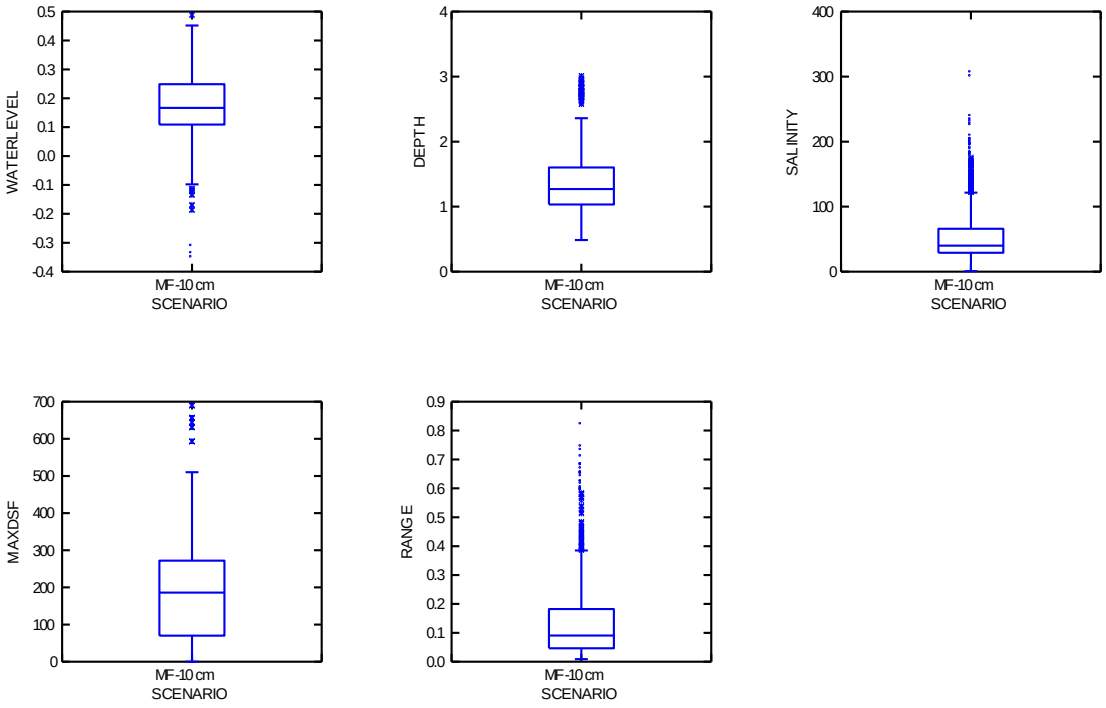

Figure 2.25. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Median Future, –10 cm SLR scenario

Sites north of Mark Point were always over the tidal range threshold. North Lagoon sites further south exceeded the threshold for a duration of 8.6 years at a return interval of 2.7 years. In the South Lagoon, the duration of exceedance was an average of 2.2 years, and the return time was 19.7 years.

The threshold for the maximum number of days since flow was exceeded for 1.6 years on average, with a return time of 17.5 years.

For the water level threshold at 0.37 m AHD, the Murray Mouth exceeded the threshold for an average of 1.4 years with a return interval of 15.5 years. The North Lagoon region was similar, exceeding the threshold for an average of 1.2 years at a return interval of 18.7 years.

In the South Lagoon, the threshold was exceeded for two single years at each site, with a return interval of 18 years.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was not exceeded at any other site.

The Murray Mouth sites did not exceed the salinity threshold. In the North Lagoon sites, the threshold was exceeded for an average of 2.0 years every 34.9 years. In the South Lagoon sites, the duration of exceedance was 29.2 years and the return interval was 3.5 years. Salinity under Median Future, -10 cm SLR conditions was greater than 100 g L^{-1} in 14% of site-years.

Depth and water level were the most evenly distributed variables (Gini = 0.04 and 0.09, respectively) for the Median Future, -10 cm SLR scenario. Tidal range and salinity were both moderately-well dispersed (Gini = 0.17 and 0.20, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with the occasional large deviation towards the high end of the spectrum (Gini = 0.43).

For the Median Future, -10 cm SLR scenario, eight out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Along the length of the Coorong the two most common states were the Estuarine/Marine state (65%) and the Average Hypersaline state (23%; Figure 2.26). The Unhealthy Hypersaline (4%), Unhealthy Marine (3%), Marine (2%) states were all uncommon and the two most-degraded states, the Degraded Marine and Degraded Hypersaline states both appeared in only 1% of the site-years each.

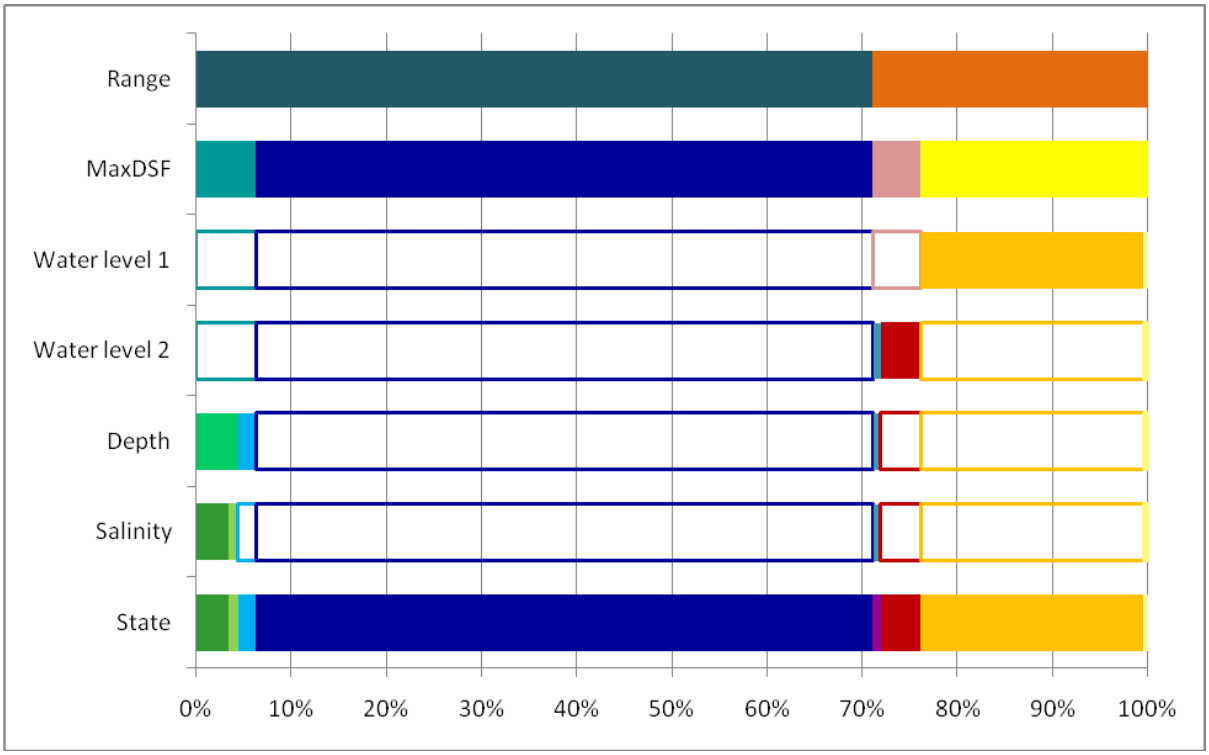

Figure 2.26. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Median Future, -10 cm SLR scenario

See Figure 2.2 for further explanation of the figure.

For 17% of site-years, transitions occurred between states (Figure 2.27). This means that the state inertia (i.e. the proportion of site-years where the state did not change) in the system for the Median Future, -10 cm SLR scenario was 83%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution ($Z_u$ranged between 3.34 and 6.76, $p < 0.001$ for 12 sites). When transitions did occur, sites changed from a marine state to a hypersaline state or vice versa (i.e. changed basin) in 6% of site-years. When sites changed within the same basin, they shifted to a more degraded state 6% of the time and to a less-degraded state 5% of the time.

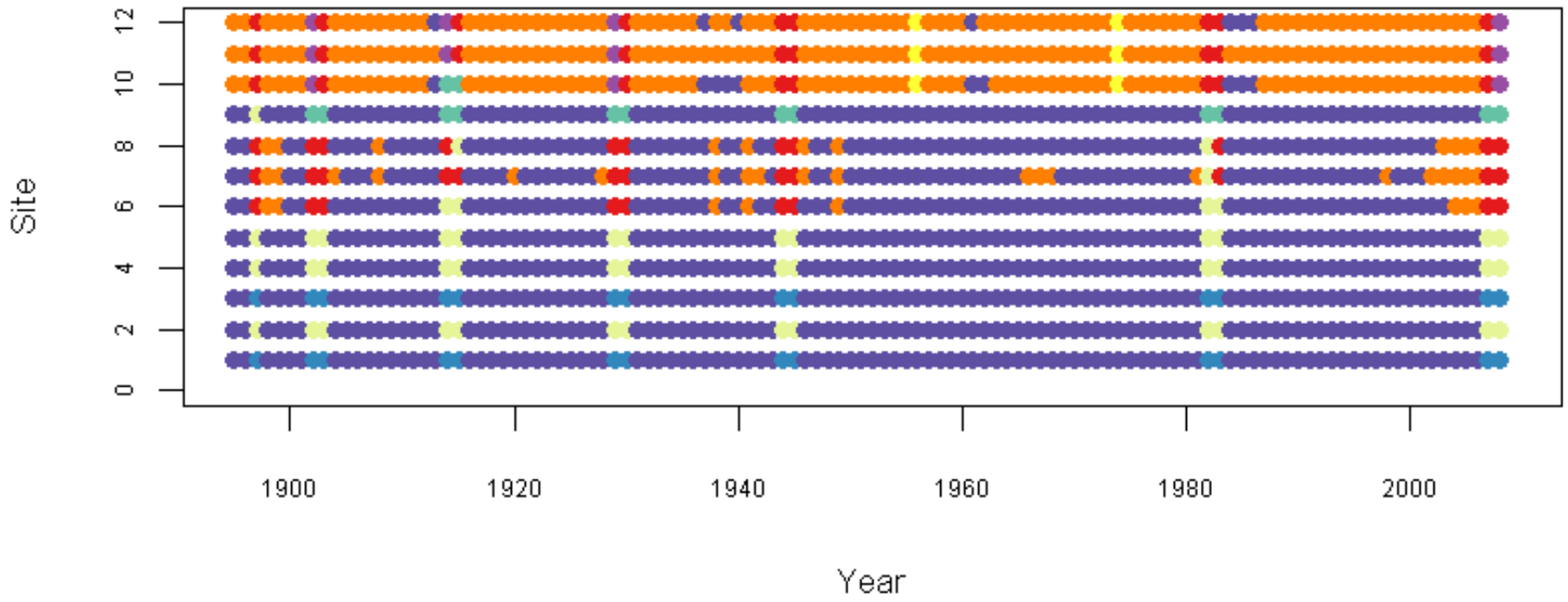

Figure 2.27. Distribution of states for each site-year under the Median Future, -10 cm scenario

See Figure 2.3 for further explanation of the figure.

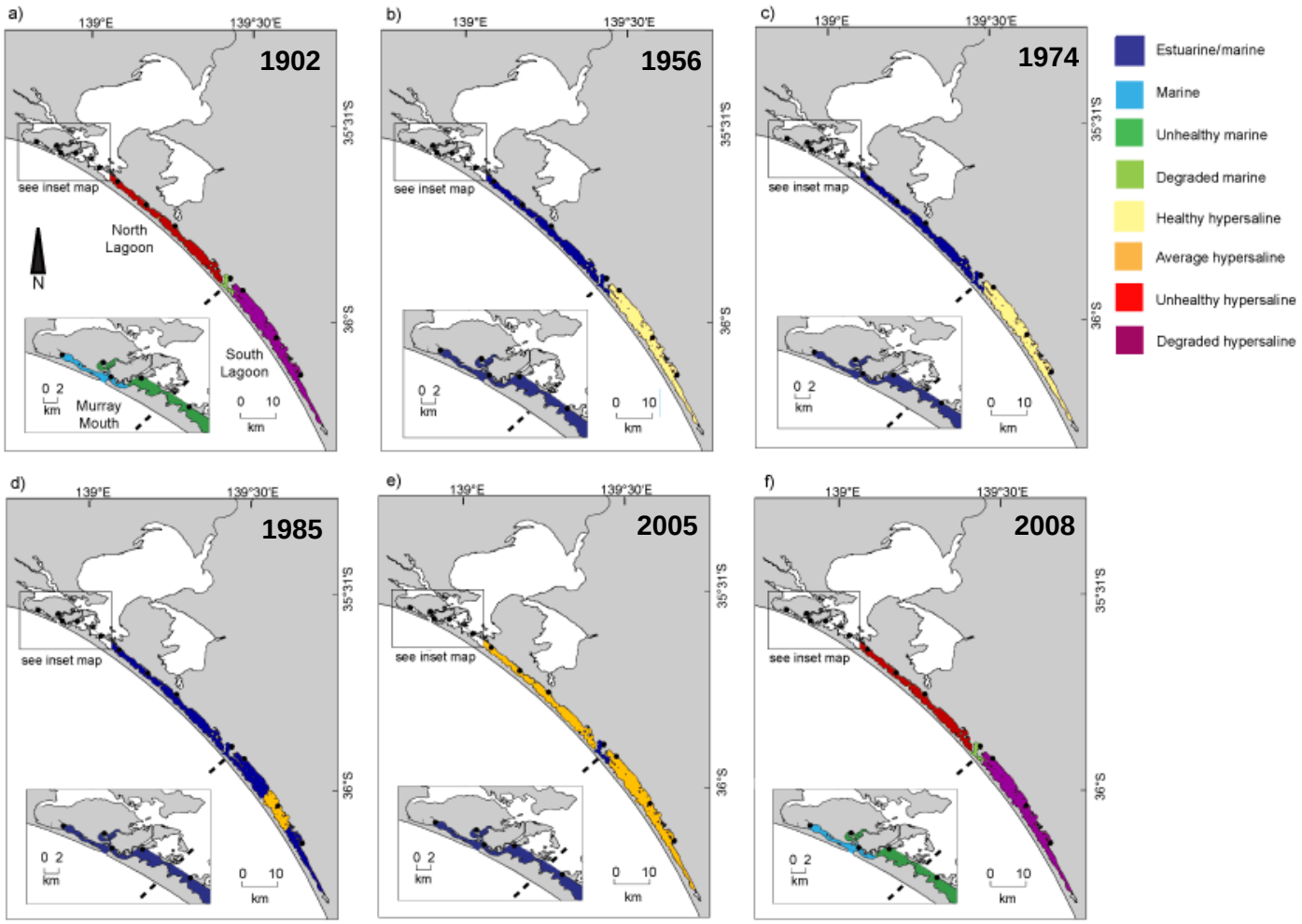

Figure 2.28. Mapping the distribution of states for seminal years under the Median Future, -10 cm SLR scenario

See Figure 2.4 for further explanation on the figure.

2.8. Median Future, +20 cm SLR

The Median Future, +20 cm SLR scenario modelled the same scenario as the Median Future scenario, but incorporating a 20-cm sea level rise.

The distributions of each of the variables driving the ecosystem states of the Coorong under the Median Future, +20 cm SLR is shown in Figure 2.29. Median water level was 0.48 m AHD, but there were outliers at both the lower and higher ends of the spectrum (minimum 0.06 m AHD and maximum 0.48 m AHD). Median water depth under the Median Future, +20 cm SLR conditions along the length of the Coorong was 1.60 m, falling between 1.34 m and 1.85 m for 50% of the time. Median salinity was slightly higher than seawater at 39.40 g L^{-1}, although there were a number of outliers at extremely high salinities. The median for the maximum number of days since flow over the barrages was 186 days, falling between 70 days and 272 days for 50% of the time. The median tidal range along the length of the Coorong over the 114-year model run was small at 0.10 m, but there were a number of outliers at extremely high tidal ranges (maximum = 0.79 m).

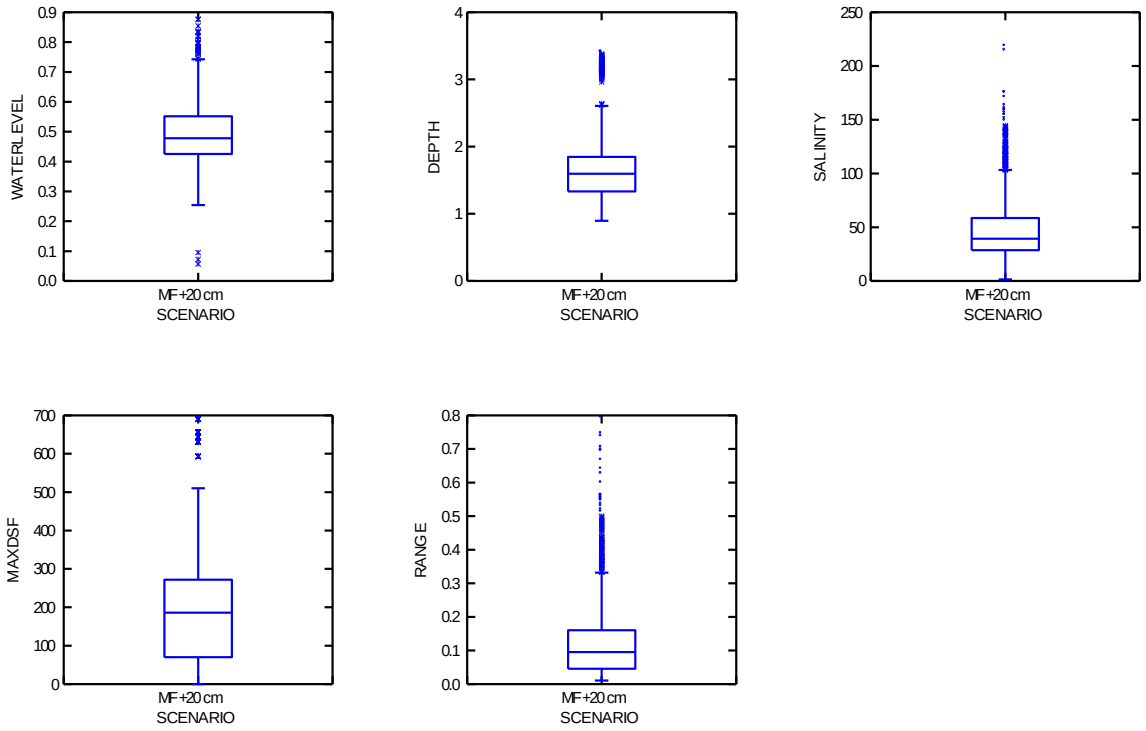

Figure 2.29. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Median Future, +20 cm SLR scenario

The tidal threshold was always exceeded at sites north of Mark Point. The remainder of the North Lagoon exceeded the threshold for 10.0 years with a return interval of 2.8 years. In the South Lagoon, the threshold was crossed for 2.6 years at a return interval of 22.5 years. The threshold for the maximum number of days since flow was exceeded for 1.6 years on average, with a return time of 17.5 years.

The return intervals for exceeding the first water level threshold (0.37 m AHD) were similar between regions, but the length of time that each exceeded the threshold varied. For the Murray Mouth region, the length of time the threshold was exceeded was 15.3 years on average, with a return time of 3.3 years. In the North Lagoon, the threshold was exceeded for 10.2 years every 2.3 years on average and in the South Lagoon, the threshold was crossed for 1.7 years with a return time of 3.8 years. The second water level threshold of -0.09 m AHD was always exceeded for this scenario.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also usually exceeded at Mark Point, with an average exceedance duration of 3.1 years and a recurrence interval of 2.5 years.

The salinity threshold was not exceeded by any of the Murray Mouth sites. In the North Lagoon, the return time was 35.7 years and 1.8 was the average number of years over the threshold. South Lagoon sites exceeded the threshold for an average of 14.7 years at a return interval of 4.7 years. Salinity under Median Future, +20 cm SLR conditions was greater than 100 g L^{-1} in 8% of site-years.

For the Median Future, +20 cm SLR scenario, depth and water level were the most evenly dispersed variables (Gini both = 0.03). Tidal range and salinity were moderately-well distributed (Gini = 0.19 and 0.20, respectively), but the maximum number of days without flow was unevenly distributed, tending to remain moderate, but with the occasional deviation towards the very high end of the spectrum (i.e. zero days since flow).

For the Median Future, +20 cm SLR scenario, seven out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the Median Future, +20 cm scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (65%) and the Healthy Hypersaline state (22%; Figure 2.30). Together, these two states accounted for 87% of the site-years modelled. The Unhealthy Hypersaline (5%), Unhealthy Marine (3%), Marine (2%), Average Hypersaline (2%) and Degraded Marine (2%) states were all uncommon. The Degraded Hypersaline state did not appear for any site-year in the entire 114-year model run.

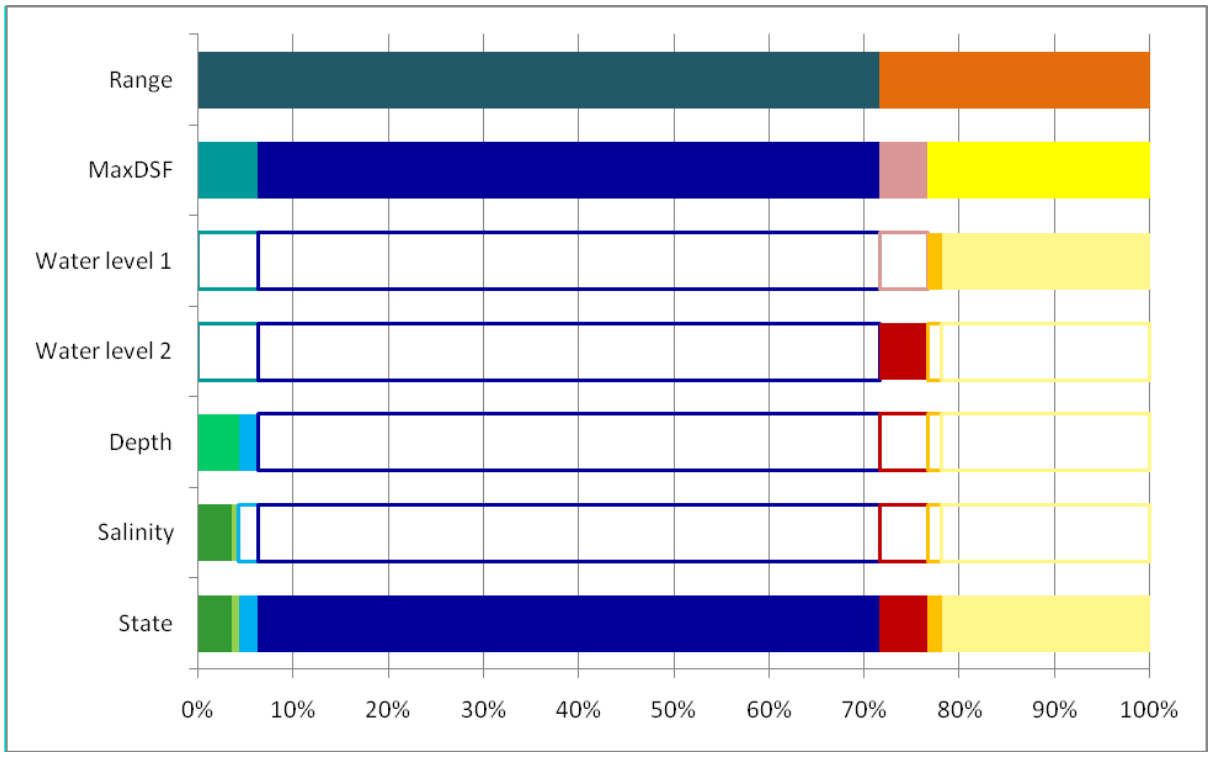

Figure 2.30. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Median Future, +20 cm SLR scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 18% (Figure 2.31). This means that the proportion of site-years where the state did not change in the system for the Median Future, +20 cm SLR scenario was 82%. Nine of the twelve sites across the 114 years showed sequences in which states which were significantly different from a random distribution (Z_u ranged between 3.39 and 4.73 for 9 sites). Those sites which showed sequences in which states were not significantly different from a random distribution were Long Point, Noonameena, Villa dei Yumpa and Jack Point. When transitions did occur, sites changed between basin (i.e. went from a marine state to a hypersaline state or vice versa) in 6% of site-years. When sites changed within the same basin, they shifted to a more degraded state 7% of the time and to a less-degraded state only 5% of the time.

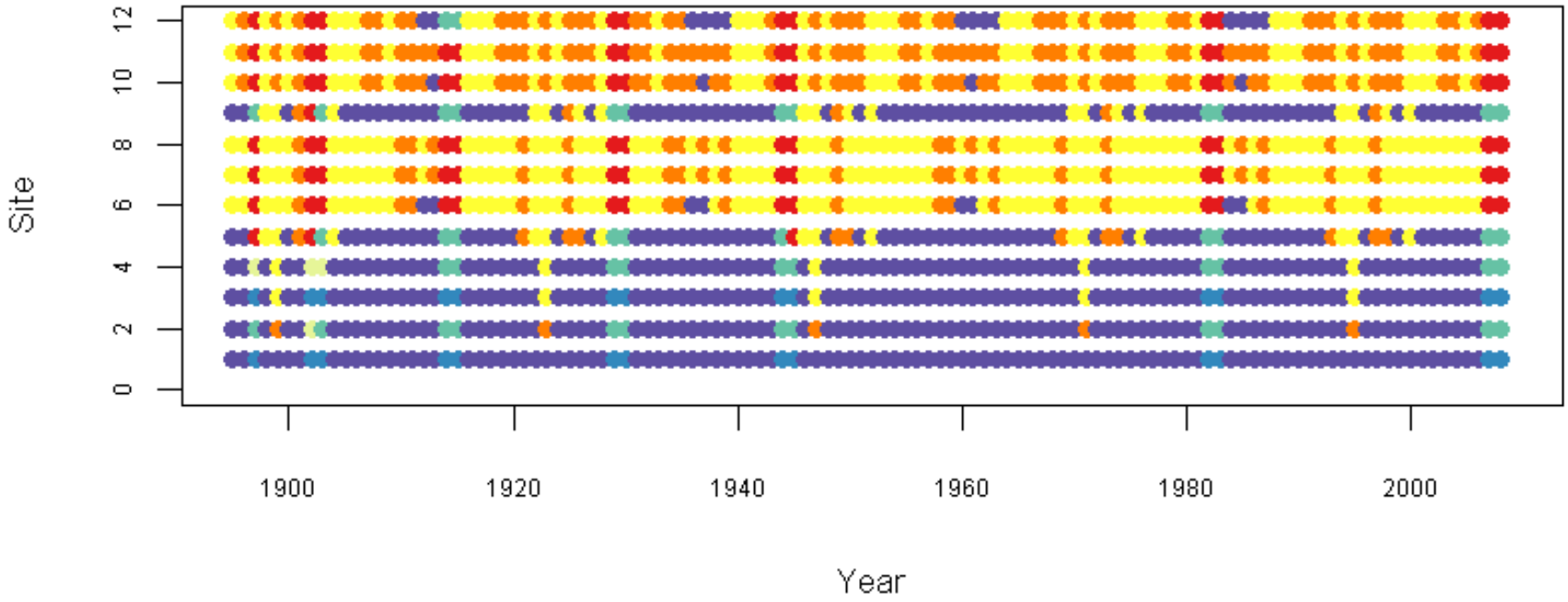

Figure 2.31. Distribution of states for each site-year under the Median Future, +20 cm SLR scenario

See Figure 2.3 for further explanation of the figure.

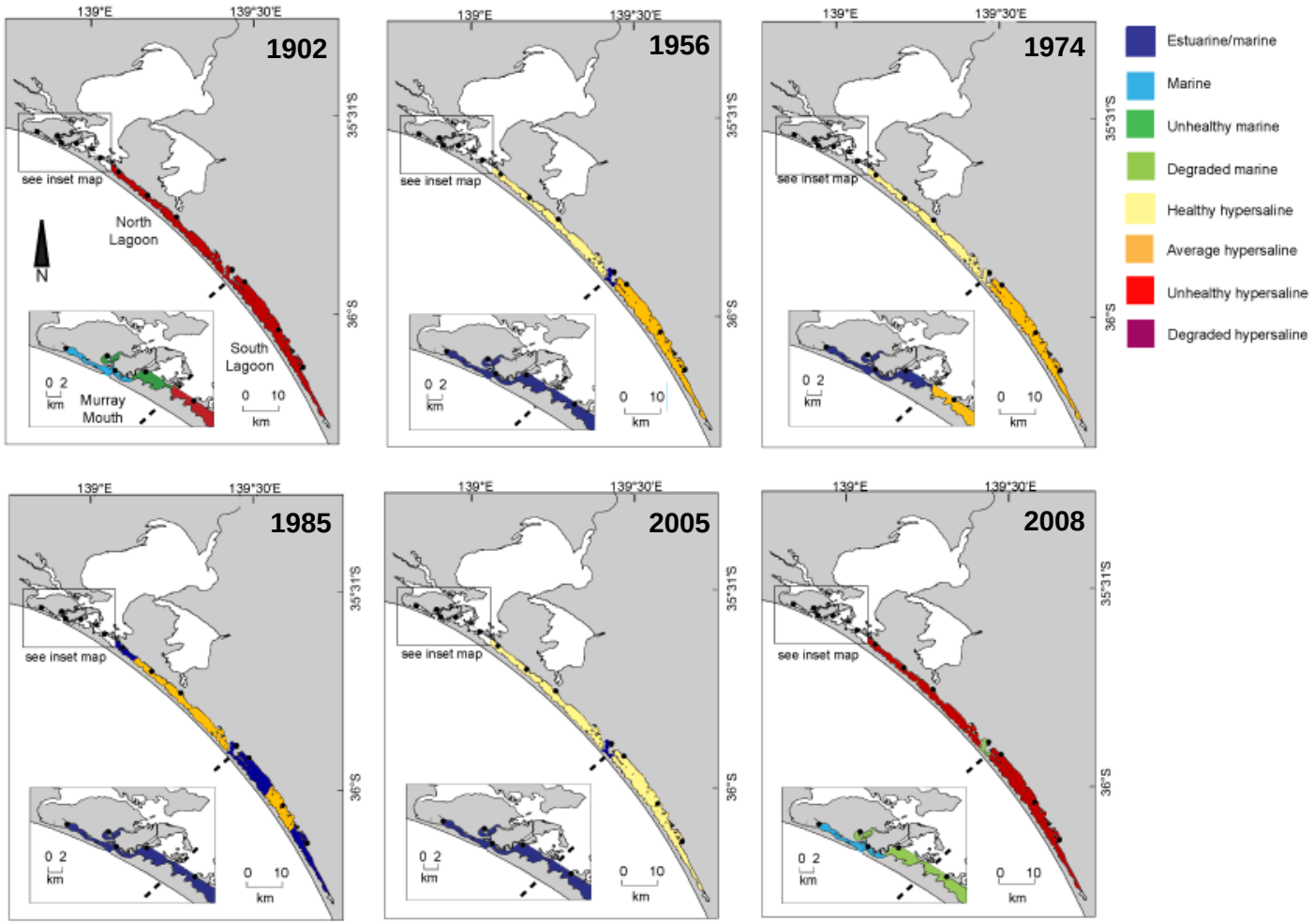

Figure 2.32. Mapping the distribution of states for seminal years under the Median Future + 20 cm SLR scenario

See Figure 2.4 for further explanation on the figure.

2.9. Median Future, +40 cm SLR

The Median Future, +40 cm SLR scenario investigated a median future climate with a 40 cm increase in sea level rise.

Figure 2.33 shows the distributions of each of the variables driving the ecosystem states of the Coorong under the Median Future, +40cm SLR conditions. Median water level was 0.68 m AHD, falling between 0.63 m AHD and 0.75 m AHD for 50% of the time. Median water depth under the Median Future, +40 cm SLR conditions along the length of the Coorong was 1.80 m, although there were some outliers at much higher depths (maximum 3.67 m). Median salinity was only slightly greater than seawater at 38.51 g L^{-1}, but there were a number of outliers at extremely high salinities (maximum 183.49 g L^{-1}). The median number of maximum days since flow over the barrages (MaxDSF) for the Median Future, +40 cm scenario was 186 days, falling between 70 days and 272 days for 50% of the time. Median tidal range along the length of the Coorong over the 144-year model run was small at 0.09 m, although there were a number of outliers at greater tidal ranges.

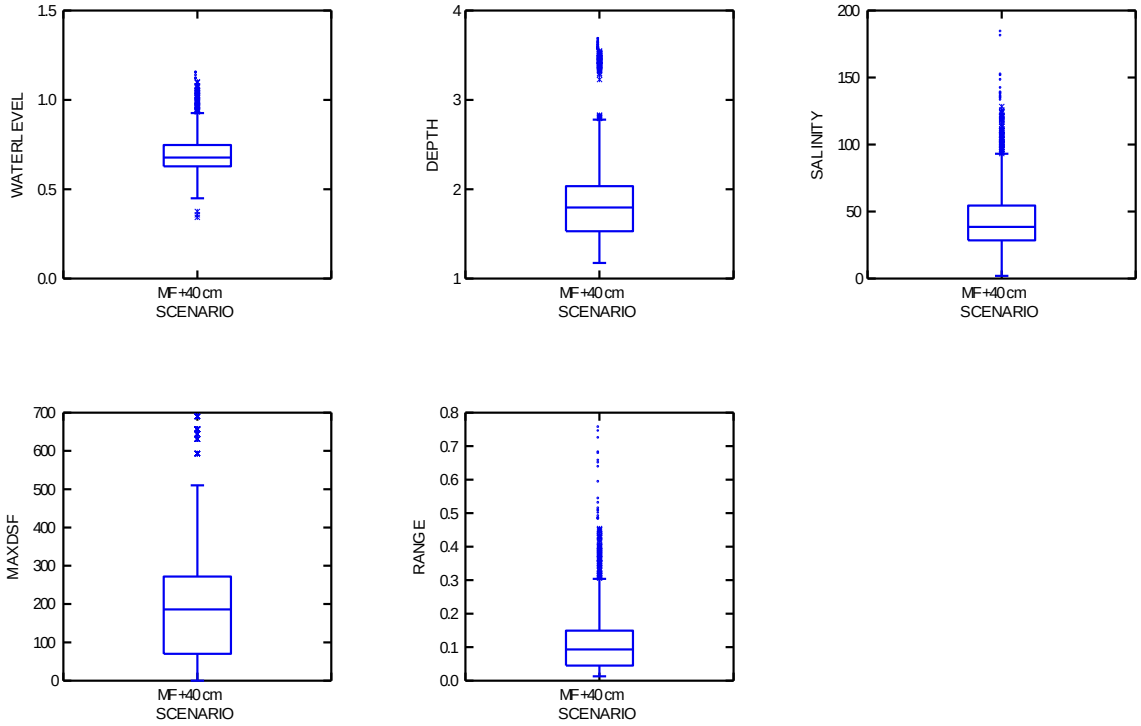

Figure 2.33. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Median Future, +40 cm SLR scenario

Pelican Point was the first site to fall below the threshold for the daily tidal range. It, along with the other North Lagoon sites, exceeded the threshold for an average of 8.2 years with a return interval of 2.4 years. South Lagoon sites exceeded the threshold for 1.5 years at a return interval of 23.5 years.

The threshold for the maximum number of days since flow was exceeded for 1.6 years on average, with a return time of 17.5 years.

The water level threshold at 0.37 m AHD was exceeded at all sites for all years with the exception of the South Lagoon sites in 2008. The lower water level threshold (-0.09 m AHD) was always exceeded.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for two single years with an average return time of 35 years, and at Salt Creek for an average of 1.3 years, recurring every 11.1 years.

South Lagoon sites exceeded the salinity threshold for 7.8 years at a return interval of 4.7 years. The North Lagoon had values of 1.9 years over the threshold every 26.5 years, while the Murray Mouth did not exceed the threshold. Salinity under Median Future, +40 cm SLR conditions was greater than 100 g L^{-1} in 5% of site-years.

Depth and water level were the most evenly distributed variables (Gini = 0.02 and 0.04, respectively) in the Median Future, +40 cm scenario. Salinity and tidal range were moderately well-dispersed (Gini = 0.19 and 0.20, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain moderate on most occasions, but with the occasional deviation towards the very high end of the spectrum (i.e. shorter time periods since flow).

For the Median Future, +40 cm SLR scenario, six out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. The two most common states along the length of the Coorong over the Median Future, +40 cm scenario were the Estuarine/Marine state (64%) and the Healthy Hypersaline state (24%; Figure 2.34). Together, these two states accounted for 88% of the site-years modelled. The Unhealthy Hypersaline (5%), Marine (2%), Unhealthy Marine (2%) and Degraded Marine (2%) states were all uncommon and the Average Hypersaline and the most-degraded state Degraded Hypersaline states were not observed in any of the site-years.

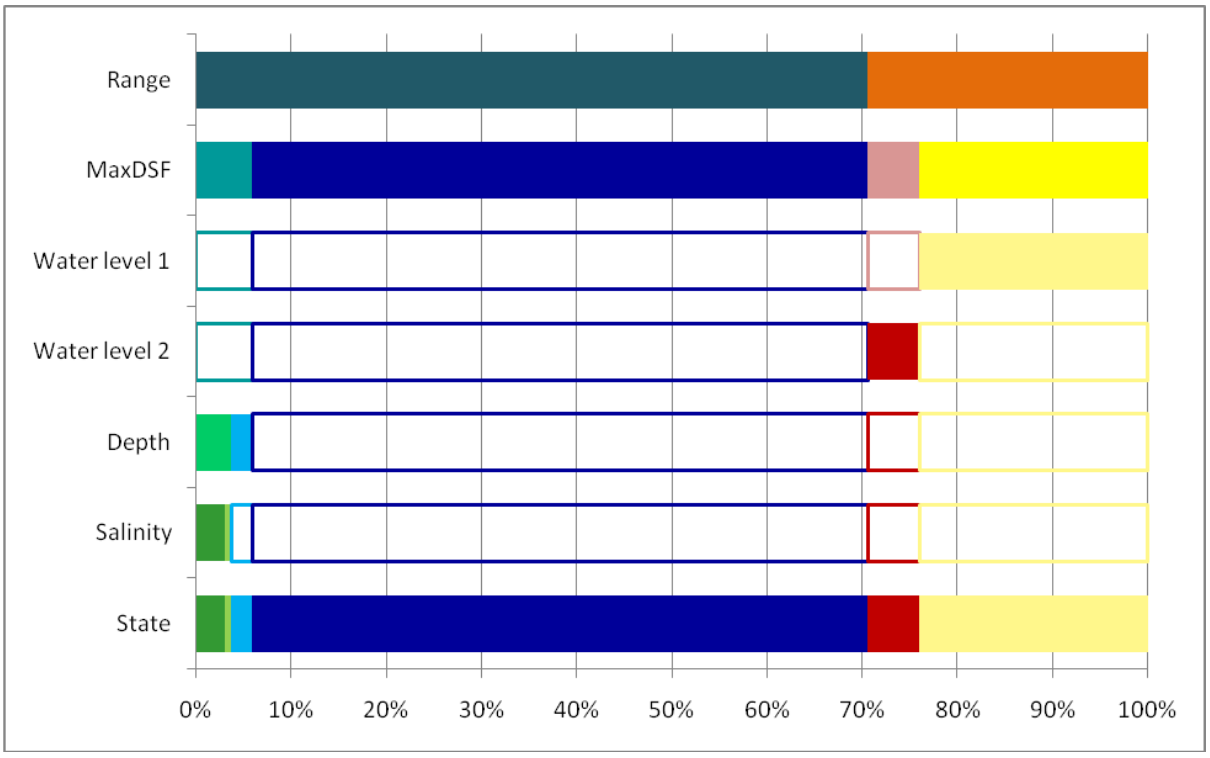

Figure 2.34. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Median Future, +40 cm SLR scenario

See Figure 2.2 for further explanation of the figure.

For 16% of the site-years, transitions occurred between states (Figure 2.35). The state inertia in the system for the Median Future, +40 cm SLR was 84%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 3.39 and 7.90 for 12 sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 7% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 5% of the time and to a less-degraded state 4% of the time.

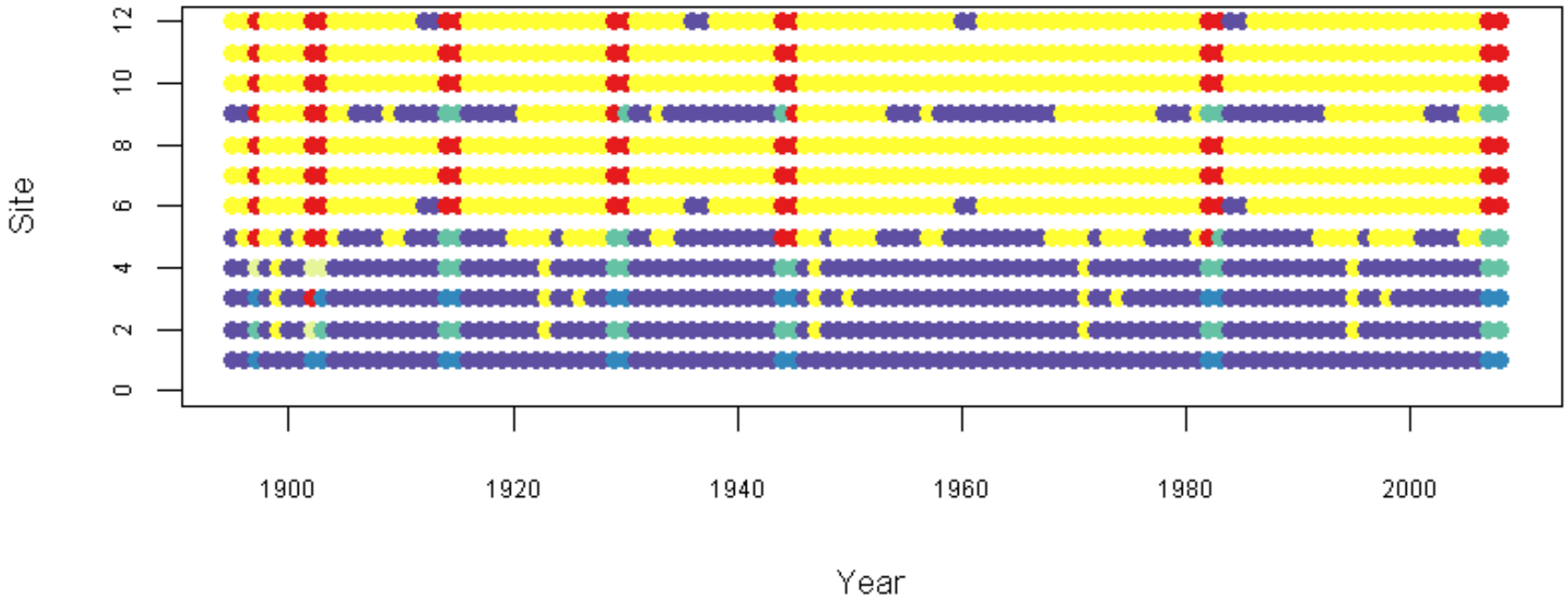

Figure 2.35. Distribution of states for each site-year under the Median Future +40 cm SLR scenario

See Figure 2.3 for further explanation of the figure.

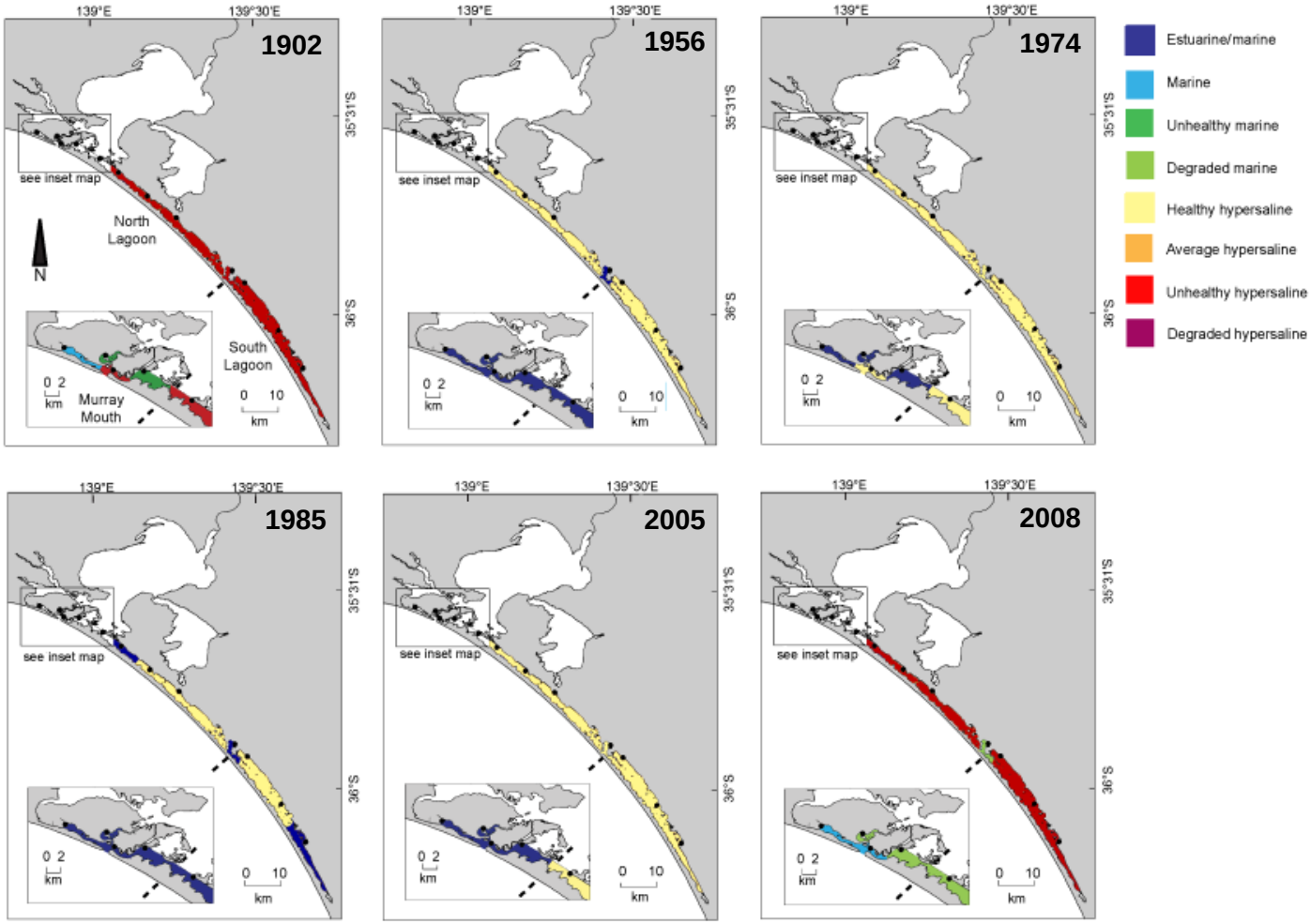

Figure 2.36. Mapping the distribution of states for seminal years under the Median Future +40 cm SLR scenario

See Figure 2.4 for further explanation of the figure.

2.10. Dry Future, -10 cm SLR

The Dry Future, -10 cm SLR scenario modelled a dry future climate with a 10 cm decrease in sea level.

The distributions of each of the variables driving the ecosystem states of the Coorong under the Dry Future, -10 cm SLR scenario is shown in Figure 2.37. The median water level was 0.12 m AHD, falling between 0.05 m AHD and 0.18 m AHD for 50% of the time. Median water depth under the Dry Future, -10 cm SLR conditions was 1.22 m, but there were a number of outliers at greater depths (maximum 3.00 m). The median salinity was greater than seawater along the length of the Coorong over the 114-year model run, at 59.49 g L^{-1}, although there were a number of outliers at extremely high salinities. Median maximum number of days since flow over the barrages (MaxDSF) for the Dry Future, -10 cm SLR scenario was 321 days, falling between 211 days and 811 days for 50% of the time. The median tidal range 0.10 m, although there were a number of outliers at greater tidal ranges (maximum 0.77 m).

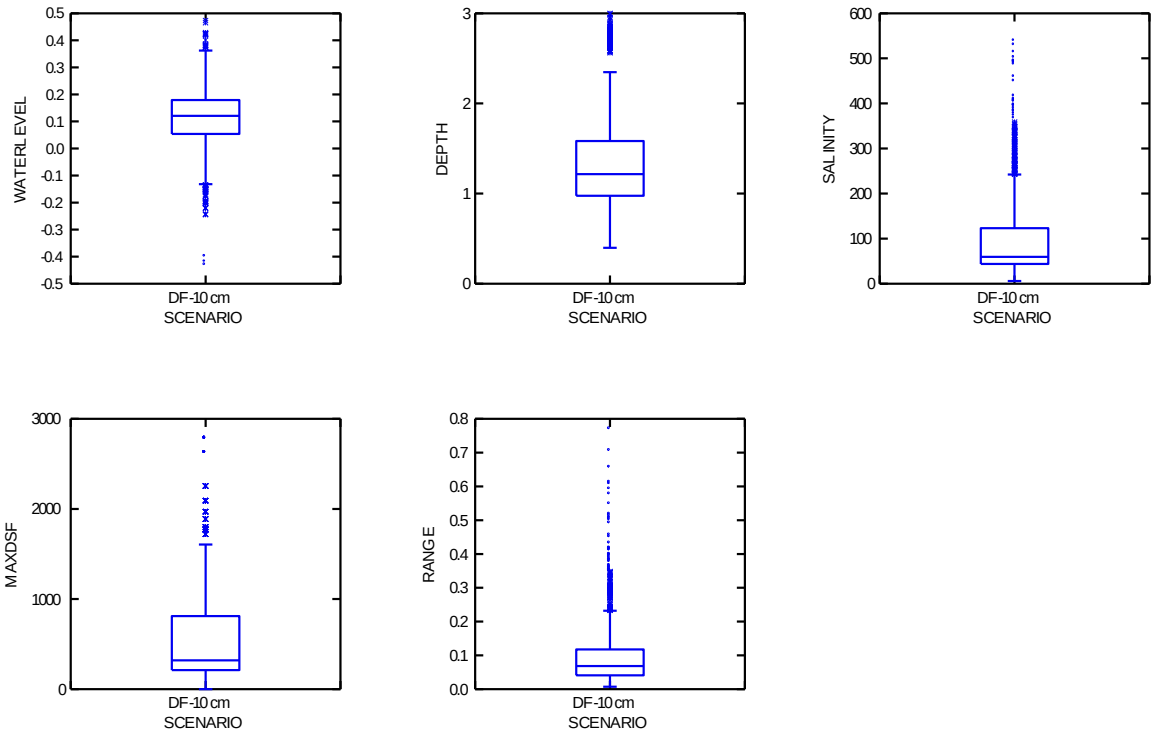

Figure 2.37. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Dry Future, -10 cm SLR scenario

The Barkers Knoll site was the only Murray Mouth site to fall below the tidal range threshold. It had an average exceedance of 37.3 years and a return time of 2.0 years. In the North Lagoon, the threshold was exceeded for 10.5 years on average at a return interval of 3.7 years. A return time of 24.0 years was observed in the South Lagoon, with sites exceeded the threshold for 1.1 years on average. Under the Dry Future -10 cm SLR scenario, the threshold for the maximum number of days with barrage flow was exceeded every 7.7 years for an average of 4.8 years at a time.

Barkers Knoll was the only Murray Mouth site to exceed the first water level threshold (0.37 m AHD) for an average of one year with a return time of 18 years. The North Lagoon sites exceeded the threshold for one year at a time with a return interval of 28.5 years. The South Lagoon sites never exceeded the threshold. For the lower water level threshold (-0.09 m AHD), the Murray Mouth and North Lagoon sites always exceeded the threshold. In the South Lagoon, sites exceeded the threshold for 4.5 years with a return interval of 3.1 years. The

depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was never exceeded at any other site.

The Murray Mouth region exceeded the salinity threshold for 1.5 years on average with a return time of 33.3 years. The North Lagoon experienced salinities over the threshold for 7.1-year intervals every 10.6 years. The South Lagoon exceeded the threshold in all site-years. Under Dry Future, -10 cm SLR conditions, salinity was greater than 100 g L^{-1} in 29% of site-years.

For the Dry Future, -10 cm SLR scenario, the two most evenly distributed variables were depth and water level (Gini = 0.04 and 0.09, respectively). This suggests that they were relatively likely to occupy any value within their range, rather than being skewed to either end of the distribution. Salinity and tidal range were both moderately-well dispersed (Gini = 0.18 and 0.21, respectively), but the maximum number of days since flow over the barrages was unevenly dispersed (Gini = 0.51).

For the Dry Future, -10 cm SLR scenario, seven out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the Dry Future, -10 cm SLR scenario model run, the two most common states were the Estuarine/Marine state (37%) and the Unhealthy Hypersaline state (17%; Figure 2.38). Together these two states only accounted for 54% of the site-years modelled. The Average Hypersaline state was the next most common (16%), following the smaller proportions for the Marine (8%), Unhealthy Marine (8%) and the Degraded Marine states (8%). The most degraded state, the Degraded Hypersaline state, was uncommon (6%), but the Healthy Hypersaline state was not observed in the114-year model run under the dry future sea level fall conditions.

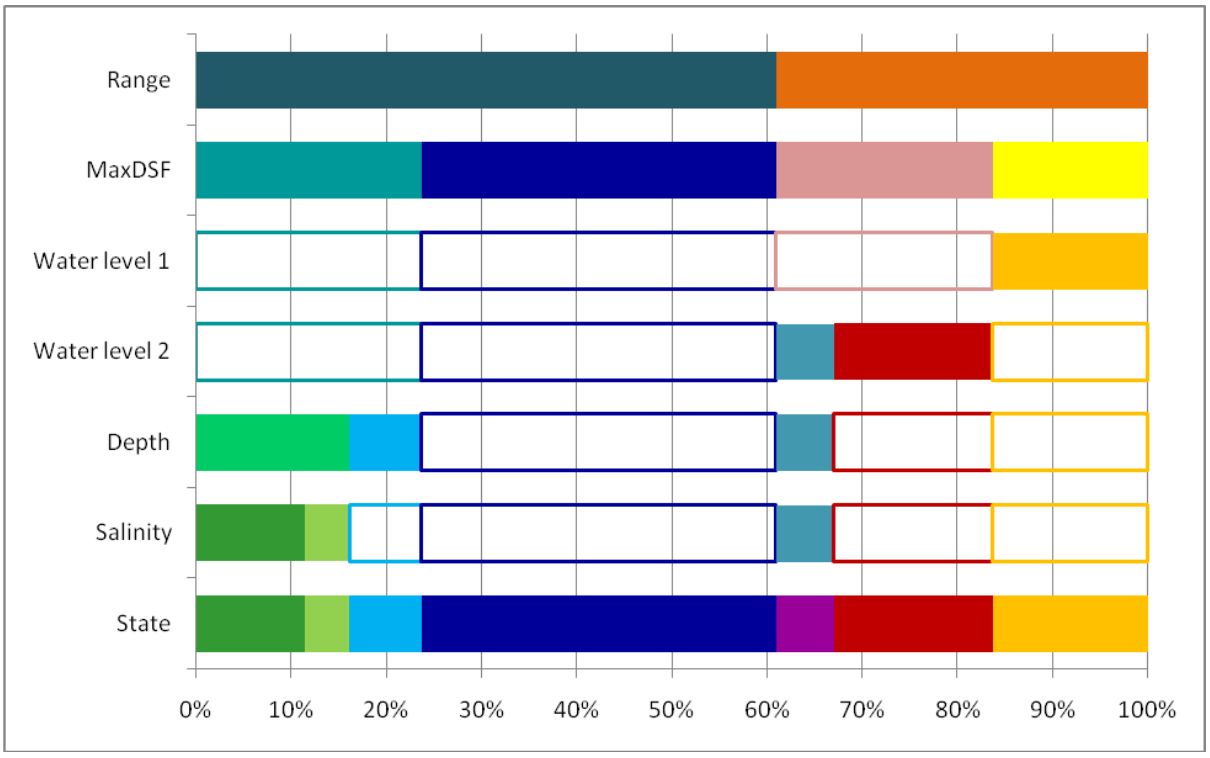

Figure 2.38. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Dry Future, -10 cm SLR scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 29% of the site-years (Figure 2.39). The proportion of site-years where the state did not change (i.e. the state inertia) in the system for the Dry Future, -10 cm SLR scenario was 71%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 6.10 and 10.17 for 12 sites). When transitons occurred, sites changed from a marine state to a hypersaline state or vice versa (i.e. chnaged basin), in 10% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 10% of the time and to a less-degraded state 9% of the time.

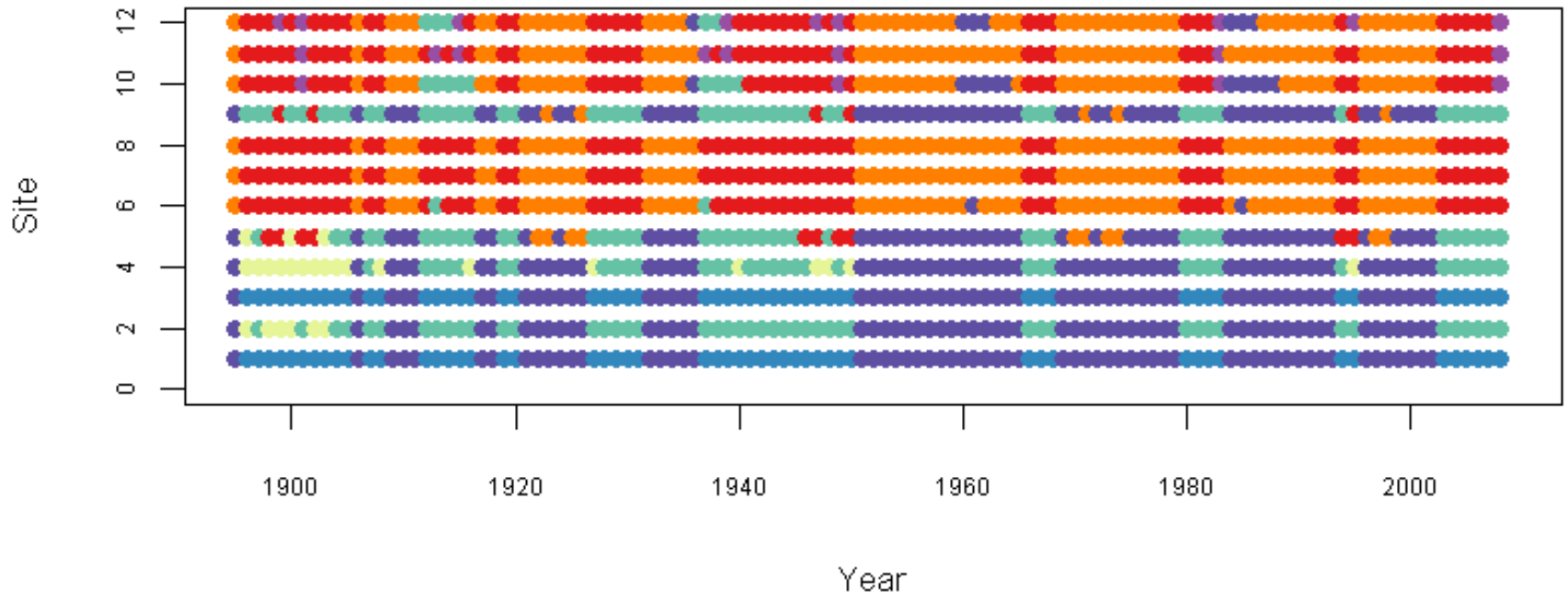

Figure 2.39. Distribution of states for each site-year under the Dry Future, -10 cm SLR scenario

See Figure 2.3 for further explanation of the figure.

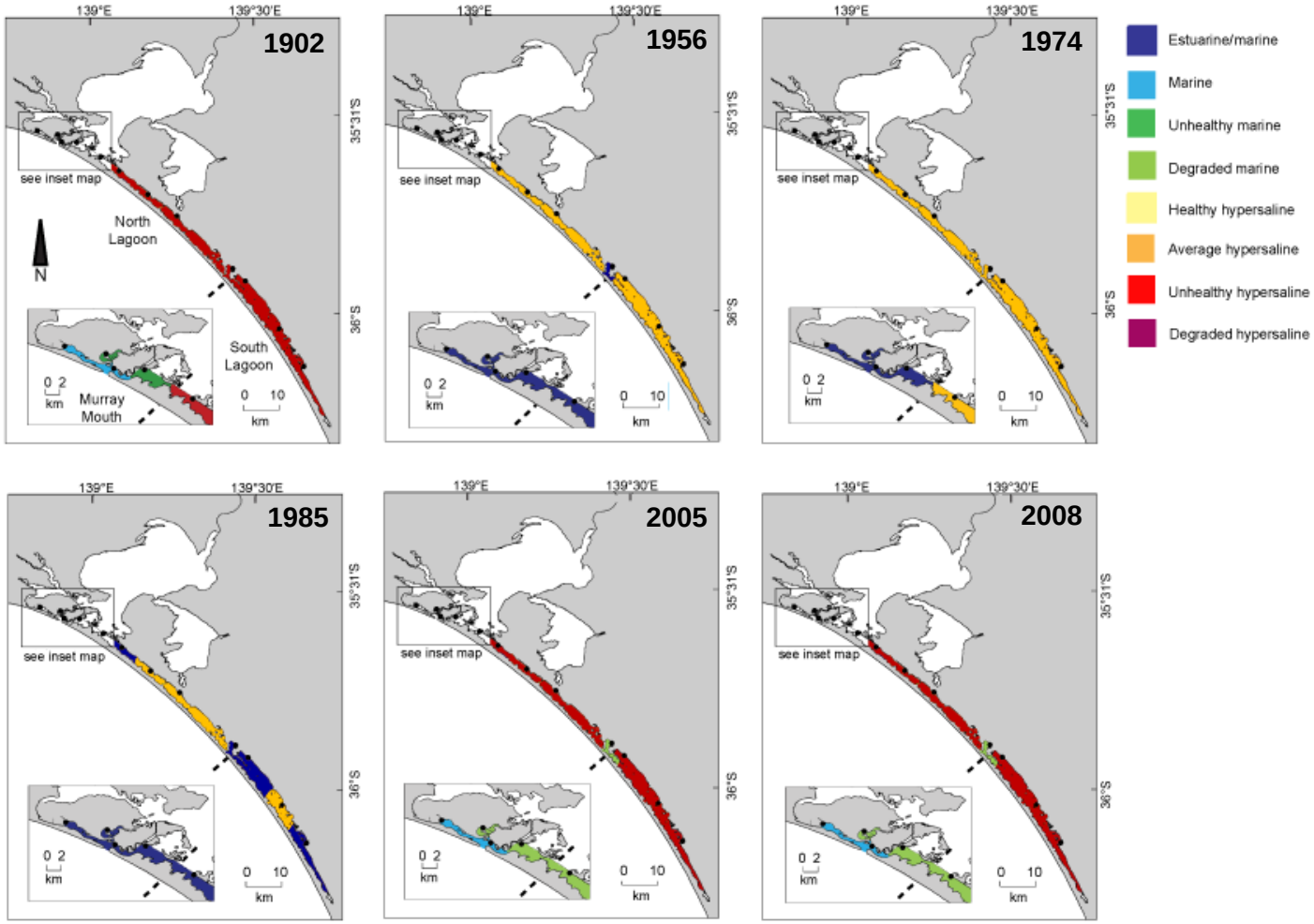

Figure 2.40. Mapping the distribution of states for seminal years under the Median Future, -10 cm SLR scenario

See Figure 2.4 for further explanation of the figure.

2.11. Dry Future, +20 cm SLR

The Dry Future, +20 cm SLR scenario modelled the same scenario as the Dry Future scenario, but incorporating a 20-cm sea level rise.

Figure 2.41 shows the distributions of each of the environmental variables driving the ecosystem states of the Coorong under the Dry Future, +20 cm SLR conditions. Median water level was 0.44 m AHD, falling between 0.39 m AHD and 0.49 m AHD for 50% of the time. The median water depth under Dry Future, +20 cm SLR conditions along the length of the Coorong was 1.56 m, although there were a number of outliers at greater depths (maximum 3.40 m). Median salinity was greater than seawater at 58.21 g L^{-1}, but there were a number of outliers at extremely high salinities. The median for the maximum number of days since flow over the barrages (MaxDSF) for the Dry Future, +20 cm SLR scenario was 321 days, falling between 211 days and 811 days for 50% of the time. Median tidal range was small at 0.07 m, although there were a number of outliers at greater tidal ranges (maximum 0.71 m).

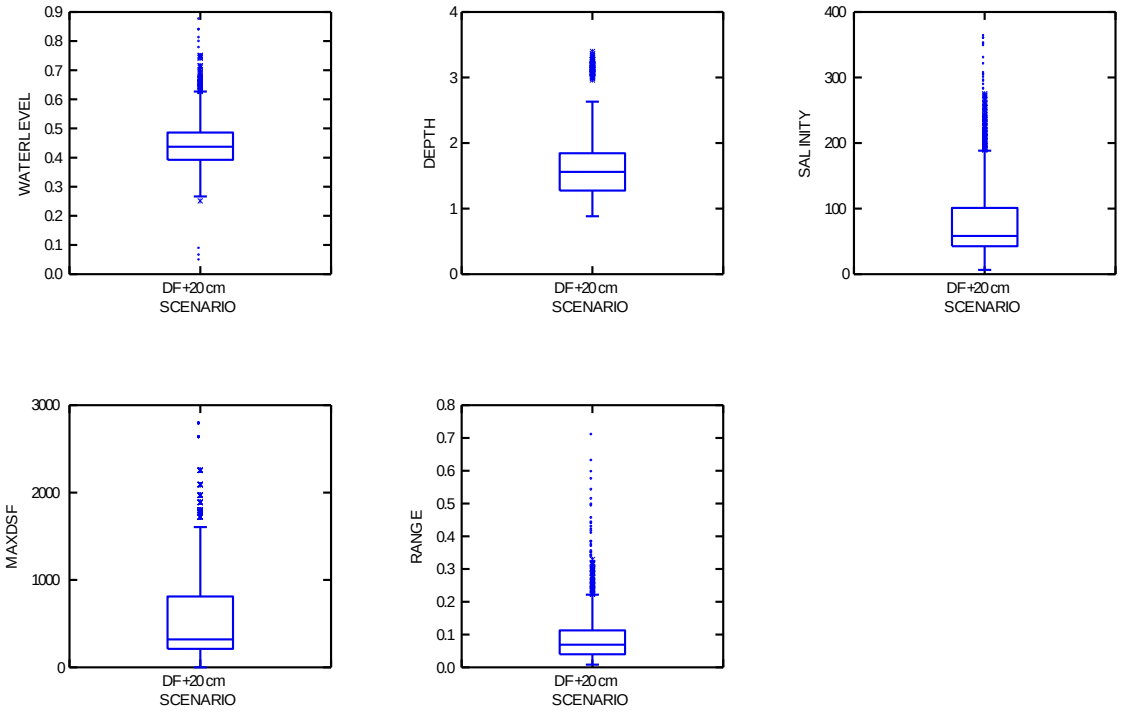

Figure 2.41. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Dry Future, +20 cm SLR scenario

Monument Road was the only site to always exceed the tidal range threshold. Other Murray Mouth sites had a return time of 2.0 years and exceeded the threshold for an average of 37.3 years. North Lagoon sites were over the threshold for an average of 12.7 years at a return interval of 3.1 years. In the South Lagoon, the threshold was exceeded for 2.8 years at a time, recurring every 22.2 years.

Under the Dry Future +20 cm SLR scenario, the threshold for the maximum number of days with barrage flow was exceeded every 7.7 years for an average of 4.8 years at a time.

The higher water level threshold (0.37 m AHD) was exceeded for an average of 30.7 years with a return time of 2.4 years in the Murray Mouth region. The North Lagoon sites exceeded the threshold for 17.9 years ever 1.8 years, on average and the South Lagoon sites exceeded the threshold for 3.0 years every 2.6 years. The lower water level threshold was always exceeded.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also regularly exceeded at Mark Point for an average duration of 2.5 years with a return time of 3.3 years.

For the salinity threshold, the Murray Mouth region exceeded the threshold every 32.0 years for 1.6 years at a time. The North Lagoon had an average exceedance of 5.6 years, and a return time of 12.8 years. The South Lagoon always exceeded the threshold. Under Dry Future, +20 cm SLR conditions, salinity was greater than 100 g L^{-1} in 25% of site-years.

The Gini coefficient was calculated for each variable driving the ecosystem state. For the Dry Future, +20 cm SLR scenario, depth and water level were the most evenly distributed variables (Gini = 0.02 and 0.04, respectively). Salinity and tidal range were both moderately-well dispersed (Gini = 0.18 and 0.21, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain high with the occasional large deviation towards the lower end of the spectrum (Gini = 0.51).

For the Dry Future, +20 cm SLR scenario, seven out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. The two most common states along the length of the Coorong over the Dry Future, +20 cm SLR model run, were the Estuarine/Marine state (38%) and the Unhealthy Hypersaline state (22%; Figure 2.42). The Healthy Hypersaline was the third most common state (14%), while the Marine (8%), Unhealthy Marine (8%), Degraded Marine (8%) and Average Hypersaline (2%) states were all uncommon. The most degraded state, the Degraded Hypersaline state, was not observed over the model run under the Dry Future, +20 cm SLR conditions.

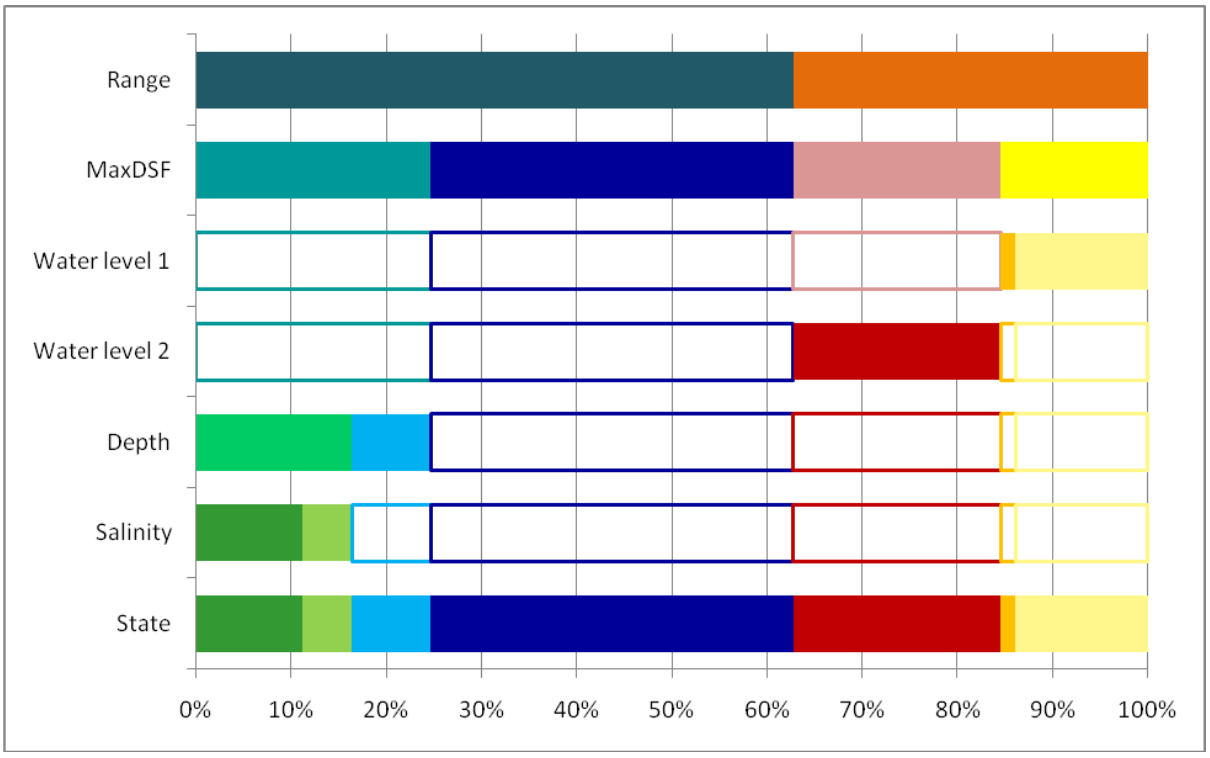

Figure 2.42. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Dry Future, +20 cm SLR scenario

See Figure 2.2 for further explanation of the figure.

For 29% of the site-years, transitions occurred between states (Figure 2.43). This means that the state inertia (i.e. the proportion of site-years where the state did not change) in the system for the Dry Future, +20 cm SLR scenario was 71%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 6.32 and 8.55 for 12 sites). When transitions did occur, sites went from a marine state to a hypersaline state or vice versa (i.e. changed basin), 11% of the site-years. When sites changed within the same basin, they shifted to a more degraded state 10% of the time and to less-degraded state 9% of the time.

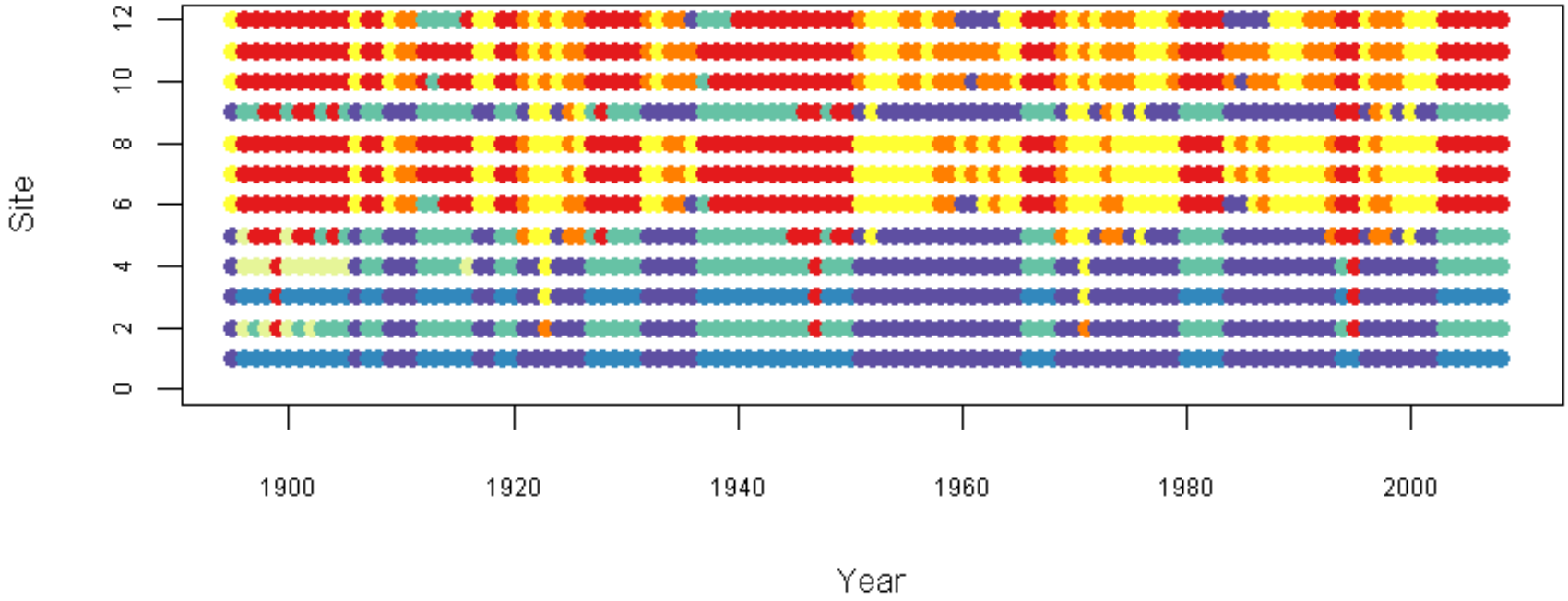

Figure 2.43. Distribution of states for each site-year under the Dry Future, +20 cm SLR scenario

See Figure 2.3 for further explanation of the figure.

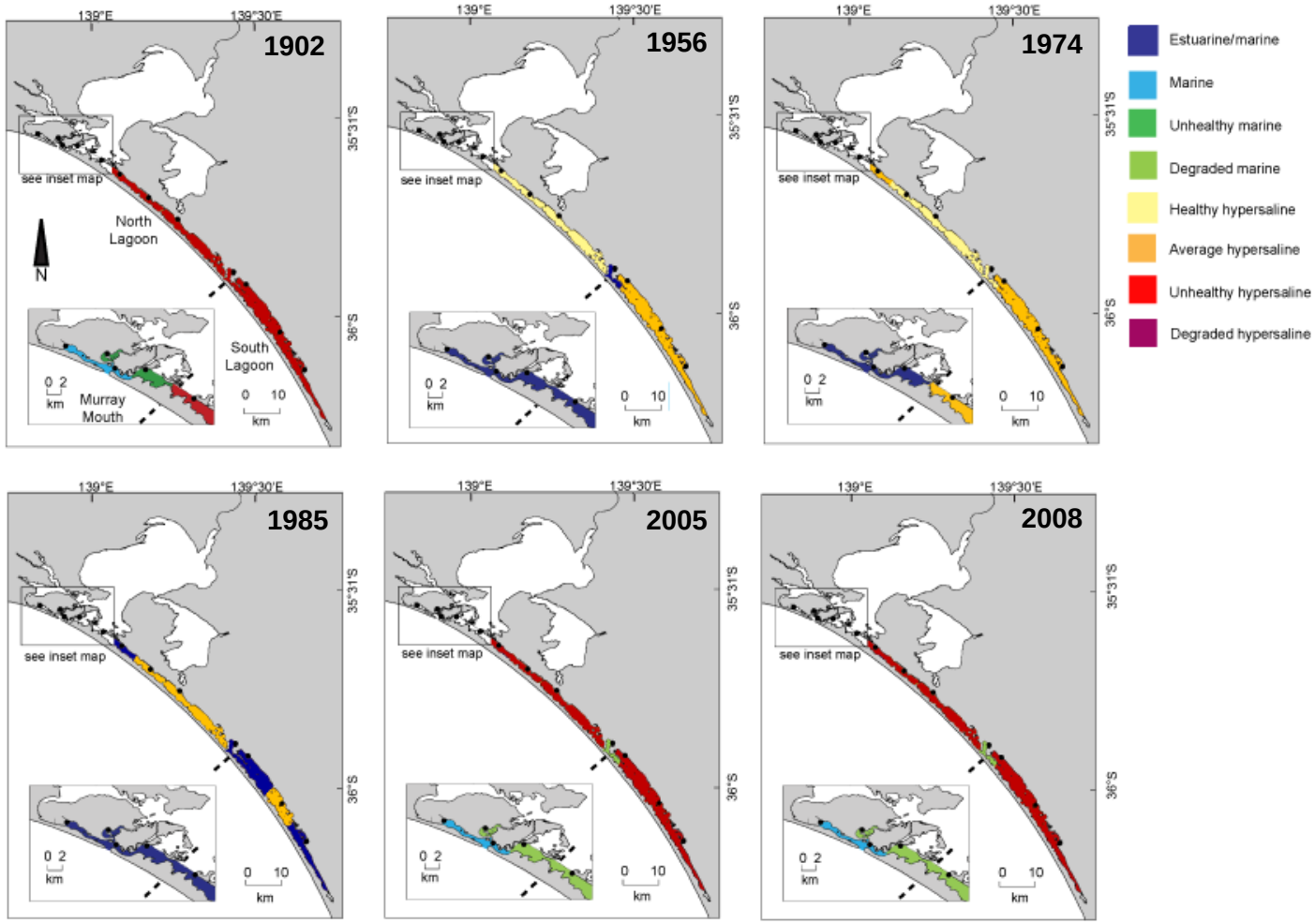

Figure 2.44. Mapping the distribution of states for seminal years under the Median Future, +20 cm SLR scenario

See Figure 2.4 for further explanation of the figure.

2.12. Dry Future, +40 cm SLR

The Dry Future, +40 cm SLR scenario investigated a dry future climate with a 40 cm increase in sea level rise.

The distributions of each of the environmental variables driving the ecosystem states of the Coorong under the Dry Future, +40 cm SLR conditions are shown in Figure 2.45. The median water level was 0.64 m AHD, falling between 0.60 m AHD and 0.69 m AHD for 50% of the time. Median water depth under the Dry Future, +40 cm SLR conditions along the length of the Coorong was 1.77 m, although there were a number of outliers at greater depths (maximum 3.67 m). The median salinity was greater than that of seawater at 79.32 g L^{-1}, falling between 51.06 g L^{-1} and 98.47 g L^{-1} for 50% of the time. Median maximum number of days since flow over the barrages (MaxDSF) for the Dry Future, +40 cm SLR scenario was 321 days, but there were some outliers at greater maximum number of days (maximum 2778 days). The median tidal range was small at 0.07 m, falling between 0.04 m and 0.11 m for 50% of the time.

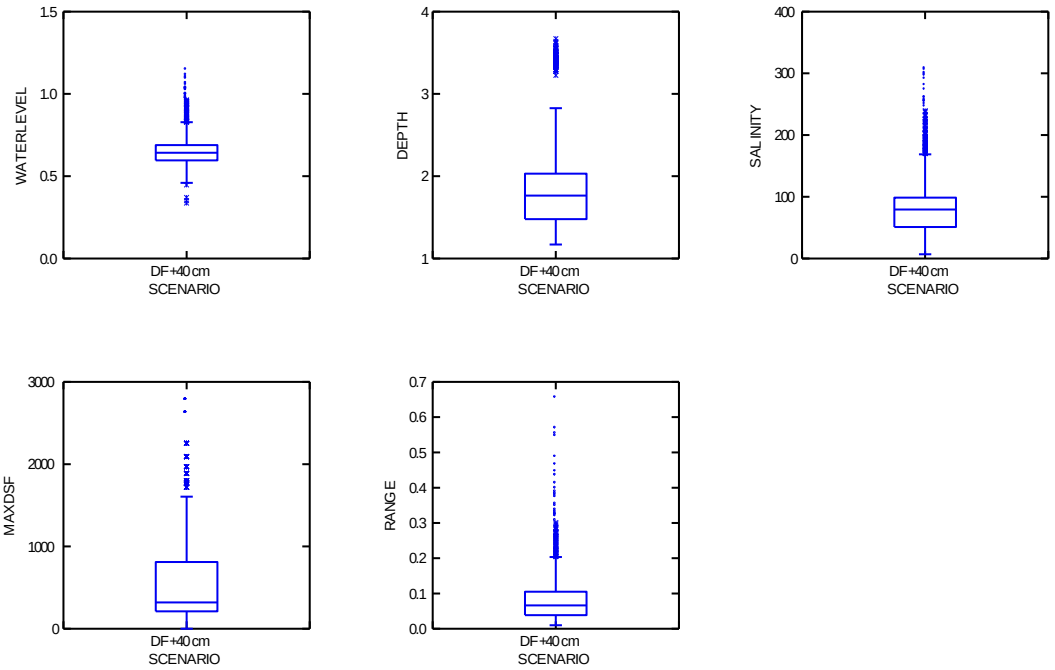

Figure 2.45. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Dry Future, +40 cm SLR scenario

Monument Road did not fall below the tidal range threshold. Other Murray Mouth sites exceeded the threshold for 21.1 years at a return interval of 2.0 years. In the North Lagoon, sites exceeded the threshold for 10.7 years at a return interval of 3.4 years. South Lagoon sites exceeded the threshold for 1.4 years at a return interval of 23.5 years.

Under the Dry Future + 40 cm SLR scenario, the threshold for the maximum number of days with barrage flow was exceeded every 7.7 years for an average of 4.8 years at a time.

The water level threshold of 0.37 m AHD was exceeded at all sites for all years with the exception of the South Lagoon sites for the final year of simulation. The lower water level threshold was always exceeded.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded for two single years at Mark Point and Salt Creek with a return time of 39 years.

Mundoo Channel was the only Murray Mouth site to fall below the salinity threshold. It exceeded the threshold for an average of 27.3 years with a return interval of 2.7 years. Ewe Island and Pelican Point were the only other two sites to fall below the threshold, with average durations of 25 and 36 years at return intervals of 2 and 3 years, respectively. Salinity under Dry Future, +40 cm SLR conditions was greater than 100 g L^{-1} in 60% of site-years.

For the Dry Future, +40 cm SLR scenario, depth, water level and salinity were the most evenly distributed variables (Gini = 0.02, 0.03 and 0.07, respectively). This suggests that they were relatively likely to occupy any value within their range, rather than being skewed to either end of the distribution. Tidal range was moderately-well dispersed (Gini = 0.21), but the maximum number of days since flow over the barrages was unevenly dispersed, tending to remain towards the high end of the spectrum, but with the occasional deviation to a lower number.

For the Dry Future, +40 cm SLR scenario, six out of the eight states were not observed during the 114-year by 12 site (1368 site-years) model run. Over the Dry Future , +40 cm SLR scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (37%) and the Unhealthy Hypersaline state (23%; Figure 2.46). Together, these accounted for 60% of the site-years modelled. The remaining 40% consisted of smaller proportions of the Healthy Hypersaline (16%), Marine (9%), Unhealthy Marine (8%) and Degraded Marine (7%) states. The most degraded state, the Degraded Hypersaline state, and the Average Hypersaline state, were both not observed under the Dry Future, +40 cm conditions.

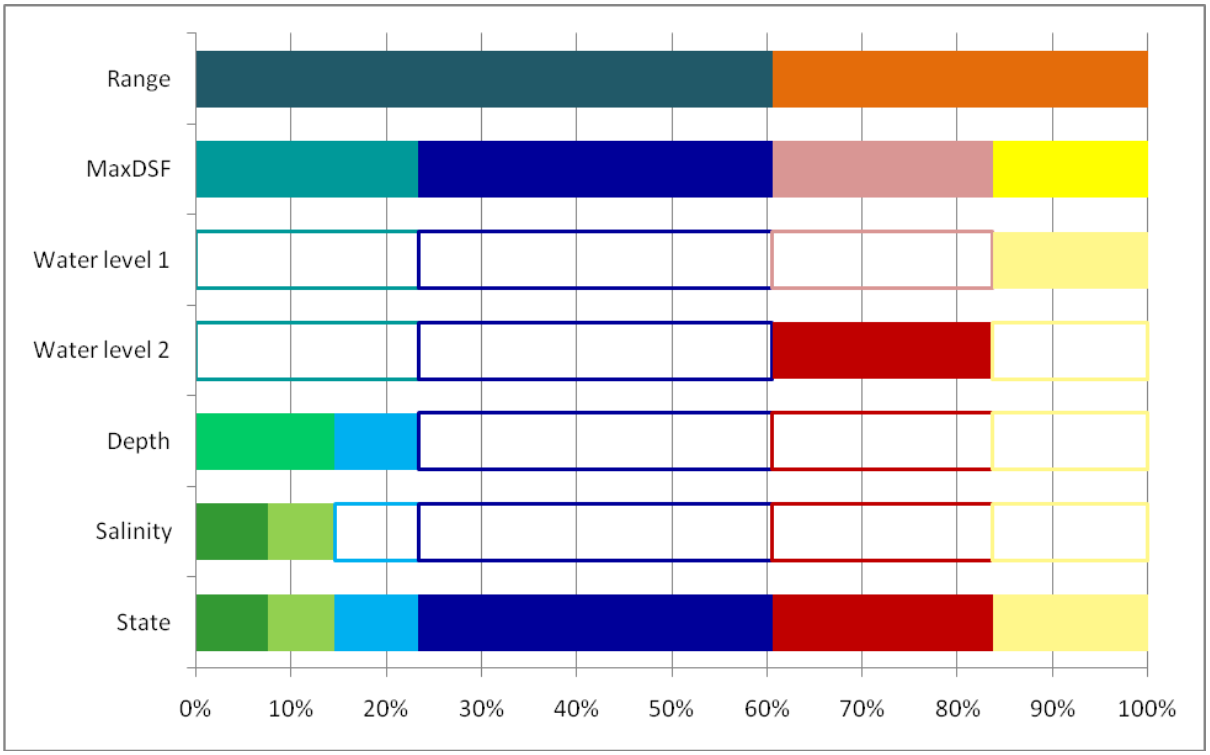

Figure 2.46. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Dry Future, +40 cm SLR scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 26% of site-years (Figure 2.47). The state inertia in the system then (i.e. the proportion of site-years where the state did not change) was 74% for the Dry Future, +40 cm SLR scenario. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 6.09 and 10.96 for 12 sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) during 11% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 8% of the time and to a less-degraded state 7% of the time.

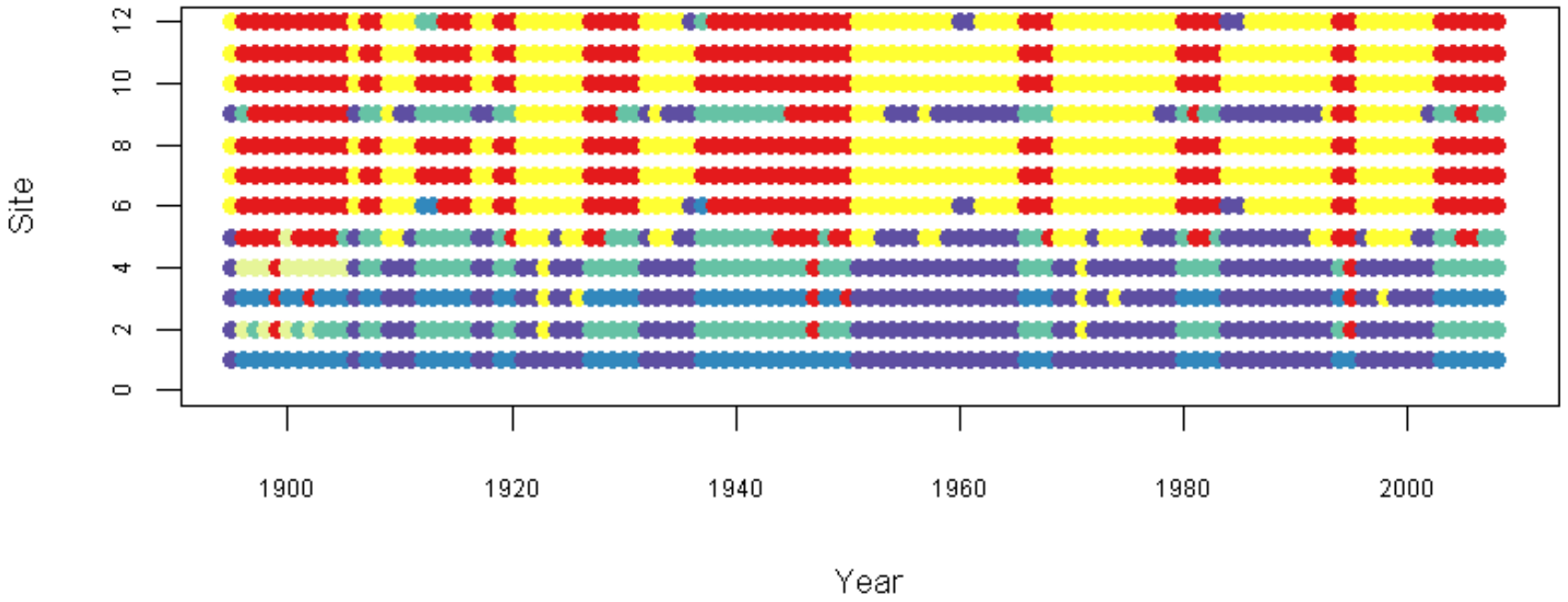

Figure 2.47. Distribution of states for each site-year under the Dry Future, +40 cm SLR scenario

See Figure 2.3 for further explanation of the figure.

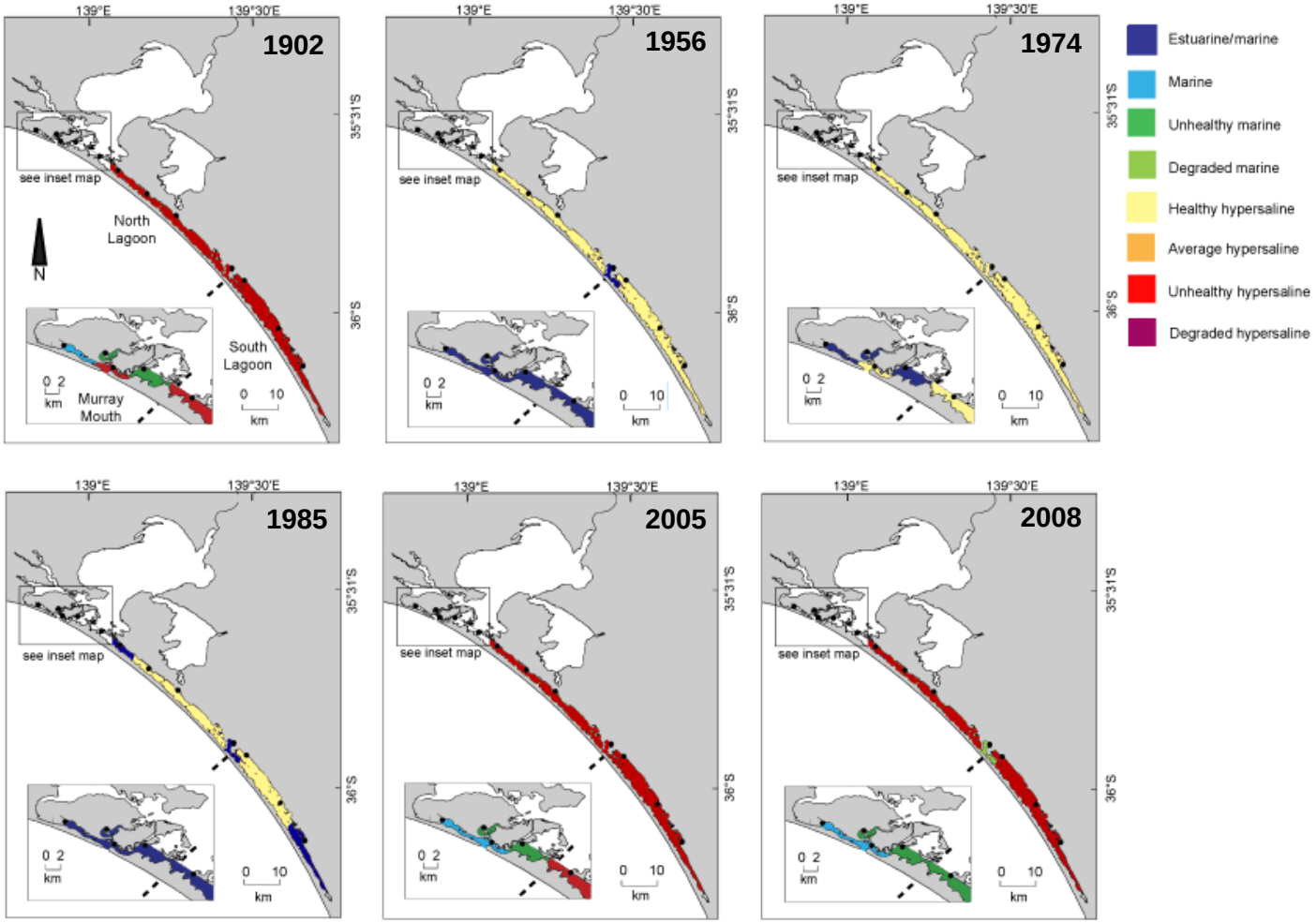

Figure 2.48. Mapping the distribution of states for seminal years under the Median Future, +40 cm SLR scenario

See Figure 2.4 for further explanation of the figure.

2.13. Historic TLM off

The Historic TLM off scenario investigated the effect of The Living Murray infrastructure in the Murray-Darling Basin under a historic climate, with no additional environmental water allocation.

Figure 2.49 shows the distribution of each of the variables driving the ecosystem states of the Coorong under the Historic TLM off conditions. Median water level was 0.30 m AHD, falling between 0.23 m AHD and 0.37 m AHD for 50% of the time. The median water depth under the Historic TLM off conditions along the length of the Coorong was 1.41 m, but there were a number of outliers at greater depths (maximum 3.15 m). Median salinity was only slightly higher than that of seawater at 36.61 g L^{-1}, falling between 25.72 g L^{-1} and 54.56 g L^{-1} for 50% of the time. The median maximum number of days since flow over the barrages for the Historic TLM off scenario was 168, although there a number of outliers at longer time periods (i.e. greater maximum number of days) since flow (maximum 677 days). Median tidal range was small 0.01 m, falling between 0.05 m and 0.2 m for 50% of the time.

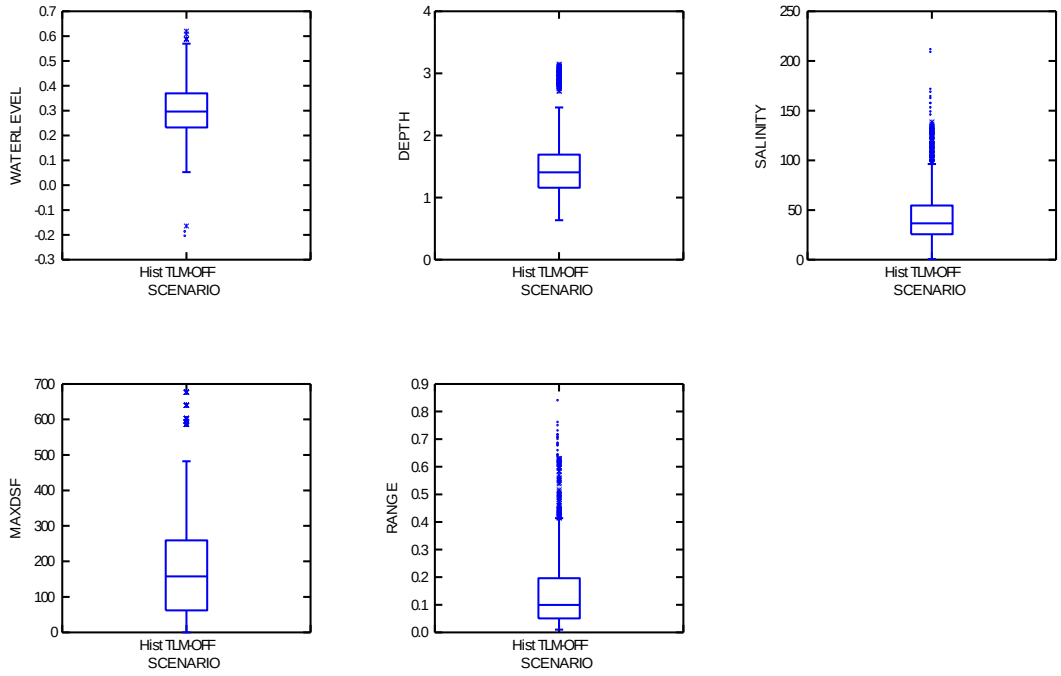

Figure 2.49. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Historic TLM off scenario

Mark Point was the northern-most site where the threshold for tidal range was not always exceeded. It, and the other North Lagoon sites further south, had an average exceedance duration of 12.3 years, and a return time of 2.5 years. The South Lagoon sites exceeded the threshold for an average of 4.8 years at a return time of 20.3 years.

For the threshold relating to the maximum number of days without flow over the barrages, the average exceedance duration was 1.8 years, with a return time of 21.2 years.

The length of time that the 0.37 m AHD water level threshold was exceeded was similar for all regions (between 1.6 and 1.8 years). The return time for the Murray Mouth region was 7.4 years, and the North and South Lagoons had return times of 4.9 and 9.5 years, respectively. The lower water level threshold was exceeded at all site for all years with the exception of the South Lagoon sites in 2008.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point every 12.5 years for 1.6 years, on average.

The Murray Mouth sites never exceeded the salinity threshold. In the North Lagoon, Mark Point and Long Point both exceeded the threshold for the last simulation year, while Noonameena and Parnka Point exceeded the threshold for a year and 1.8 years at a time with return times of 62 and 19.4 years, respectively. In the South Lagoon, sites exceeded the threshold for 8.6 years with a return time of 9.1 years on average. Salinity under Historic TLM off conditions was greater than 100 g L^{-1} in 6% of site-years.

The Gini coefficient was calculated for each variable driving the ecosystem states. For the Historic TLM off scenario, depth and water level were the most evenly distributed variables (Gini = 0.04 and 0.07, respectively). Tidal range and salinity were both moderately-well dispersed (Gini = 0.17 and 0.21, respectively), but the maximum number of days since flow over the barrages was unevenly dispersed, tending to remain towards the lower end of the spectrum, although there were the occasional deviations towards longer time periods (i.e. lower number of days).

For the Historic TLM off scenario, eight out of the eight scenarios were observed during the 114-year by 12 site (1368 site-years) model run. The two most common states along the length of the Coorong, over the Historic TLM off model run were the Estuarine/Marine state (68%) and the Average Hypersaline state (19%; Figure 2.50). The Unhealthy Marine, Healthy Hypersaline and Unhealthy Hypersaline states were all uncommon and contributed the same proportion to the states present (4%). Smaller proportions of the Marine (2%) and the Degraded Marine (1%) states were also observed over the 114-year model run. The most degraded state, the Degraded Hypersaline state appeared in less than 1% of the site-years under the Historic TLM off conditions.

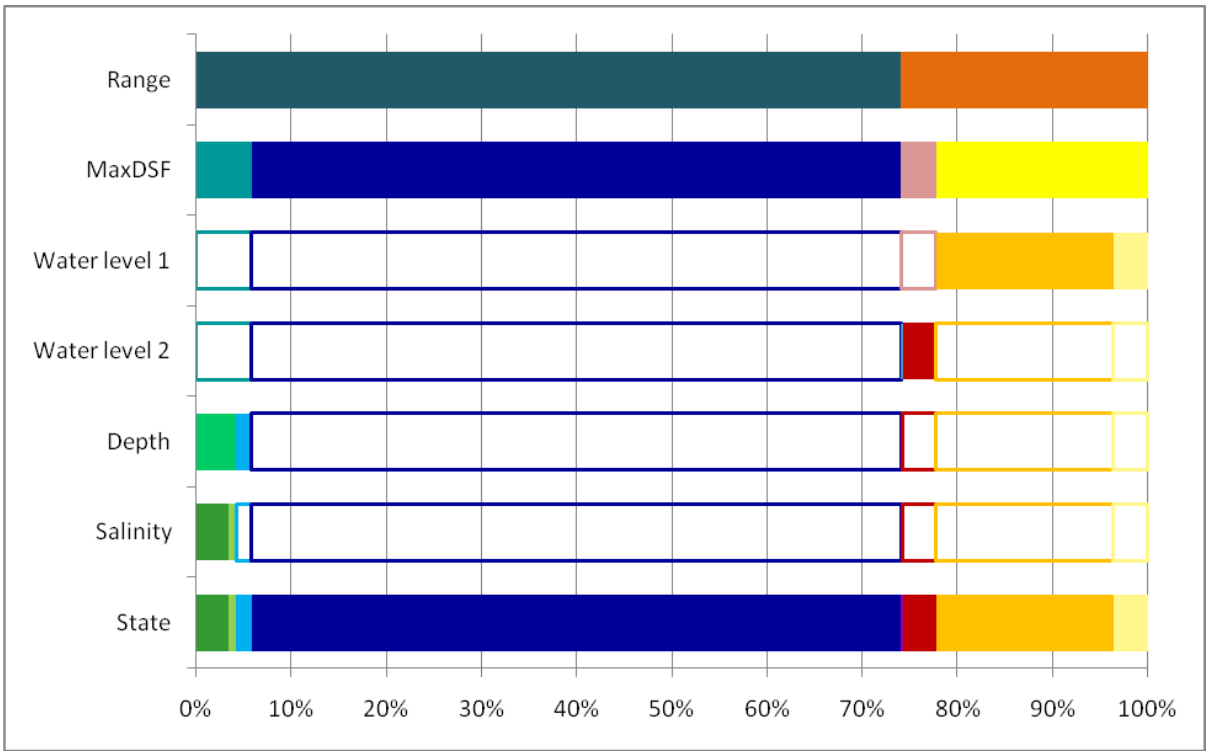

Figure 2.50. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Historic TLM off SLR scenario

See Figure 2.2 for further explanation of the figure.

For 17% of site-years transitions occurred between states (Figure 2.51). This means that the state inertia (i.e. the proportion of site-years where the state did not change) in the system for the Historic TLM off scenario was 83%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 4.31 and 8.00 for 12 sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) at 4% of the times. When sites changed within basins, they shifted from a more degraded state 9% of the time and to a less-degraded state 5% of the time.

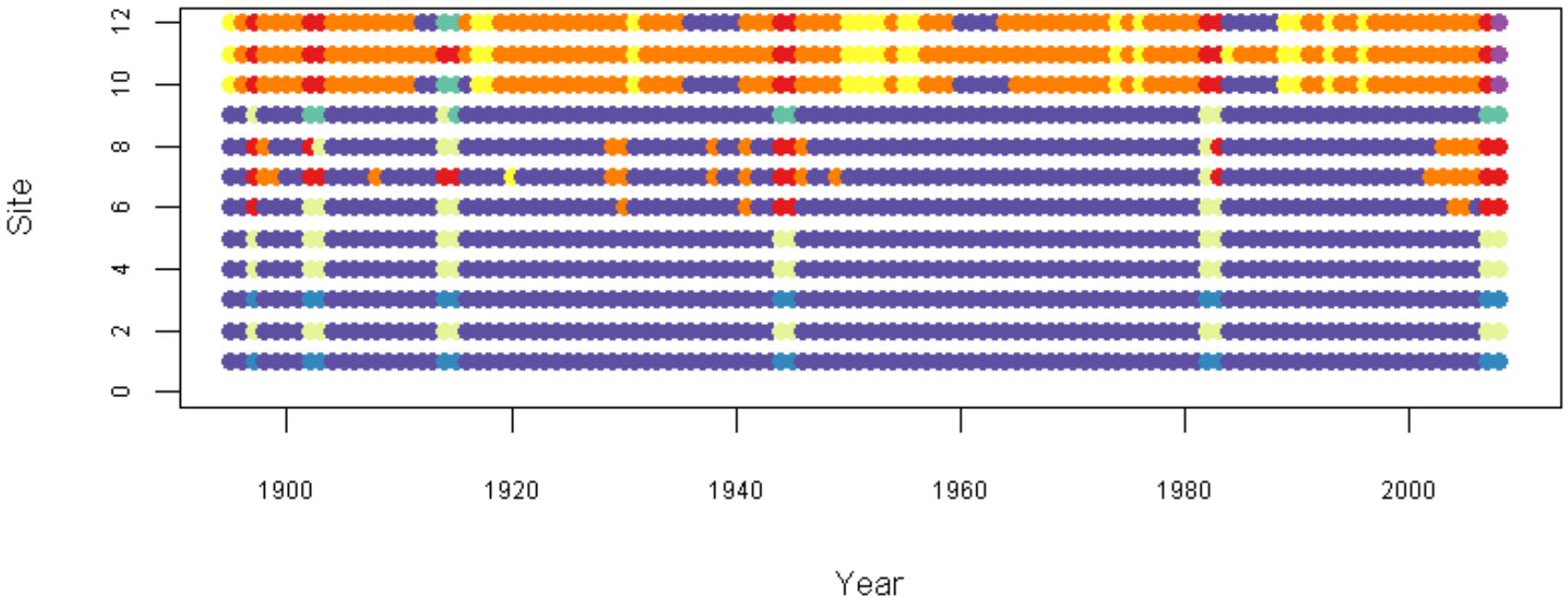

Figure 2.51. Distribution of states for each site-year under the Historic TLM off scenario

See Figure 2.3 for further explanation of the figure.

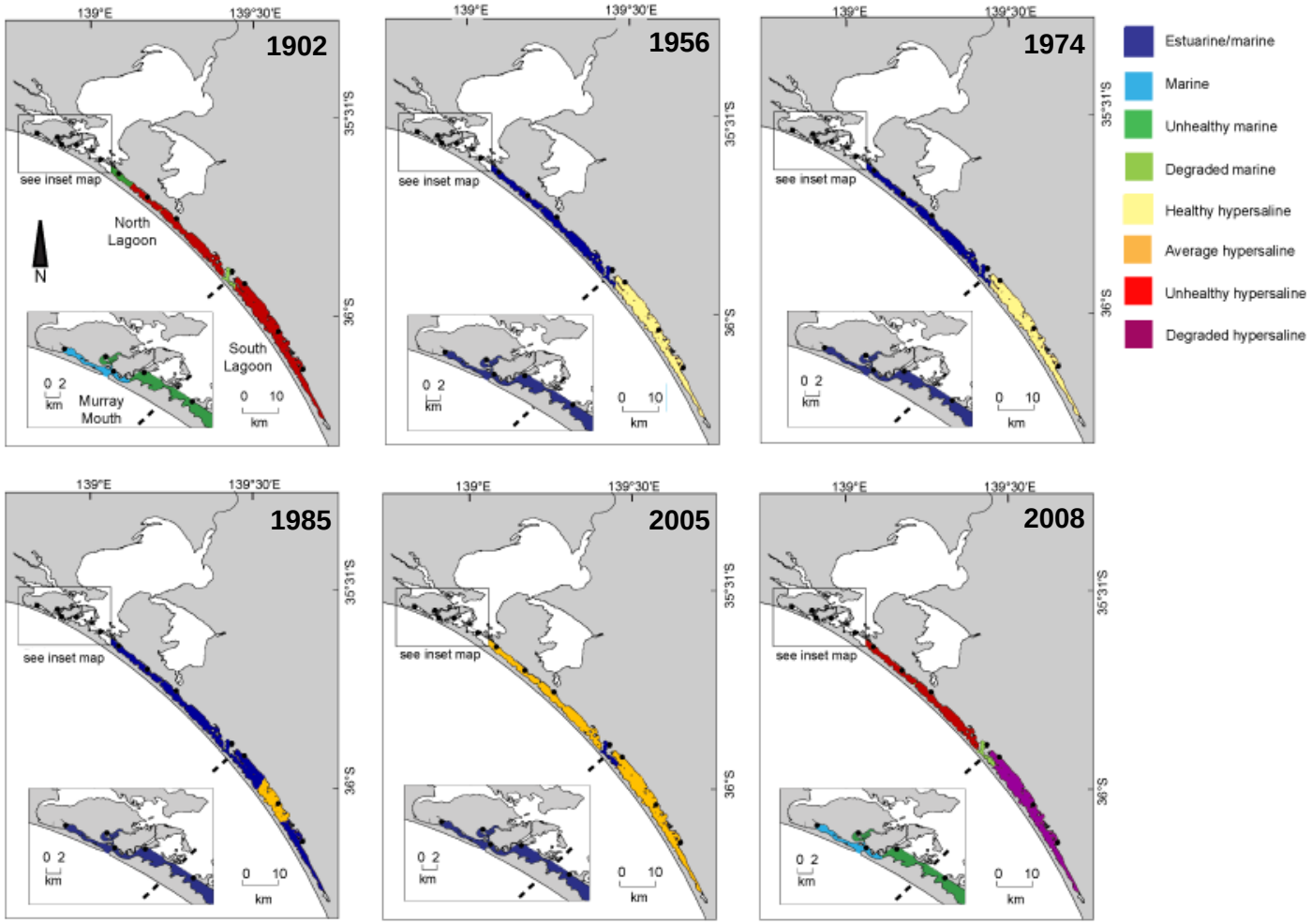

Figure 2.52. Mapping the distribution of states for seminal years under the Historic TLM off scenario

See Figure 2.4 for further explanation of the figure.

2.14. Historic TLM on

The Historic TLM on scenario was as per the Historic TLM off scenario, with the addition of 500 GL as an environmental water allocation under TLM.

The distributions of each of the variables driving the ecosystem states of the Coorong under the Historic TLM on scenario are shown in Figure 2.53. The median water level was 0.30 m AHD, but there were some outliers at extremely low depths (minimum -0.20 m AHD). Median water depth was 1.42 m, falling between 1.17 m and 1.70 m for 50% of the time. The median salinity along the length of the Coorong under the Historic TLM on conditions was slightly lower than that of seawater at 32.09 g L^{-1}, although there were a number of outliers at extreme salinities. Median maximum number of days since flow over the barrages was low at 43 days and median tidal range was also small at 0.10 m.

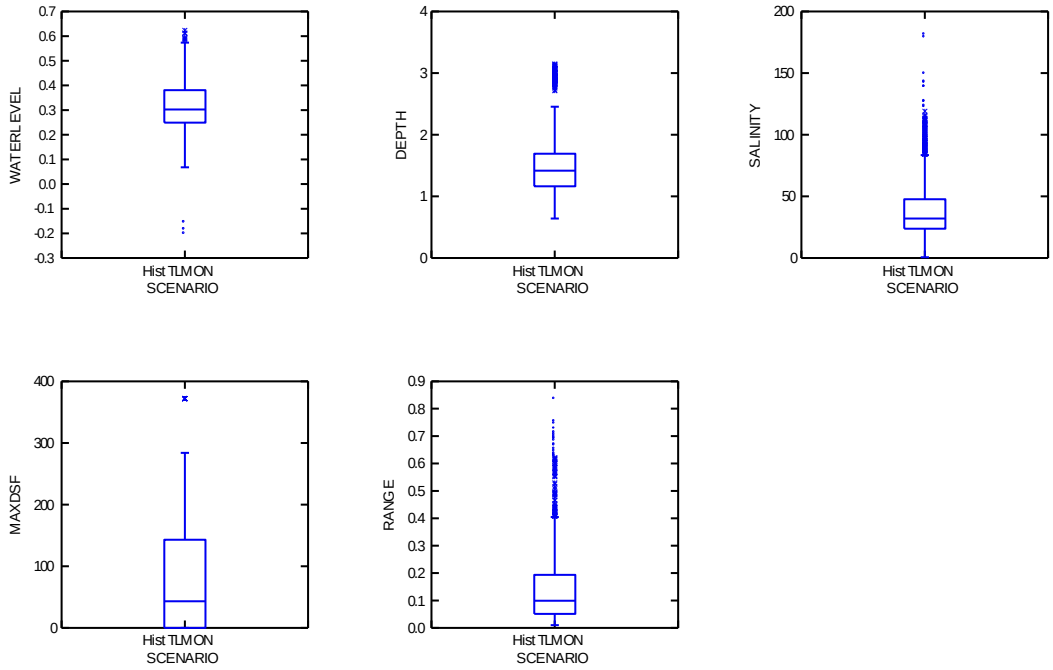

Figure 2.53. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Historic TLM on scenario

All Murray Mouth sites and North Lagoon sites north of Mark Point, always exceeded the threshold for daily tidal range. The remaining North Lagoon sites exceeded the threshold for an average of 12.7 years at a return interval of 2.4 years. In the South Lagoon, sites exceeded the threshold for 4.6 years, recurring every 20.5 years.

Under the Historic TLM on scenario, the threshold for days without barrage flow was exceeded only in the 113th and 114th years.

The threshold for water level at 0.37 m AHD was exceeded for about 1.6 years on average throughout the Coorong. Return times were an average of 6.6 in the Murray Mouth region, 4.4 in the North Lagoon and 9.5 in the South Lagoon. The lower water level threshold was exceeded in all years with the exception of the South Lagoon sites, again for the final year of simulation.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for an average of 1.5 years with a return time of 10.7 years.

The salinity threshold was not exceeded in the Murray Mouth region. In the North Lagoon, several sites had salinities above the threshold for the last simulation year, but Parnka Point

had a return time of 51 years and exceeded the threshold for only one year at a time. South Lagoon sites exceeded the threshold for an average of 6.8 years with a return time of 6.9 years. Salinity under Historic TLM on conditions was greater than 100 g L^{-1} in 3% of site-years.

Depth and water level were the most evenly distributed variables for the Historic TLM on scenario (Gini = 0.03 and 0.07, respectively). Tidal range and salinity were both moderately-well dispersed (Gini = 0.17 and 0.20, respectively). The maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with the occasional large deviations towards the high end of the spectrum (Gini = 0.60).

For the Historic TLM on scenario, seven out of the eight states appeared during the 114-year by 12 site (1368 site-years) model run. Over the Historic TLM on scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (74%) and the Average Hypersaline state (22%; Figure 2.54). Together, these accounted for 96% of the site-years modelled. The Healthy Hypersaline state was uncommon (4%), while the remaining Marine, Unhealthy Marine, Unhealthy Hypersaline states appeared in less than 1% of site-years and the Degraded Hypersaline state was not observed.

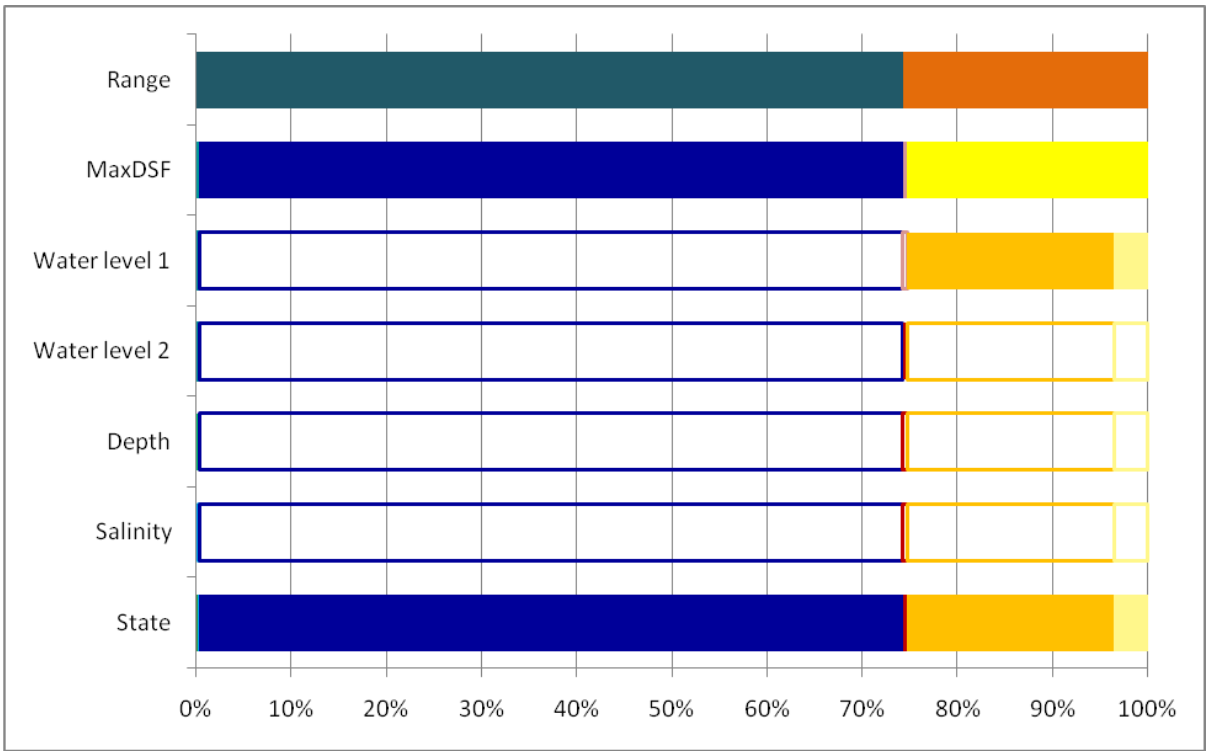

Figure 2.54. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Historic TLM on scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 10% of site-years (Figure 2.57). The proportion of site-years that did not change (i.e. state inertia) was 90%. Six of the twelve sites showed sequences in which states across the 114 years was signifcantly different from a random distribution (Z_u ranged 2.43 and 7.53 for six sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 2% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same baisn, they shifted to a more degraded state 5% of the time and to a less-degraded state 5% of the time.

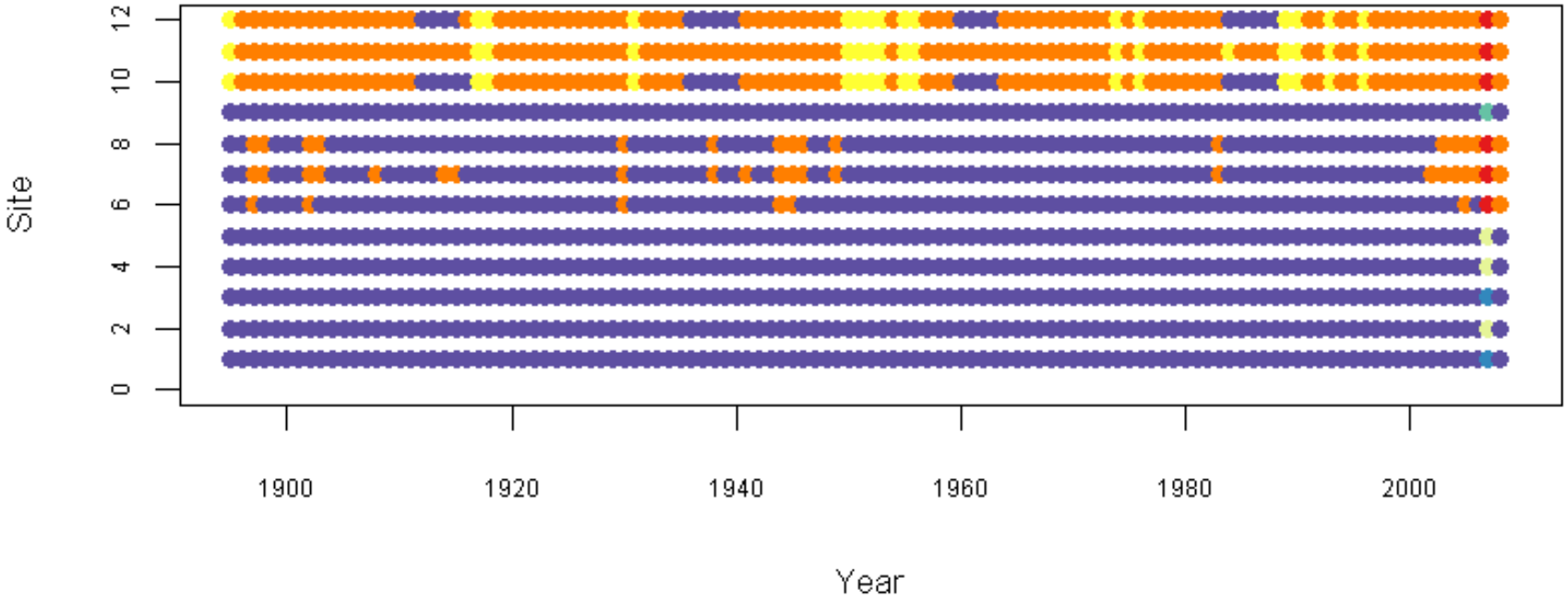

Figure 2.55. Distribution of states for each site-year under the Historic TLM on scenario

See Figure 2.3 for further explanation of the figure.

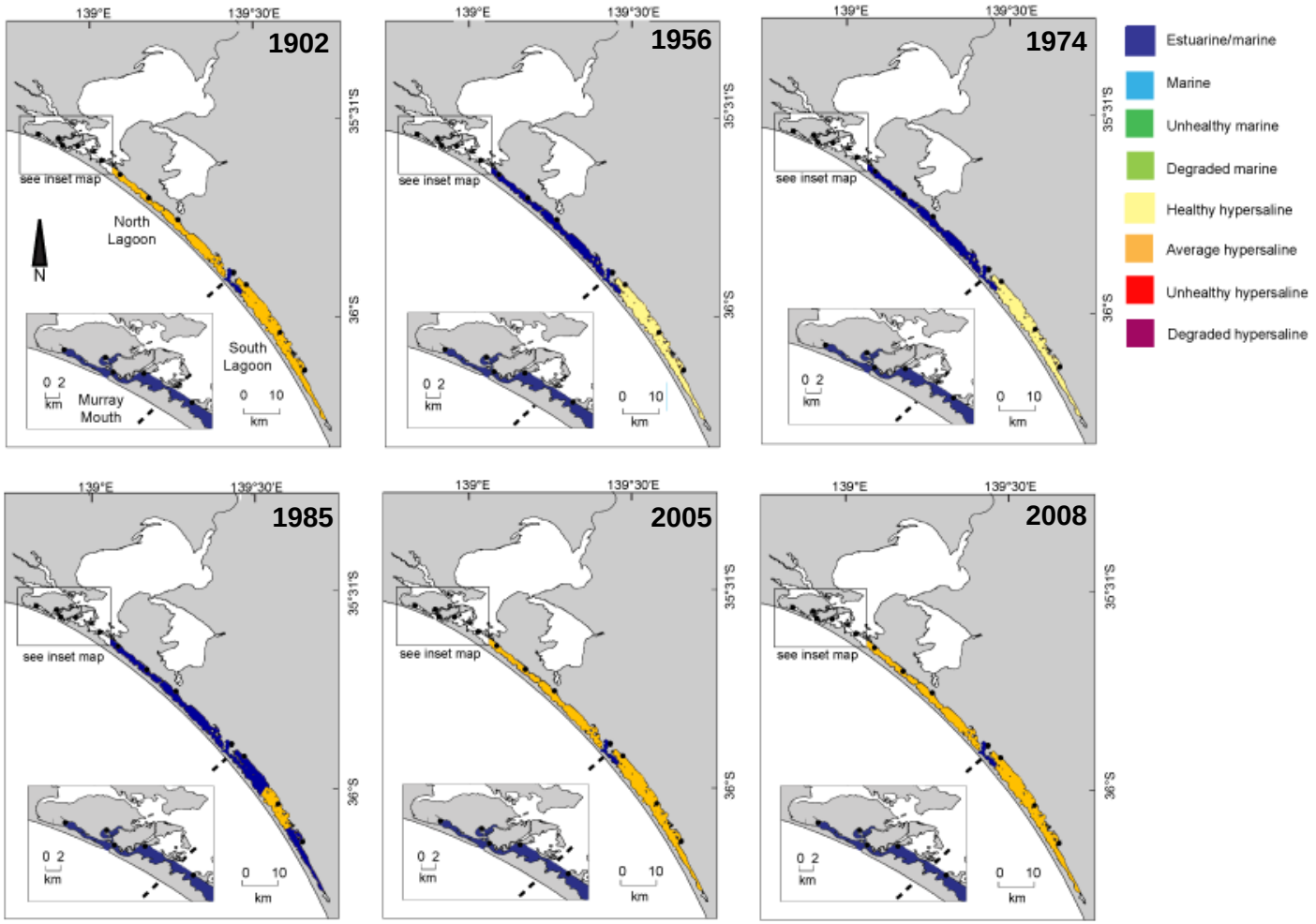

Figure 2.56. Mapping the distribution of states for seminal years under the Historic TLM on scenario

See Figure 2.4 for further explanation of the figure.

2.15. Median TLM off

The Median TLM off scenario investigated the effect of The Living Murray infrastructure in the Murray-Darling Basin under a median future climate, without the additional environmental water allocation.

Figure 2.57 shows the distributions of each of the variables driving the ecosystem states of the Coorong under the Median TLM off conditions. Median water level was 0.27 m AHD, but there were some outliers at lower depths (minimum -0.24 m AHD). The median water depth was 1.38 m, falling between 1.14 m and 1.68 m for 50% of the time. The median salinity along the length of the Coorong over the 114-year model run was slightly higher than that of seawater 41.31 g L^{-1}, although there were a number of outliers at extremely high salinities. Median maximum number of days since flow over the barrages (MaxDSF) for the Median TLM off scenario was 196 days, falling between 78 days and 294 days for 50% of the time. The median tidal range was small at 0.10 m, but there were some outliers at greater tidal ranges (maximum 0.82 m).

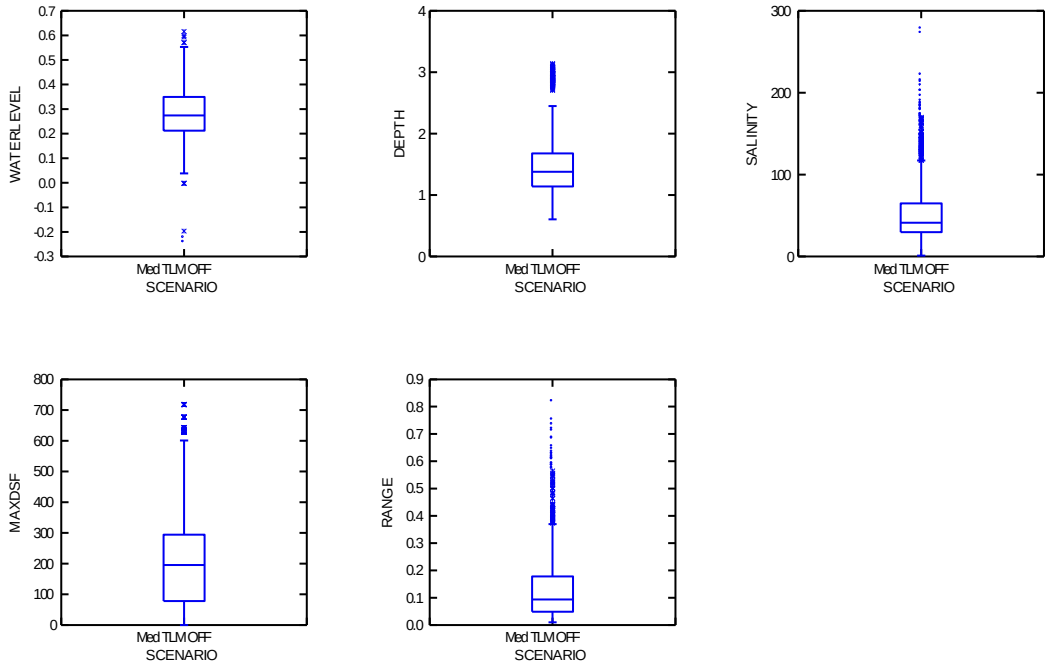

Figure 2.57. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Median TLM off scenario

All sites north of Mark Point always exceeded the tidal range threshold. Other North Lagoon sites had an exceedance duration of 10.1 years on average, at a return interval of 2.6 years. South Lagoon sites, on average, exceeded the threshold for 4.6 years every 20.5 years.

A return interval of 14.9 years and an average duration of 2.8 years was recorded for exceeding the threshold for the number of days without flow over the barrages for the Median TLM off scenario.

All sites in the Coorong exceeded the 0.37 m AHD water level threshold for between 1.6 and 1.7 years on average. The return times varied, at 10.8 for the Murray Mouth region, 6.7 for the North Lagoon and 13.7 for the South Lagoon sites. The only sites that did not exceed the lower water level threshold (-0.09 m AHD) were the three South Lagoon sites in 2008.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point every 17.8 years for 1.2 years, on average.

The salinity threshold was not exceeded in the Murray Mouth region. In the North Lagoon, sites exceeded the threshold for 1.6 years with a return time of 31.6 years. The South Lagoon exceeded the threshold with a return time of 4.2 years, for an average duration of 23.3 years. Under Median TLM off conditions, salinity was greater than 100 g L^{-1} in 13% of site-years.

For the Median TLM off scenario, depth and water level were the most evenly distributed variables (Gini = 0.04 and 0.07, respectively). This suggests they are relatively likely to occupy any value within their range, rather than being skewed to either end of the distribution. Tidal range and salinity were both moderately-well dispersed (Gini = 0.18 and 0.20, respectively) but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with the occasional deviation towards the high end of the spectrum (Gini = 0.42).

For the Median TLM off scenario, eight out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. The two most common states along the length of the Coorong over Median TLM off scenario model run were the Estuarine/Marine state (65%) and the Average Hypersaline state (19%; Figure 2.58). The Unhealthy Hypersaline (5%), Unhealthy Marine (4%), Marine (2%) and Healthy Hypersaline (2%) states were all uncommon. The two most degraded states represented the lowest proportions of site-years, with the Degraded Marine state and the Degraded Hypersaline state appearing in only 1% of the 114-year model run under the Median TLM off conditions.

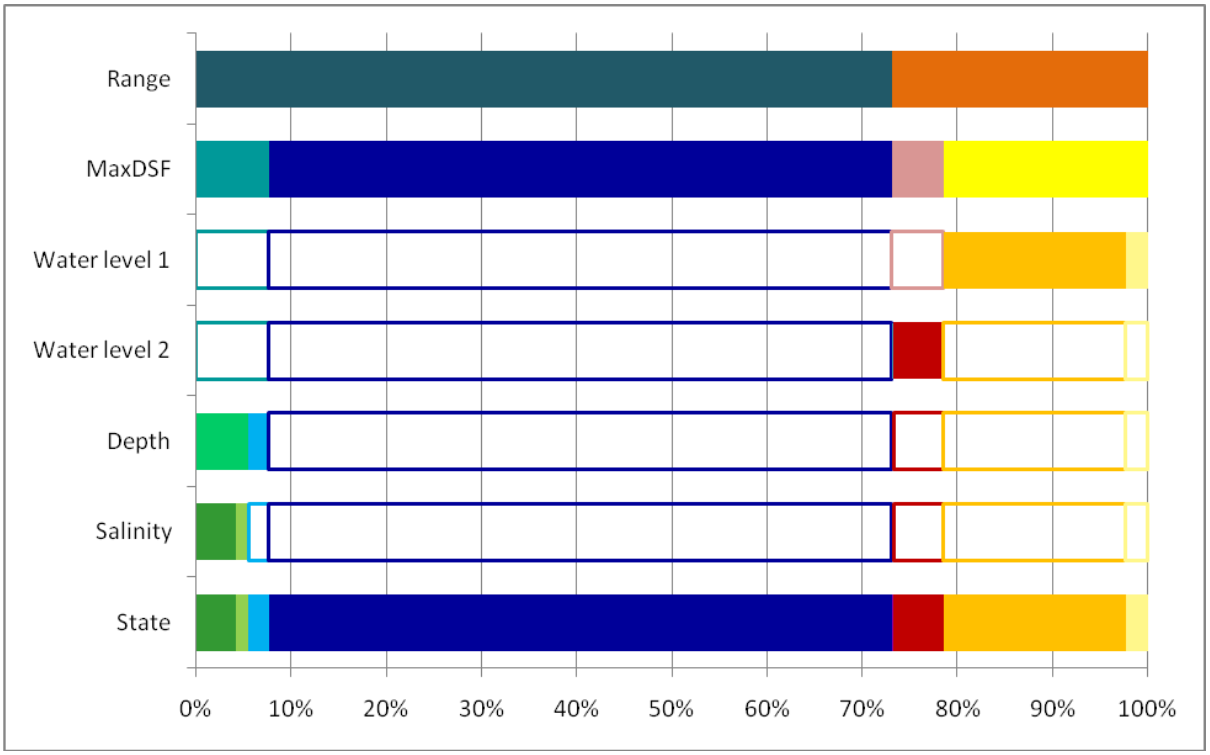

Figure 2.58. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Median TLM off scenario

See Figure 2.2 for further explanation of the figure.

For 20% of site-years transitions occurred between states (Figure 2.59). The state inertia in the system under the Median TLM off scenario then, (i.e. the proportion of site-years where the state did not change) was 80%. The sequence in which states appeared at each of the sites across the 144 years was signficantly different from a random distribution (Z_u ranged between 4.60 and 8.39 for 12 sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 5% of site-years, indicaing a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 8% of the time and to a less-degraded state 6% of the time.

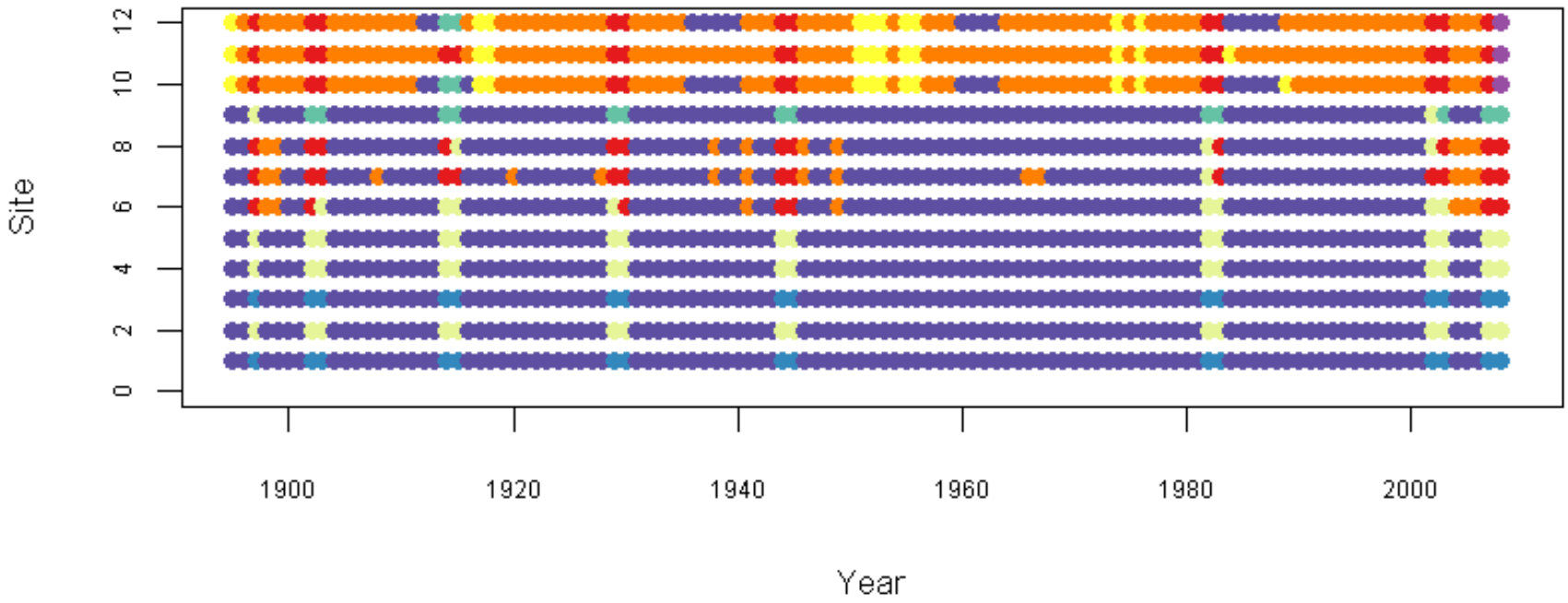

Figure 2.59. Distribution of states for each site-year under the Median TLM off scenario

See Figure 2.3 for further explanation of the figure.

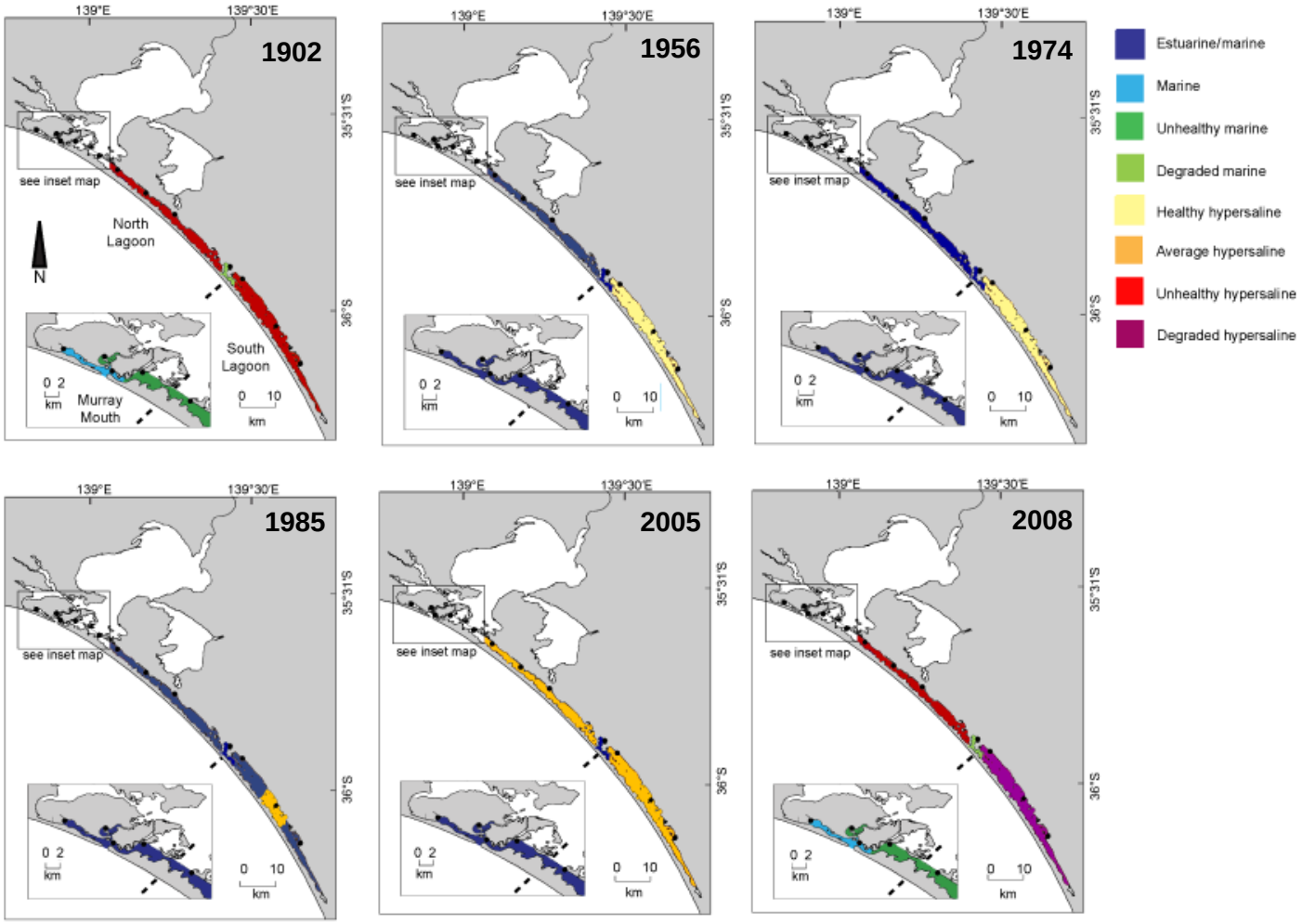

Figure 2.60. Mapping the distribution of states for seminal years under the Median TLM off scenario

See Figure 2.4 for further explanation of the figure.

2.16. Median TLM on

The Median TLM on scenario investigated the effect of The Living Murray infrastructure in the Murray-Darling Basin under a median future climate, including the additional environmental water allocation.

The distributions of each of the variables driving the ecosystem states of the Coorong under the Median TLM on conditions are shown in Figure 2.61. Median water level was 0.28 m AHD, falling between 0.22 m AHD and 0.35 m AHD for 50% of the time. The median water depth was 1.40 m but there were a number outliers at greater depths, approximately two times the median (maximum 3.14 m). Median salinity along the length of the Coorong over the 114-year model run was only slightly higher than that of seawater at 36.15 g L^{-1}, falling between 26.74 g L^{-1} and 58.47 g L^{-1} for 50% of the time. The median maximum number of days since flow over the barrages for the Median TLM on scenario was 88 days, although there are some outliers at greater time periods (i.e. higher maximum number of days since flow; maximum 616 days). The median tidal range was small at 0.10 m, falling between 0.05 m and 0.17 m for 50% of the time.

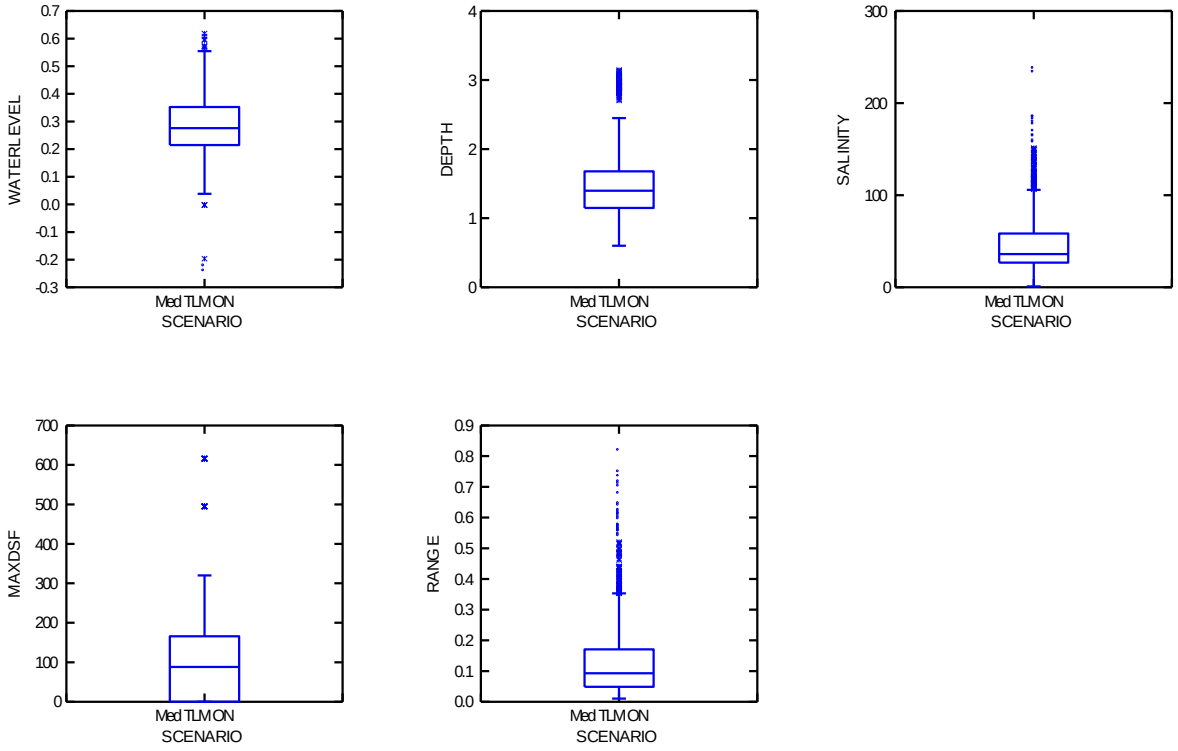

Figure 2.61. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Median TLM on scenario

Sites north of Mark Point were always over the threshold for daily tidal range. For sites south of Mark Point in the North Lagoon, the threshold was exceeded for 9.9 years at a return time of 2.7 years. In the South Lagoon, the threshold was exceeded for 4.6 years at a return interval of 20.5 years.

Under the Median TLM on scenario, the threshold for days without barrage flow was exceeded only in the 113th and 114th years.

The water level threshold at 0.37 m AHD was exceeded for 1.6 years on average along the Coorong. Return times in the Murray Mouth region were 7.8 years on average, with the North and South Lagoons having return times of 6.7 and 13.7 years, respectively. The South Lagoon sites did not exceed the lower threshold for water level in 2008. All other site years had water levels above -0.09 m AHD.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for an average of 1.2 years every 14.2 years, on average.

The salinity threshold was not exceeded in the Murray Mouth region. The North Lagoon sites exceeded the threshold for an average of 1.4 years with a return time of 23.0 years. South Lagoon sites exceeded the threshold for 21.9 years with a return time of 5.2 years. Salinity under Median TLM on conditions was greater than 100 g L^{-1} in 9% of site-years.

The Gini coefficient was calculated for each variable driving the ecosystem states. For the Median TLM on scenario, depth and water level were the most evenly dispersed variables (Gini = 0.03 and 0.07, respectively). Tidal range and salinity were moderately-well distributed (Gini = 0.18 and 0.19, respectively), but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with the occasional large deviation towards the high end of the spectrum (Gini = 0.54).

For the Median TLM on scenario, eight out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the Median TLM on scenario model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (72%) and the Average Hypersaline state (23%; Figure 2.62). Together these two states accounted for 95% of the site-years modelled. The Healthy Hypersaline (3%) and Unhealthy Hypersaline (1%) states were uncommon and the Marine, Unhealthy Marine, Degraded Marine and Degraded Hypersaline states appeared in less than 1% of site-years each.

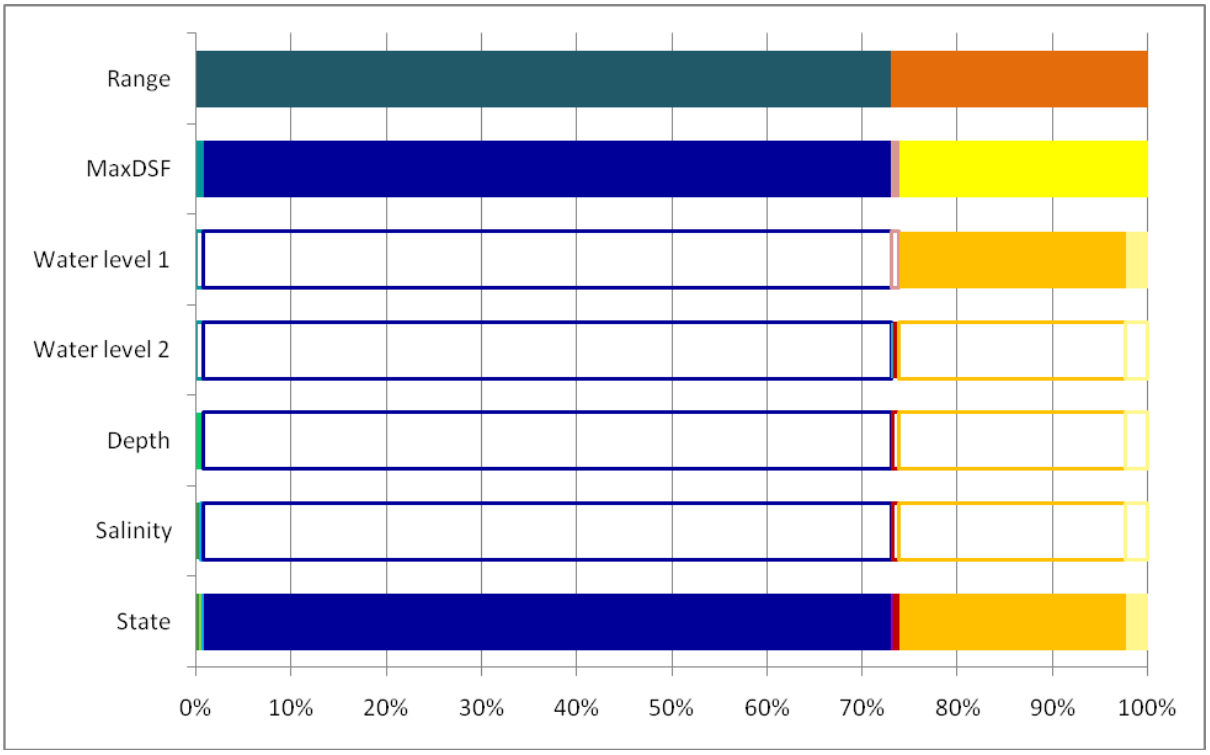

Figure 2.62. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Median TLM on scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 3% of site-years (Figure 2.65). This means that the state inertia (i.e. the proportion of site-years where the state did not change) in the system for the Median TLM on scenario was 97%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 4.47 and 9.18 for 12 sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) in 1% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 1% of the time and to a less-degraded state 1% of the time.

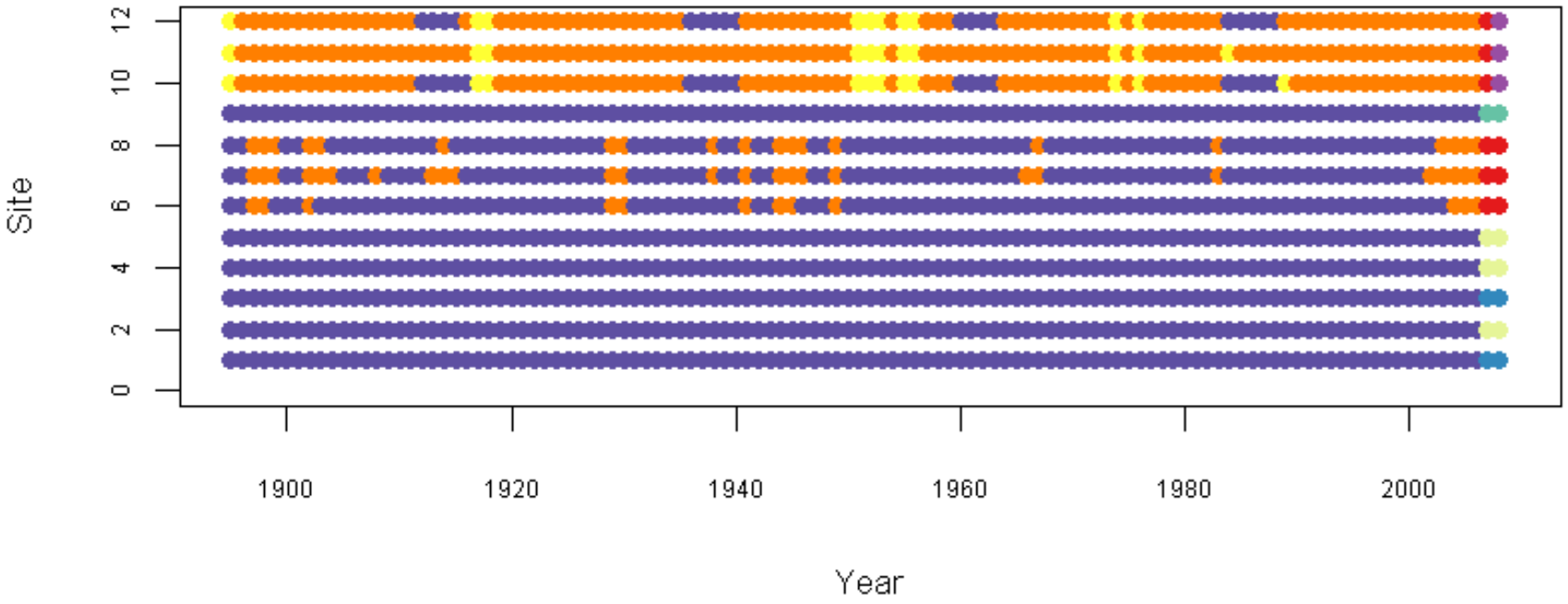

Figure 2.63. Distribution of states for each site-year under the Median TLM on scenario

See Figure 2.3 for further explanation of the figure.

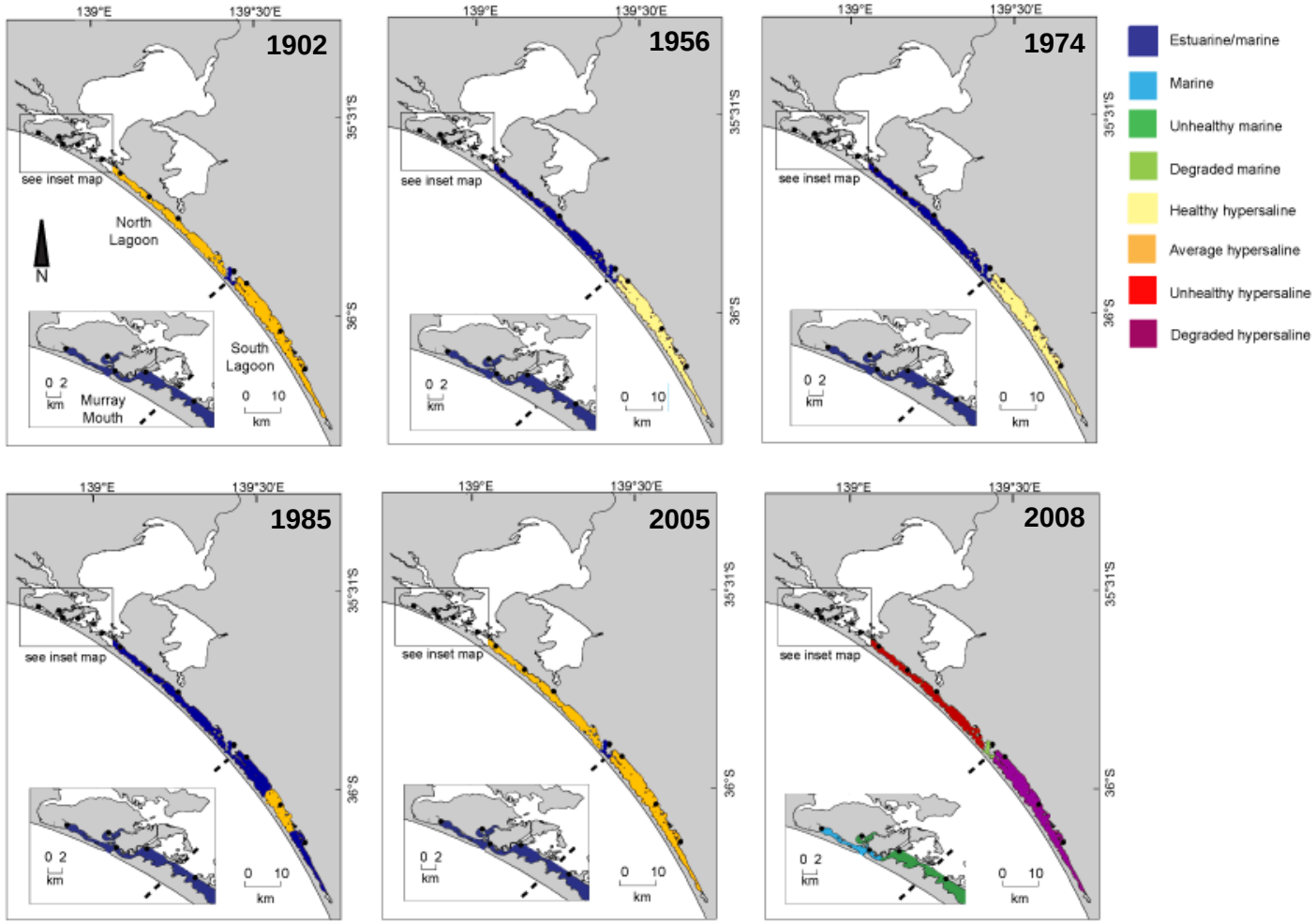

Figure 2.64. Mapping the distribution of states for seminal years under the Median TLM on scenario

See Figure 2.4 for further explanation of the figure.

2.17. Dry TLM off

The Dry TLM off scenario modelled the effect of TLM infrastructure without any additional environmental water allocation.

Figure 2.65 shows the distributions of each of the variables driving the ecosystem states of the Coorong under the Dry TLM off conditions. Median water level was 0.23 m AHD, falling between 0.17 m AHD and 0.28 m AHD for 50% of the time. The median water depth was 1.33 m, although there were some outliers at greater depths (maximum 3.13 m). Median salinity under the Dry TLM off conditions along the length of the Coorong was greater than that of seawater at 58.38 g L^{-1}, falling between 42.76 g L^{-1} and 113.39 g L^{-1} for 50% of the time. The median maximum number of days since flow over the barrages over the 114-year model run was 323 days, but there were a number of outliers at greater time periods (maximum = 2777 days). Median tidal range was small at 0.07, falling between 0.04 m and 0.12 m for 50% of the time.

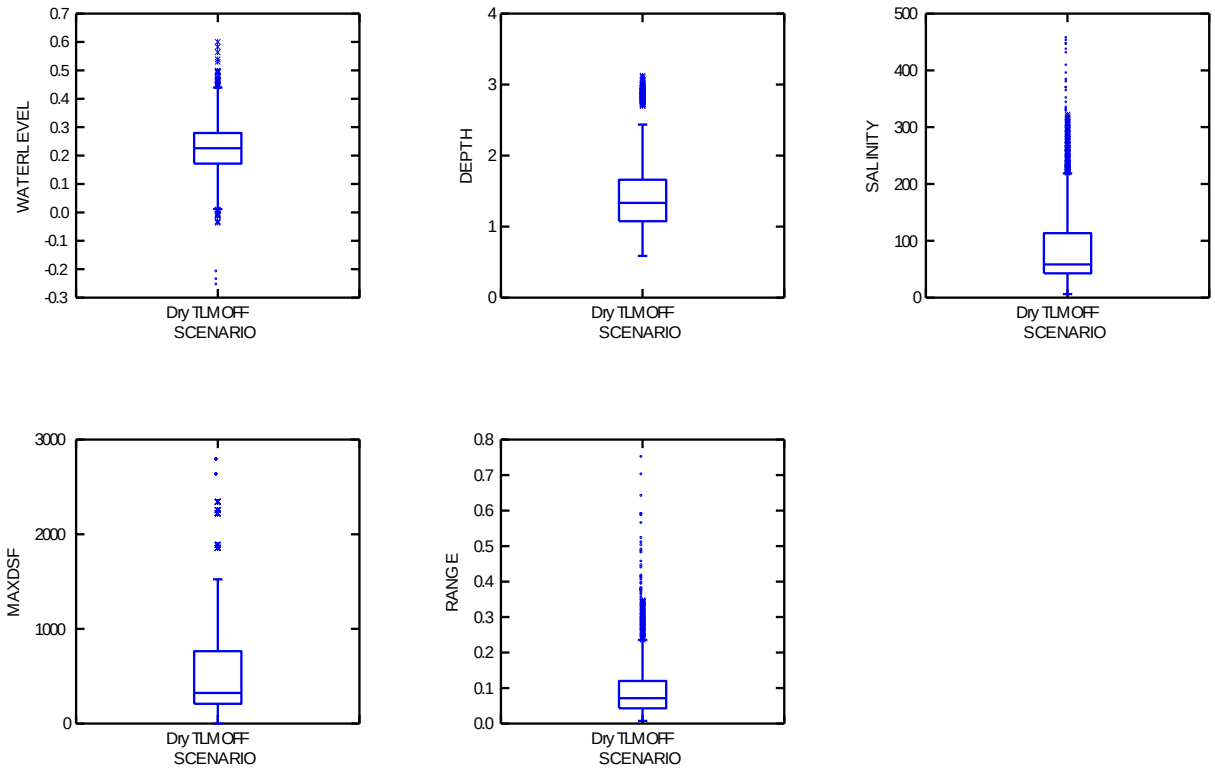

Figure 2.65. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Dry TLM off scenario

Barkers Knoll was the only Murray Mouth site to fall below the threshold for daily tidal range. It exceeded the threshold for an average of 37.3 years, at a return interval of 2.0 years. In the North Lagoon, sites exceeded the threshold for 11.4 years, recurring every 3.2 years and in the South Lagoon, the values were 4.8 years and 20.2 years, respectively.

The threshold for the maximum number of days without barrage flows was exceeded for an average of 4.5 years at a return interval of 6.9 years.

The water level threshold at 0.37 m AHD was exceeded in the Murray Mouth region for an average of 1.3 years with a return time of 18.8 years. In the North Lagoon, the average length of time the threshold was exceeded was 1.4 years recurring every 17.8 years. The South Lagoon sites exceeded the threshold for one year every 39 years.

Only the South Lagoon sites in 2008 failed to exceed the -0.09 m AHD threshold for water level.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for two single years with an average return time of 28.5 years.

Murray Mouth sites exceeded the salinity threshold for an average of 1.3 years with a return time of 32.8 years. North Lagoon sites exceeded the threshold for 7.0 years every 12.8 years. In the South Lagoon, both Jack Point and Salt Creek exceeded the salinity for all years bar the first simulation year. Villa dei Yumpa exceeded the threshold for an average of 61 years with a return time of 2.0 years. Under Dry TLM off conditions, salinity was greater than 100 g L^{-1} in 28% of site-years.

For the Dry TLM off scenario, depth and water level were the most evenly dispersed variables (Gini = 0.03 and 0.07, respectively). This suggests that they were relatively likely to occupy any value within their range, rather than being skewed to either end of the distribution. Salinity and tidal range were both moderately-well distributed (Gini = 0.17 and 0.20, respectively), but the maximum number of days without flow was unevenly distributed, tending to remain low on most occasions, but with the occasional large deviations towards the higher end of the spectrum (i.e. less number of days without flow).

For the Dry TLM off scenario, eight out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. The two most common states along the length of the Coorong over the Dry TLM off model run were the Estuarine/Marine state (38%) and the Unhealthy Marine state (20%; Figure 2.66). Together, these accounted for 68% of the site-years modelled. The Average Hypersaline and Unhealthy Marine states appeared in similar proportions over the 114-year model run (14% and 13%, respectively). The Marine (8%) and Degraded Marine (7%) states were both uncommon and the Healthy Hypersaline and Degraded Hypersaline states appeared in less than 1% of site-years each.

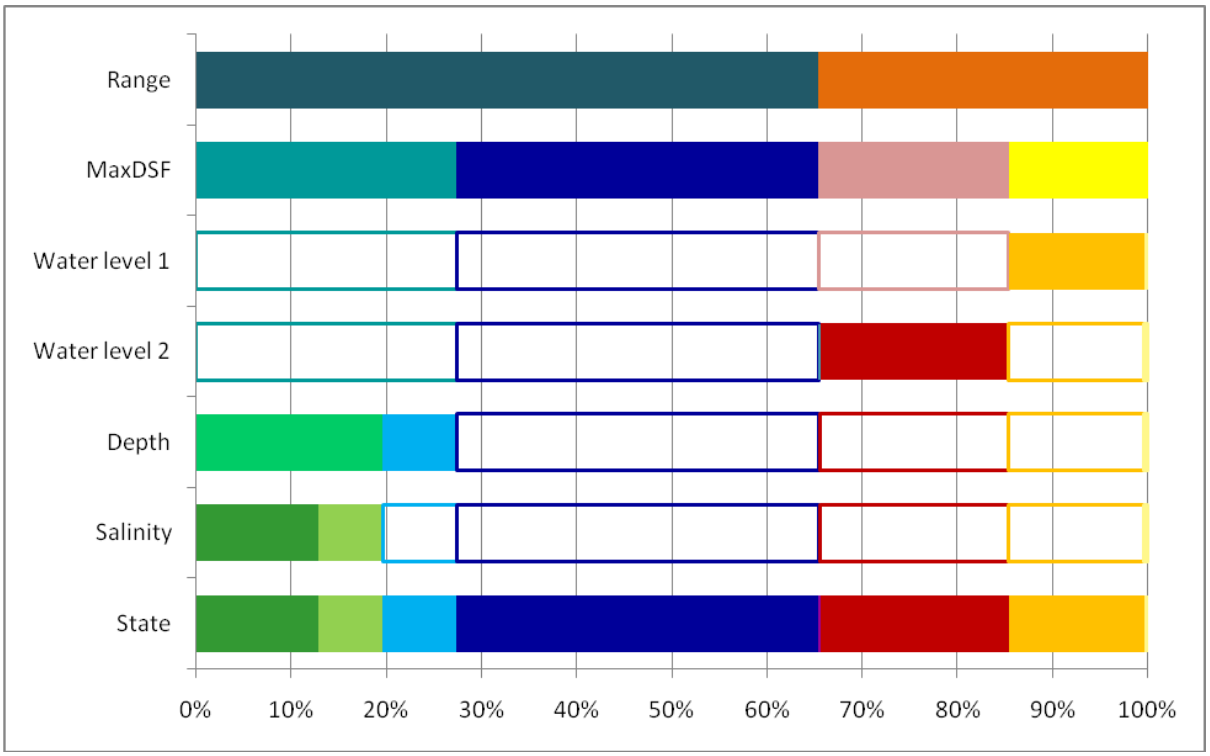

Figure 2.66. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Dry TLM off scenario

See Figure 2.2 for further explanation of the figure.

For 28% of site-years transitions occurred between states (Figure 2.67). The proportion of site-years where the state did not change (i.e. the state inertia) was 72%. The sequence in which states appeared at each site across the 114 years was significantly different from a random distribution (Z_u ranged between 5.59 and 9.77 for 12 sites). When transitions did occur, sites changed basins (i.e. went from a marine state to a hypersaline state or vice versa) in 10% of site-years. When sites changed within the same basin, they shifted to a more degraded state 10% of the time and to a less-degraded state 8% of the time.

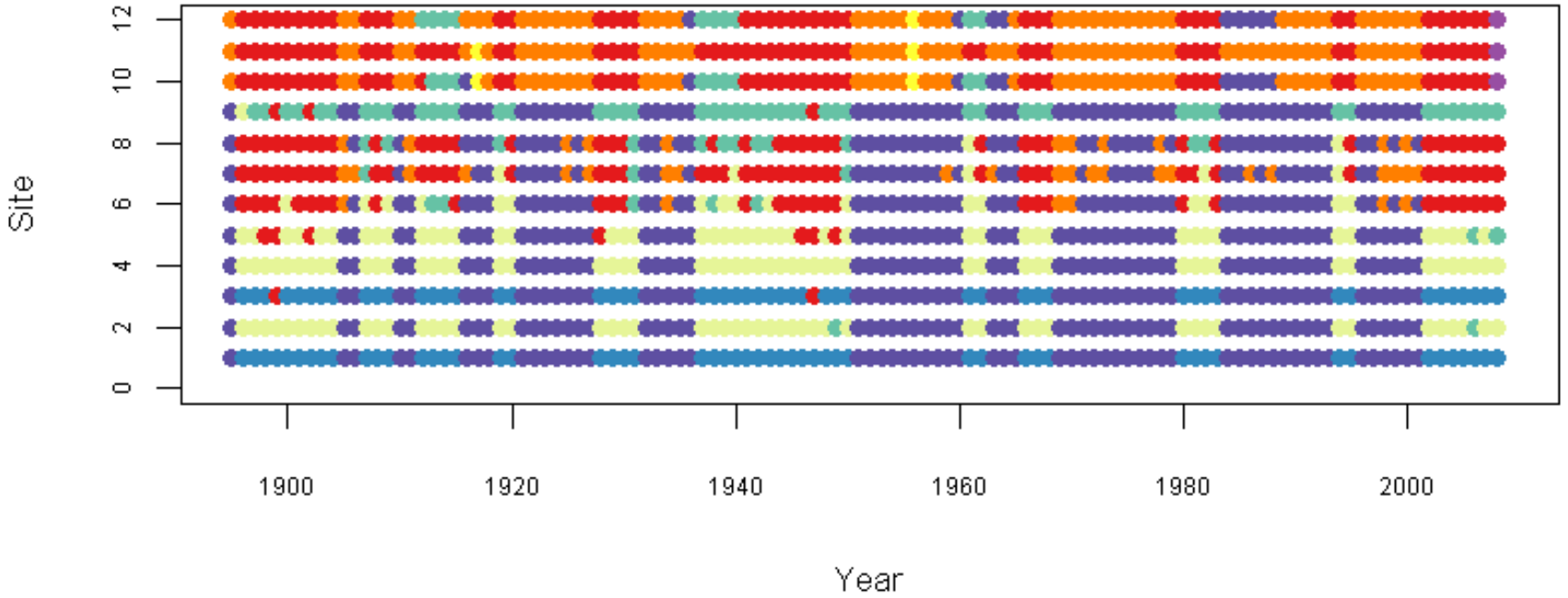

Figure 2.67. Distribution of states for each site-year under the Dry TLM off scenario

See Figure 2.3 for further explanation of the figure.

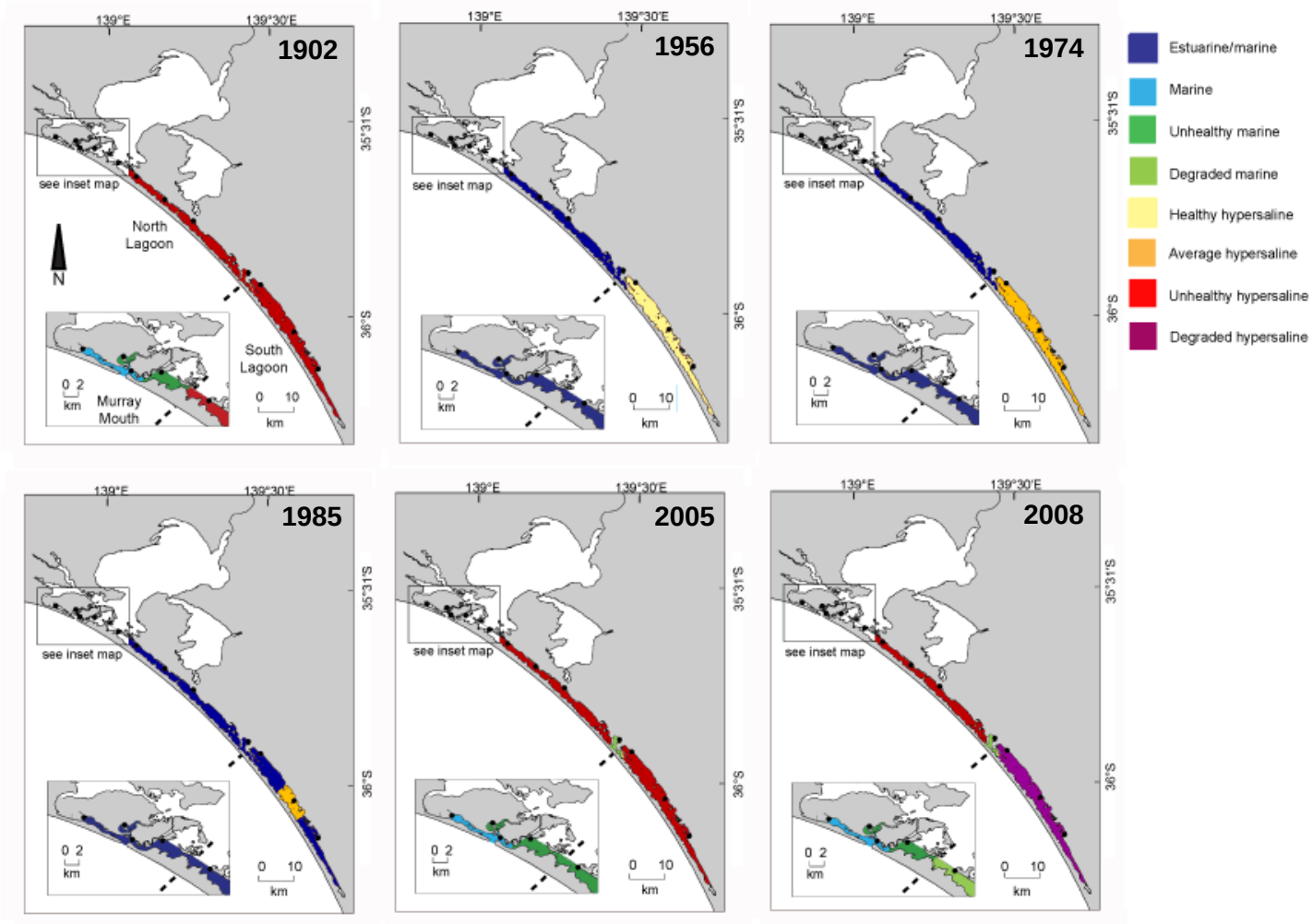

Figure 2.68. Mapping the distribution of states for seminal years under the Dry TLM off scenario

See Figure 2.4 for further explanation of the figure.

2.18. Dry TLM on

The Dry TLM on scenario modelled the effect of TLM initiative, including both the infrastructure and the additional environmental water allocation.

The distributions of each of the variables driving the ecosystem states of the Coorong under the Dry TLM on conditions are shown in Figure 2.69. Median water level was 0.25 m AHD, falling between 0.19 m AHD and 0.31 m AHD for 50% of the time. The median water depth under Dry TLM on conditions along the length of the Coorong was 1.36 m, falling between 1.10 m and 1.66 m for 50% of the time. Median salinity was greater than that of seawater along the length of the Coorong over the 114-year model run, at 50.80 g L^{-1}, although there were a number of outliers at extremely high salinities (maximum 380.70 g L^{-1}). The median for the maximum number of days since flow over the barrages (MaxDSF) for the Dry TLM on scenario was 208 days, while the median tidal range was small, at 0.07 m.

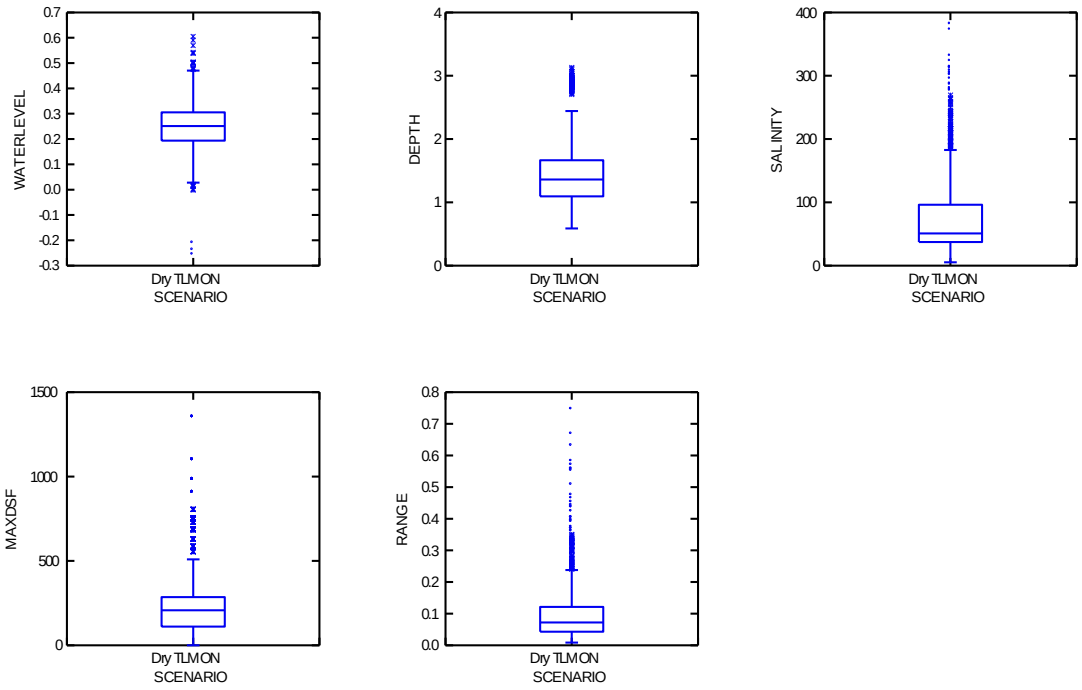

Figure 2.69. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Dry TLM on scenario

Pelican Point was the northernmost site to fall below the threshold for daily tidal range. North Lagoon sites exceeded the threshold for an average of 11.3 years at a return interval of 2.8 years. In the South Lagoon, the duration of exceedance was 4.6 years and the return time was 20.3 years.

The threshold for the maximum number of days without flow over the barrages was exceeded at an average return interval of 13.0 years for 2.4 years at a time under the Dry TLM on scenario.

Average water levels in the Murray Mouth region exceeded the 0.37 m AHD threshold every 13.5 years for an average of 1.5 years at a time. In the North Lagoon, the return time was 17.8 years, with the water levels staying above the threshold for 1.4 years at a time. The South Lagoon sites only exceeded the threshold for a year at a time, with a return interval of 39.0 years. The lower water level threshold was exceeded for all sites except the South Lagoon sites in 2008.

The depth threshold was exceeded for all years at the Monument Road and Barkers Knoll sites. It was also exceeded at Mark Point for two single years with an average return time of 28.5 years.

Sites in the Murray Mouth exceeded the salinity threshold for an average of only a year at a time, with a return time of 51 years. For North Lagoon sites, the average length of time over the threshold was 4.7 years with a return time of 13.1 years. In the South Lagoon, Villa dei Yumpa exceeded the threshold for 60 years, with a return time of 3 years while the two southern-most sites were over the threshold for all years bar the first. Salinity under Dry TLM on conditions was greater than 100 g L^{-1} in 24% of site-years.

For the Dry TLM on scenario, depth and water level were the most evenly distributed variables (Gini = 0.03 and 0.06, respectively). Salinity and tidal range were both moderately-well dispersed (Gini = 0.16 and 0.19, respectively) but the maximum number of days without flow was unevenly dispersed, tending to remain low on most occasions, but with occasional deviations towards the high end of the spectrum (Gini = 0.48).

For the Dry TLM on scenario, eight out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the Dry TLM on model run, the two most common states along the length of the Coorong were the Estuarine/Marine state (54%) and the Average Hypersaline state (26%; Figure 2.70). Together, these accounted for 80% of the site-years modeled. The remaining 20% consisted of the Unhealthy Hypersaline (8%), Unhealthy Marine (6%), Marine (3%) and Degraded Marine (3%) states which were all uncommon and the Healthy Hypersaline and Degraded Hypersaline states that appeared in less than 1% of site-years each.

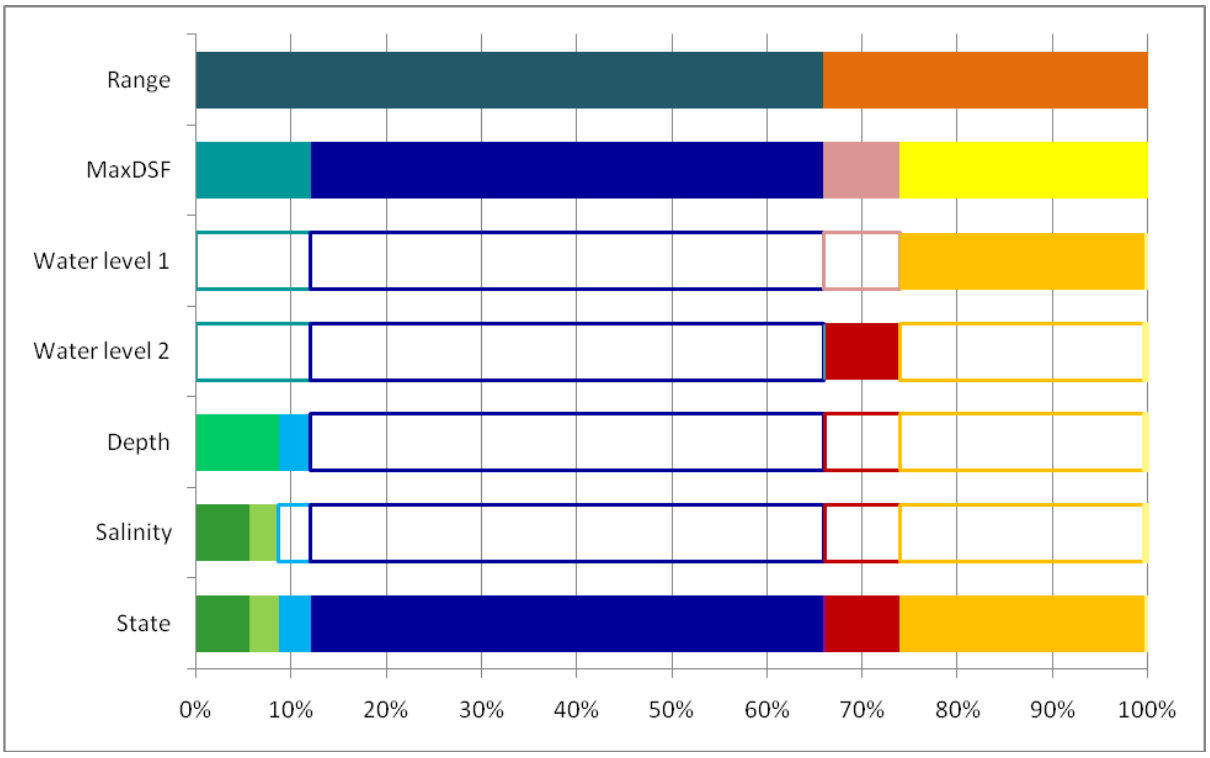

Figure 2.70. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Dry TLM on scenario

See Figure 2.2 for further explanation of the figure.

Transitions occurred between states for 23% of site-years (Figure 2.71). This means that the state inertia (i.e. the porportion of site-years where the state did not change) in the system for the Dry TLM off scenario was 77%. The sequence in which states appeared at each of the sites across the 114 years was signifcantly different from a random distribution (Z_u ranged between 4.90 and 9.77 for 12 sites). When transitions did occur, sites changed basin (i.e. went from a marine state to a hypersaline state or vice versa) 10% of site-years, indicating a shift in the penetration of the tidal prism. When sites changed within the same basin, they shifted to a more degraded state 7% of the time and to a less-degraded state 6% of the time.

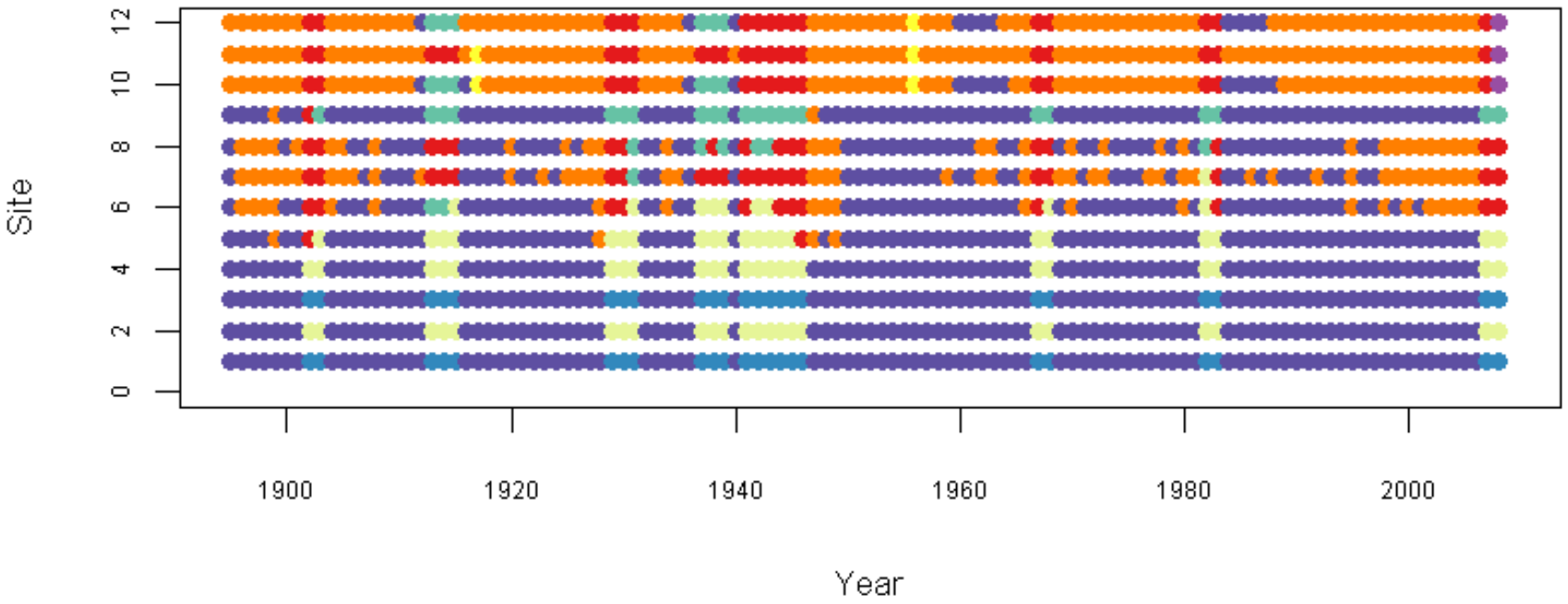

Figure 2.71. Distribution of states for each site-year under the Dry TLM on scenario

See Figure 2.3 for further explanation of the figure.

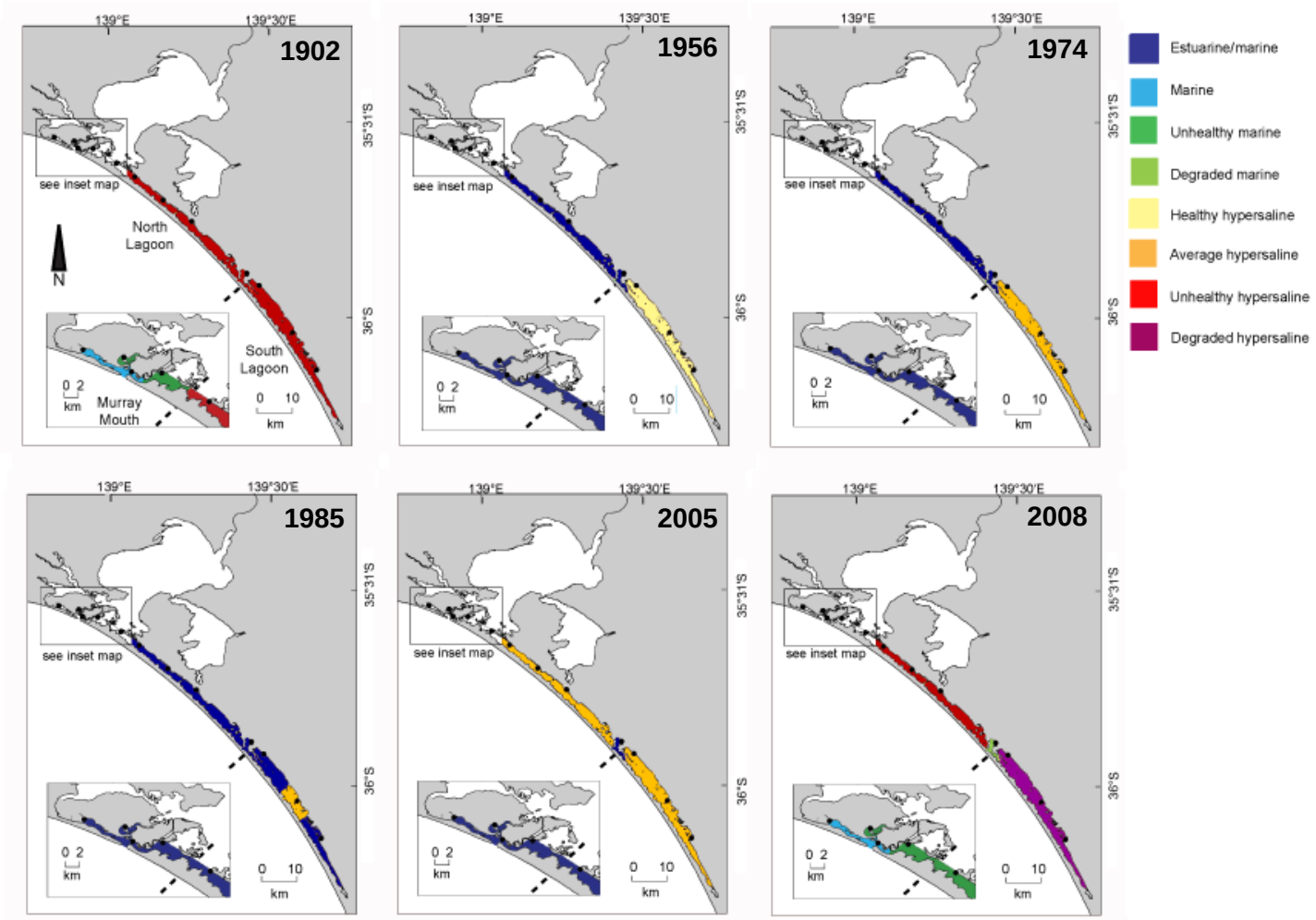

Figure 2.72. Mapping the distribution of states for seminal years under the Dry TLM on scenario

See Figure 2.4 for further explanation of the figure.

2.19. MM Dredging

The MM Dredging scenario investigates the effect of the current dredging works at the Murray Mouth. It includes a minimum mouth depth of -2 m AHD, under Historic climatic conditions and average USED flows.

Figure 2.73 shows the distributions of each of the variables driving the ecosystem states of the Coorong under the MM Dredging conditions. Median water level was 0.28 m AHD, falling between 0.23 m AHD and 0.35 m AHD for 50% of the time. Median water depth from two years ago (Depth Year2) along the length of the Coorong was 1.41 m, falling between 1.15 m and 1.68 m for 50% of the time. The median annual range was small at 0.10 m, but there are a number of outliers at greater tidal ranges (maximum 1.27 m).

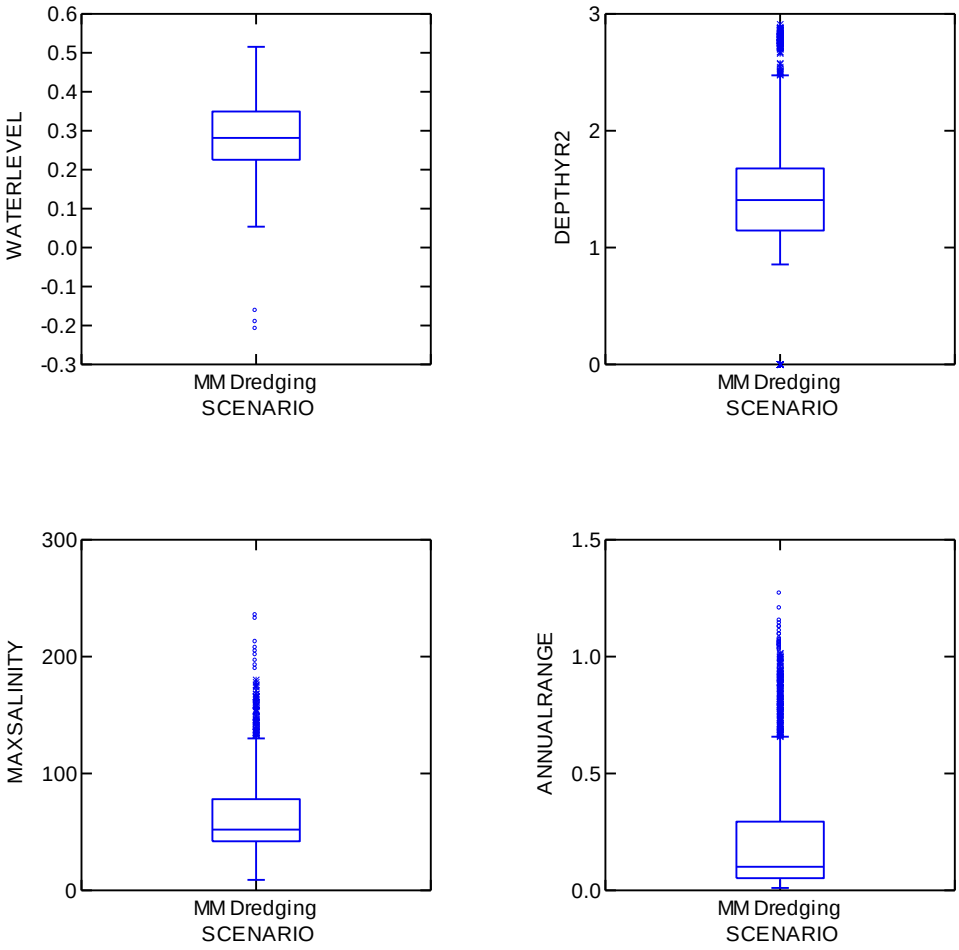

Figure 2.73. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the MM Dredging scenario.

Note that under the MM Dredging scenario, maximum salinity is presented only for sites 4-12, as a relationship could not be calculated for the predicted sites 1-3.

The water level threshold for the marine model was exceeded at sites in the Murray Mouth region for an average of 13.3 years with a return interval of 2.1 years. In the North Lagoon, sites exceeded the threshold for 19.4 years at an average recurrence of 2.0 years. South Lagoon sites had a return interval of 2.7 years for an average of 3.8 years at a time.

The water level threshold from the hypersaline model was exceeded by sites in the Murray Mouth region for an average of 1.4 years at a return interval of 8.4 years. North Lagoon sites

exceeded the threshold for 1.5 years on average, with a recurrence time of 5.0 years. The South Lagoon sites had a similar length of exceedance (at 1.6 years) and a return interval of 10.2 years.

The threshold for water level in the previous year from the marine model was exceeded at all years and sites with the exception of South Lagoon sites in 2008. The water level in the previous year threshold from the hypersaline basin model was exceeded in Murray Mouth sites for an average of 21.5 years at a return interval of 7.7 years. In the North Lagoon, sites exceeded the threshold for longer, with an average of 3.6 years, recurring every 5.1 years. South Lagoon sites exceeded the threshold every 9.5 years for an average of 1.5 years. The maximum salinity under MM Dredging conditions was greater than 100 g L^{-1} in 14% of site-years.

The depth threshold (for depth two years' previous) was only exceeded at Monument Road and Barkers Knoll. Barkers Knoll exceeded the threshold for all years except the final two in the simulation. Monument Road exceeded the threshold for an average of 55.0 years with a return interval of 2.0 years.

All sites exceeded the threshold for the annual range in water level with the exception of the Pelican Point, Mark Point, Jack Point and Salt Creek sites, none of which exceeded it in the final year of simulation.

The threshold for maximum salinity was never exceeded at Murray Mouth or North Lagoon sites. South Lagoon sites exceeded the threshold for an average of 1.7 years at a return interval of 7.1 years.

For the MM Dredging scenario, water depth (from two years ago) was the most evenly distributed variable (Gini = 0.03). Water level and annual range were both moderately-well dispersed (Gini = 0.10 and 0.12, respectively).

For the MM Dredging scenario, seven out of the eight states were observed during the 114-year by 12 site (1368 site-years) model run. Over the MM Dredging scenario model run, the two most common states were the Estuarine/Marine state (55%) and the Marine state (17%; Figure 2.74). The Average Hypersaline state was the third most common appearing in 16% of the site-years and the less common states included the Unhealthy Marine (4%), Degraded Hypersaline (3%), Healthy Hypersaline (3%) and the Unhealthy Hypersaline (2%) states. The Degraded Hypersaline state did not appear over the 114-year model run under the MM Dredging conditions.

Transitions occurred between states for 15% for site-years (Figure 2.75). This means that the state inertia (i.e. the proportions of site-years where the state did not change) in the system for the MM Dredging scenario was 85%. Six of the twelve sites across the 114 years showed sequences in which states appeared in series that were significantly different from a random distribution (Z_u ranged between 2.00 and 8.64 for six sites). When transitions did occur, sites changed within the same basin, they shifted to a more degraded state 7% of the time and to a less-degraded state 8% of the time. No transitions between basins (i.e. went from a marine state to a hypersaline state or vice versa) were observed for site-years.

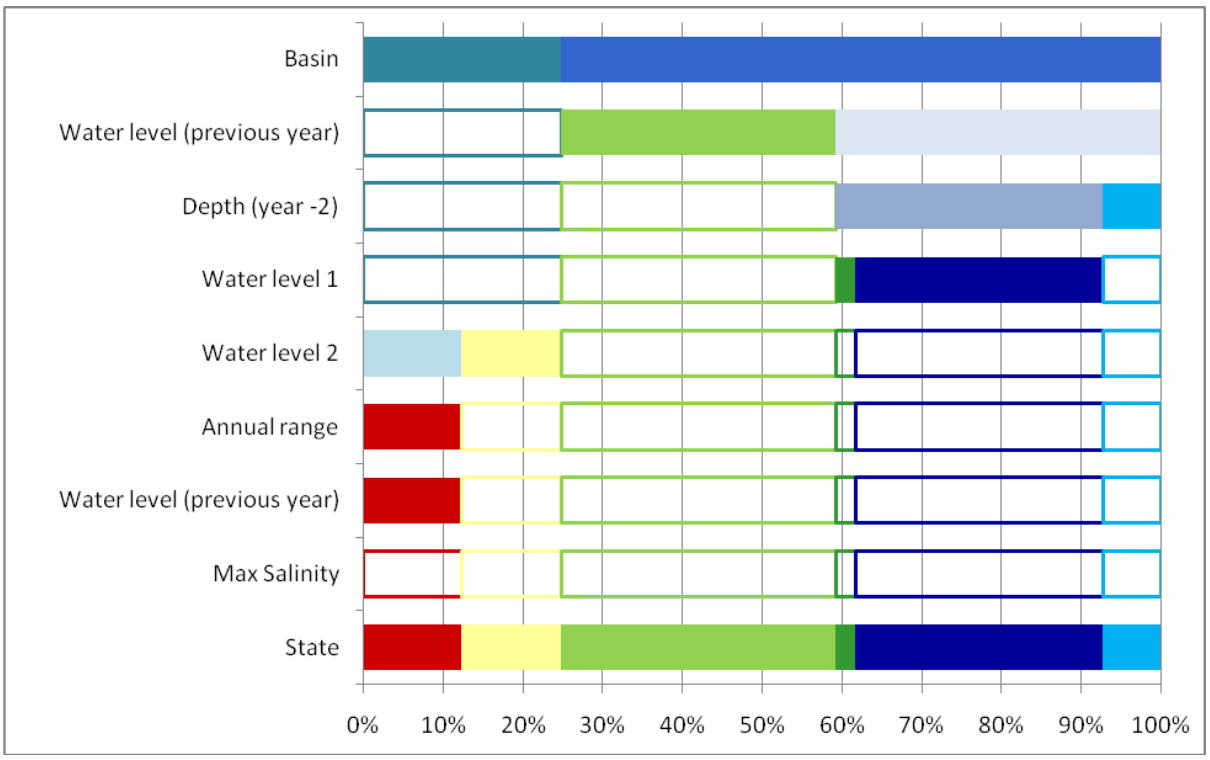

Figure 2.74. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the MM Dredging scenario

See Figure 2.2 for further explanation of the figure.

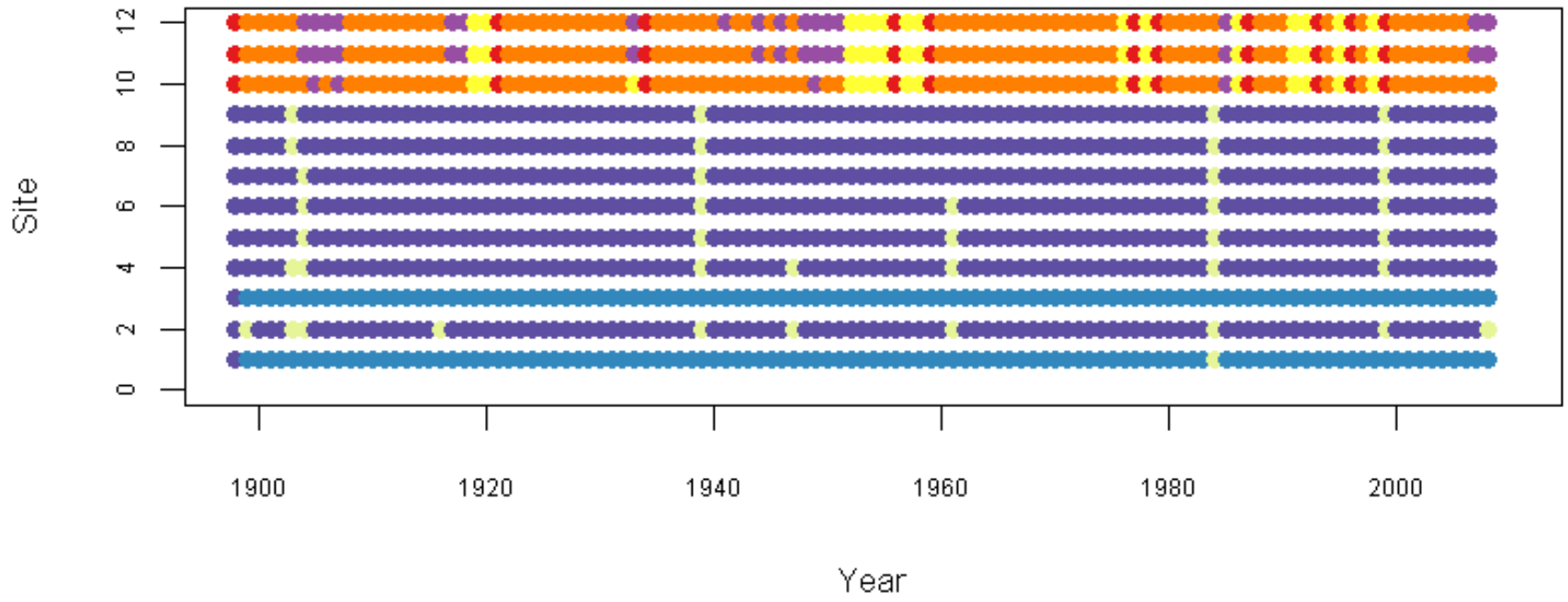

Figure 2.75. Distribution of states for each site-year under the MM Dredging scenario

See Figure 2.3 for further explanation of the figure.

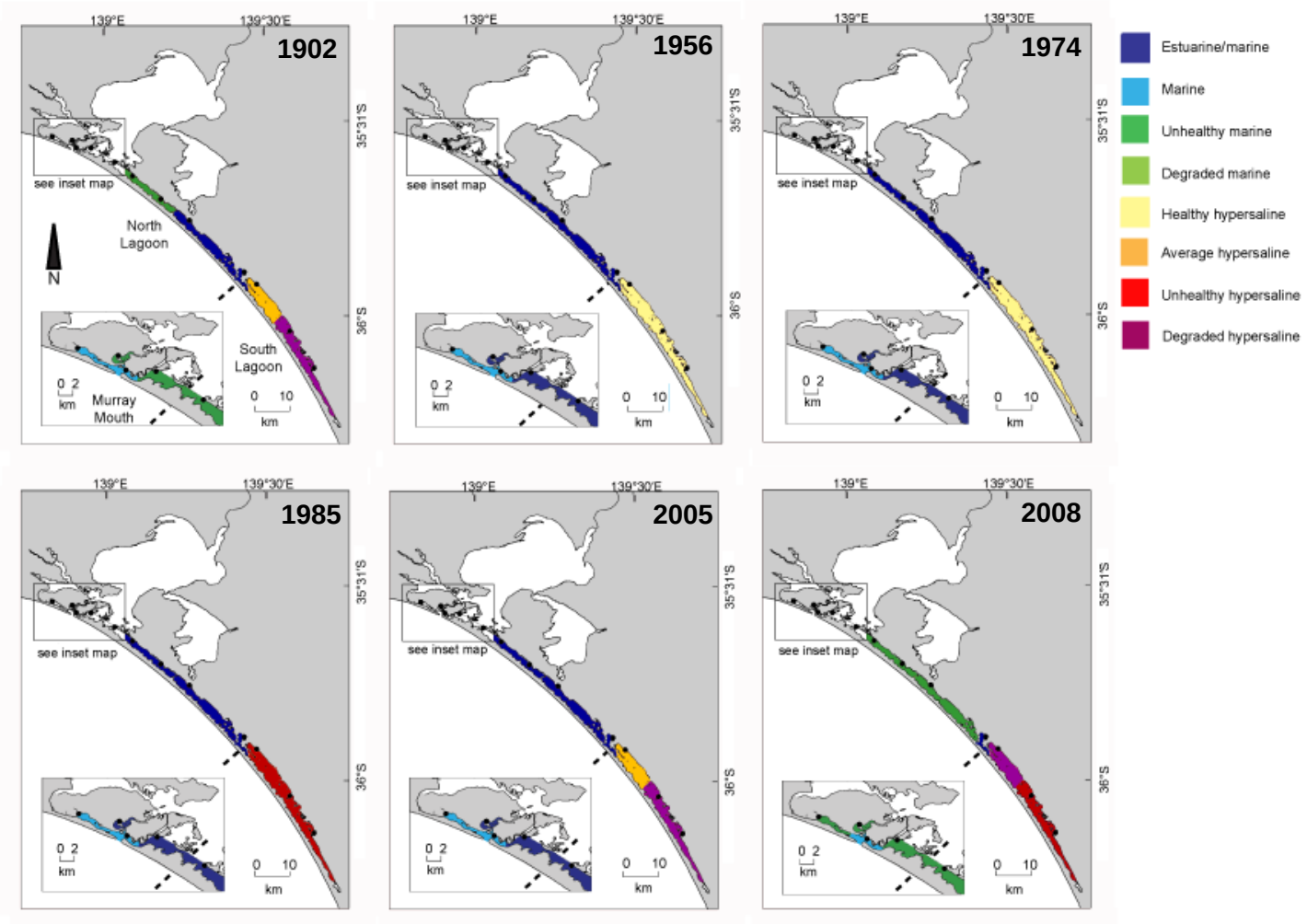

Figure 2.76. Mapping the distribution of states for seminal years under the MM Dredging scenario

See Figure 2.4 for further explanation of the figure

2.20. Max USED Flows

The Max USED Flows scenario modelled the effect of a theoretical maximum volume of water potentially available through Salt Creek from 1971 to 2006. This was intended to provide an understanding of the maximum benefit possible from augmenting the USED scheme. The scenario assumes a historic climate.

Figure 2.77 shows the distributions of each variables driving the ecosystem states of the Coorong under the Max USED Flows conditions. Median water level was 0.30m AHD, falling between 0.24 m AHD and 0.37 m AHD for 50% of the time. The median water depth from two years ago (Depth Year2) under the Max USED Flows conditions along the length of the Coorong was 1.43 m, falling between 1.18 m and 1.69 m for 50% of the time. Median annual range was 1.03 m, although there were some outliers at greater tidal ranges (maximum = 1.94 m).

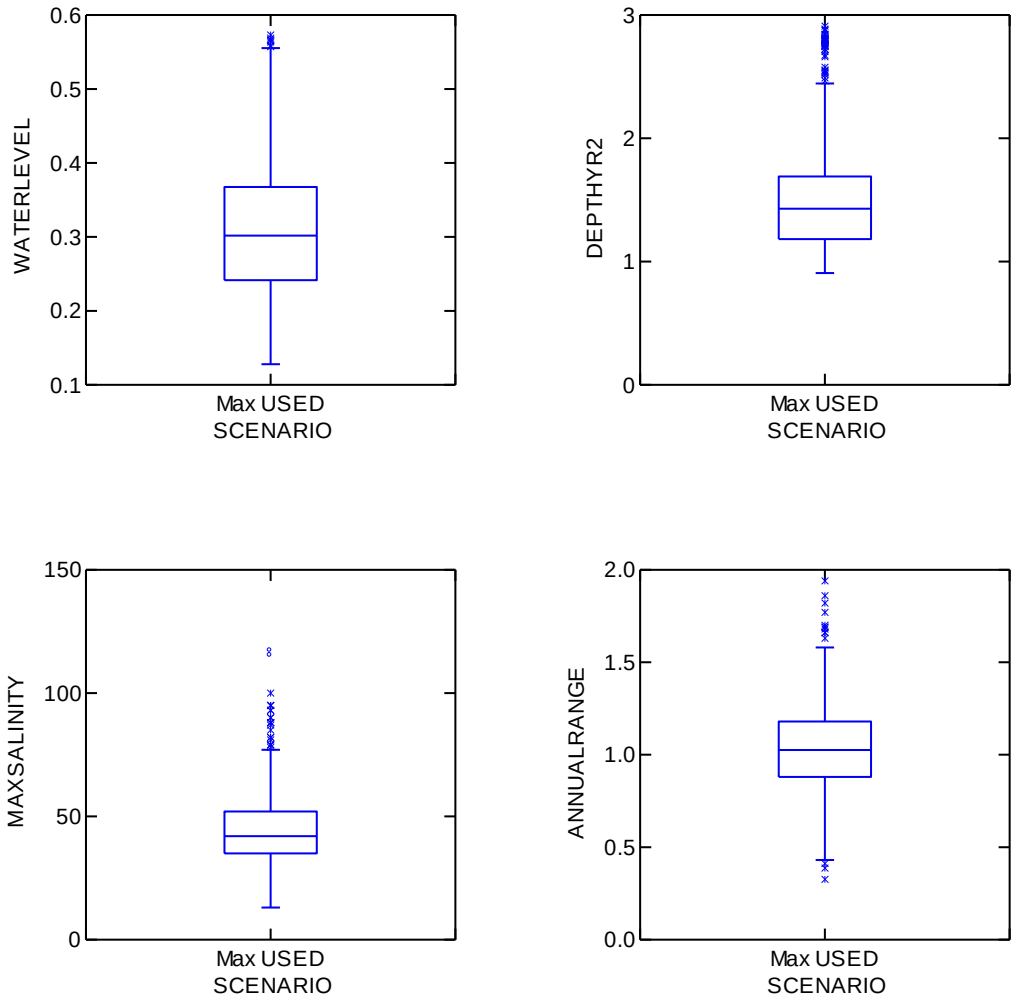

Figure 2.77. Boxplots showing the distribution of values for each of the variables driving the ecosystem states of the Coorong for the Max USED Flows scenario.

Note for the Max USED Flows Scenario, data is for the years 1971-2006, and the maximum salinity is presented only for sites 4-12, as a relationship could not be calculated for the predicted sites 1-3.

The water level threshold for the marine basin model (-0.19 m AHD) was exceeded for an average of 9.0 years at a return time of 2.0 years for the Murray Mouth region. Noonameena and Parnka Point always exceeded the threshold, and the other North Lagoon sites exceeded

the threshold for an average of 8.8 years, also with a return interval of 2.0 years. Sites in the South Lagoon had an average exceedance time of 5.6 years, recurring every 2.0 years.

The water level threshold for the hypersaline basin model (-0.37 m AHD) was exceeded for an average of 1.3 years with a return time of 4.9 years in the Murray Mouth region. For North Lagoon sites, the average exceedance was longer at 2.6 years, and the return time was 3.5 years. The South Lagoon sites exceeded the threshold for a single year at an average interval of 8.3 years.

The threshold for water levels in the previous year for the marine basin model was always exceeded along the length of the Coorong. The threshold for water level in the previous year for the hypersaline basin model was never exceeded at Barkers Knoll. The other Murray Mouth sites exceeded the threshold for an average of 1.3 years, at a return interval of 4.9 years. In the North Lagoon, sites exceeded the threshold for an average of 2.6 years, recurring every 3.4 years. South Lagoon sites exceeded the threshold for a single year at a return interval of 7.6 years. Maximum salinity under Max USED Flows conditions was greater than 100 g L^{-1} in 1% of site-years.

The depth threshold (for the depth two years' previous) was exceeded for all years at the Monument Road and Barkers Knoll sites, with the exception of 1999 for the Monument Road site. No other site ever exceeded the depth threshold.

The threshold for annual range in water level was exceeded by all site-years with the exception of 2003 and 2004 for the Monument Road site and 2004 for the Mundoo Channel site.

The maximum salinity threshold was not exceeded for any site in any year.

For the Max USED Flows scenario, water depth (from two years ago) was the most evenly dispersed variable (Gini = 0.03). Annual range and water levels were both moderately-well distributed (Gini = 0.11 and 0.27, respectively).

For the Max USED Flows scenario, six out of the eight states were observed during the 36-year by 12 site (432 site-years) model run. Under the Max USED Flows conditions, the two most common states along the length of the Coorong were the Estuarine/Marine state (56%) and the Average Hypersaline state (20%; Figure 2.78). Together, these two accounted for 76% of the site-years modelled. The third most common state was the Marine state (16%) and the less common states included the Unhealthy Hypersaline state (3%), Unhealthy Marine state (2%) and the Healthy Hypersaline state (2%). The two most-degraded states, the Degraded Marine and the Degraded Hypersaline states, did not appear in the any site-years over the 36-year model run under the Max USED Flows conditions.

Transitions occurred between states 13% of the time (Figure 2.79). This means that the proportion of site-years where the state did not change (i.e. the state inertia) in the system was 87%. Seven of the twelve sites across the 114 years showed sequences in which states appeared significantly different from a random distribution (Z_u ranged between 2.12 and 4.06 for seven sites). When transitions did occur, sites changed within the same basin: they shifted from a more degraded state 5% of the time and to a less-degraded state 8% of the time. There were no transitions between basins (i.e. went from a marine state to a hypersaline state or vice versa) for any of the 432 site-years.

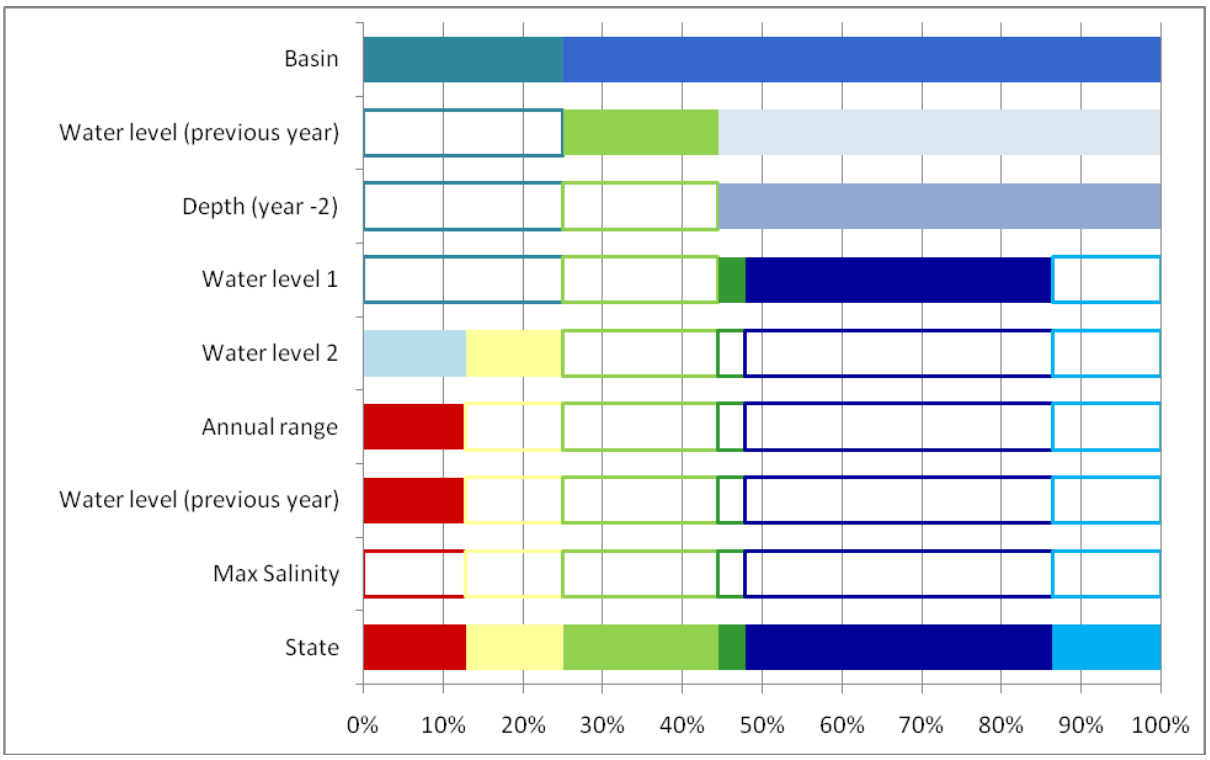

Figure 2.78. Proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Max USED Flows scenario

See Figure 2.2 for further explanation of the figure.

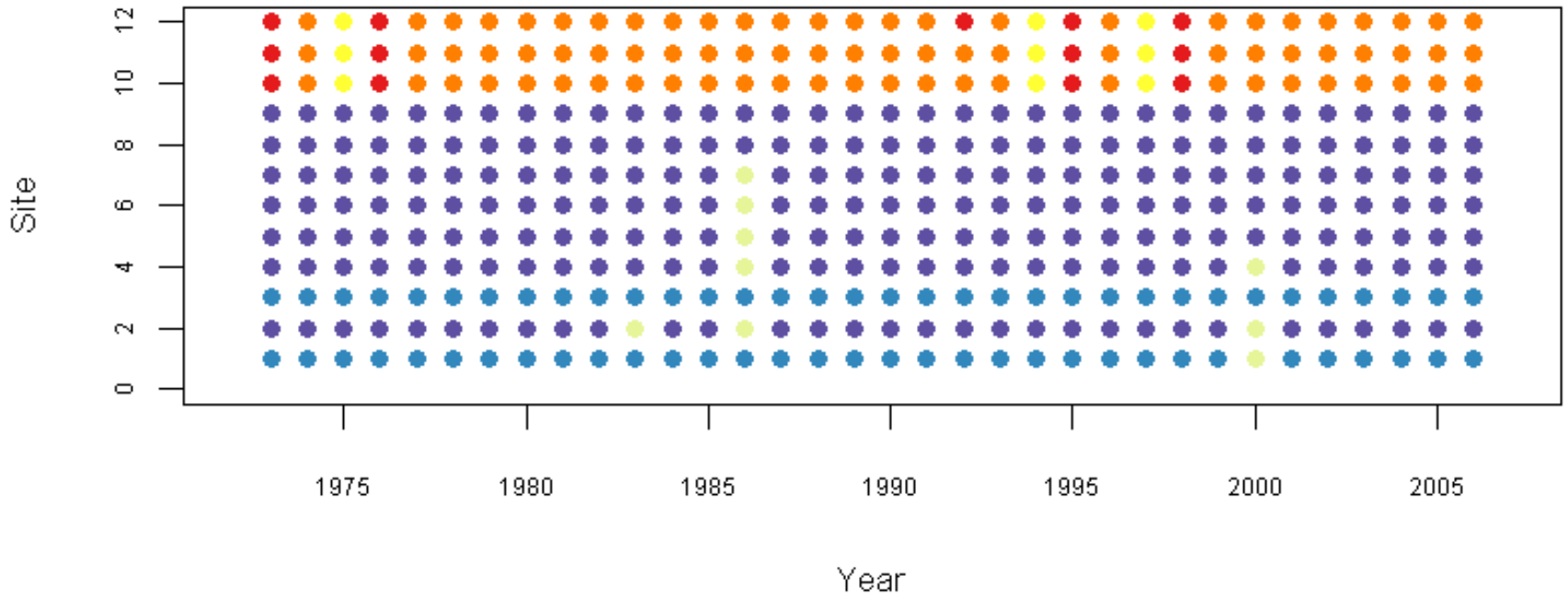

Figure 2.79. Distribution of states for each site-year under the Max USED Flows scenario

See Figure 2.3 for further explanation of the figure.

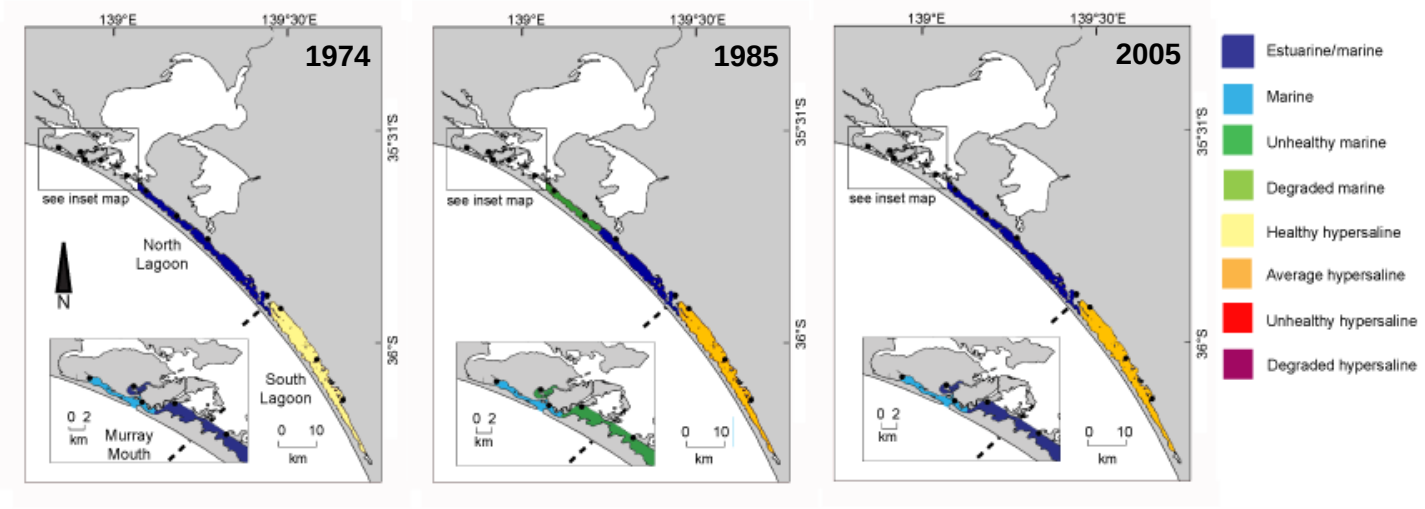

Figure 2.80. Mapping the distribution of states for seminal years under the Max USED Flows scenario

See Figure 2.4 for further explanation of the figure. Note that fewer years are presented for the Max USED Flows scenario due to the shorter model run.

3. References

Lester, R. E. and Fairweather, P. G. (2009) Predicting the future ecological condition of the Coorong. The effect of management actions & climate change scenarios. Flinders University, Adelaide.

4. Appendices

Appendix A – How to read outputs presented

This appendix provides an introduction to each of the figures that have been presented in this report, and a summary of how to read each. They are presented in the order in which they appear in the report.

A.1 Boxplots

Boxplot figures were presented for each set of scenarios to represent the hydrodynamic model output for the variables that drive ecosystem states in the Coorong.

In a boxplot, the interquartile range is represented by a box (Figure A.1). That is, the limits of the box show the range for which the variable in question falls for 50% of the time. The whiskers on the box show an interval which is 1.5 times the interquartile range, and more extreme (outliers) values are represented by points. Finally, the median is represented by a line through the box at the relevant height.

Boxplots are presented that compare each group of scenarios, in line with the research questions.

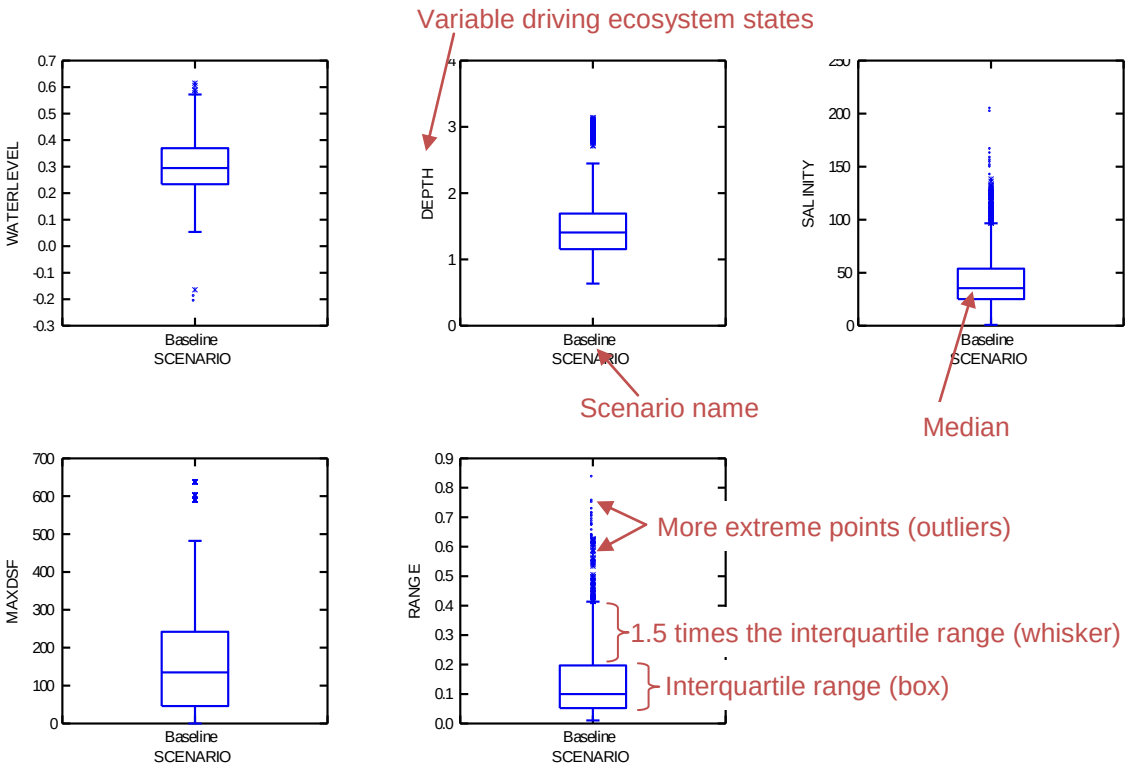

Figure A.1. Example of boxplots from the Baseline scenario, highlighting points to note

a) Water levels (m AHD), b) water depths from the previous year (m), c) salinities (g L^{-1}), d) maximum number of days since flow (MaxDSF, days) and e) tidal range (m)

A.2 Proportion of site-years in each ecosystem state with threshold exceedances

The next figure, read from the top, shows a cumulative break-down of the proportion of site-years that exceed each threshold, until the bottom bar shows the proportion of site-years seen in each ecosystem state (Figure A.2). The figure is based on the ecosystem state decision tree (Figure 3.1 in Lester and Fairweather, 2009 and each of the thresholds in the tree is represented. The first splitting variable, the average daily tidal range is the first (top) bar in the figure. The proportion of site-years that fall below the threshold are shown on the left-hand side of the bar (dark green), and those that exceed the threshold are on the right (dark orange). The second bar builds on the first, using the next splitting variable in the decision tree; the maximum number of days without flow. This time, the bar is split into four, with the left-hand-most segment showing the proportion of site-years below both the days without flow and the tidal range threshold (shown in aqua). The next segment (shown in blue), indicates the proportion of site-years below the threshold for tidal range, but above the threshold for days without flow, thus these first two together add to the same proportion as the dark green bar above (i.e. below the tidal range threshold). This continues along the bar, with the pink segment representing the proportion of site-years above the tidal range threshold but below the days without flow threshold, and the yellow bar showing those site-years above both thresholds.

For the remaining splitting variables, the threshold is only relevant to a subset of the decision tree. For example, the depth threshold is only relevant to site-years that fell below both the tidal range and the days without flow thresholds. The solid colours indicate the subset of the site-years for which each threshold is relevant, with the remainder shown as unfilled outlines. Each bar builds on the divisions in the previous bars.

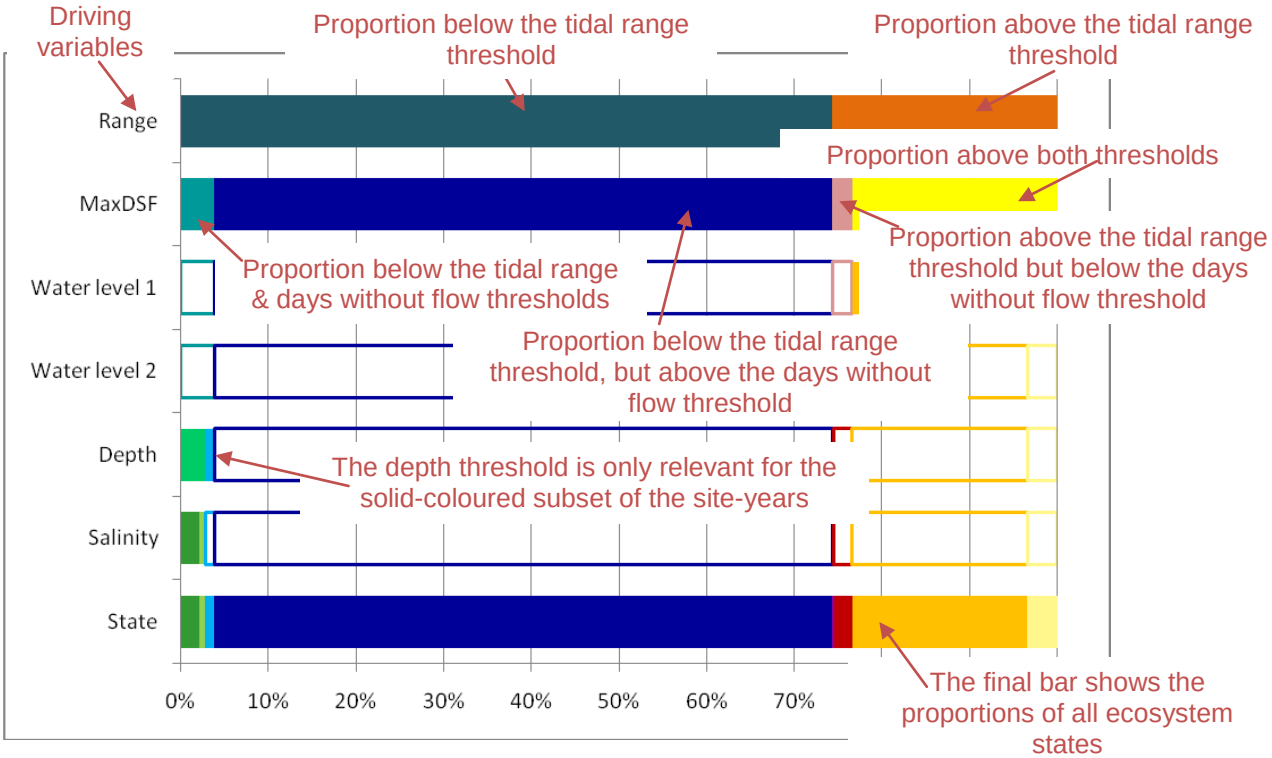

Figure A.2. Example of proportion of site-years in each ecosystem state and that exceed the thresholds for variables driving them for the Baseline scenario, highlighting points to note in red

Each of the upper six bars shows one threshold for a variable driving ecosystem states in the Coorong. The two solid blocks represent the proportion of site-years that fall below (on the left) and above (on the right) the threshold. Going from top to bottom, each bar builds on the previous until the bottom bar illustrates the distribution of ecosystem states for this scenario. The final bar shows the states with dark green representing the Degraded Marine state, light green is Unhealthy Marine, light blue is Marine, dark blue is Estuarine/Marine, purple is Degraded Hypersaline, red is Unhealthy Hypersaline, orange is Average Hypersaline and yellow is Healthy Hypersaline.

The final (bottom) bar shows the proportion of site-years in each ecosystem state, after dividing the total according to each splitting variable in the decision tree. Each colour represents one ecosystem state, according to the key given below the figure.

A.3 Distribution of ecosystem states in space and time

The distribution of ecosystem states for each site in each year is presented in Figure A.3. Sites are numbered from north to south, with the Monument Road site near Goolwa as Site 1 through to Salt Creek as Site 12 (see Figure 1.1). Each site-year is represented by a circle, the colour of which indicates the relevant ecosystem state. A key outlining the colour-coding for each of the eight ecosystem states is given below the figure.

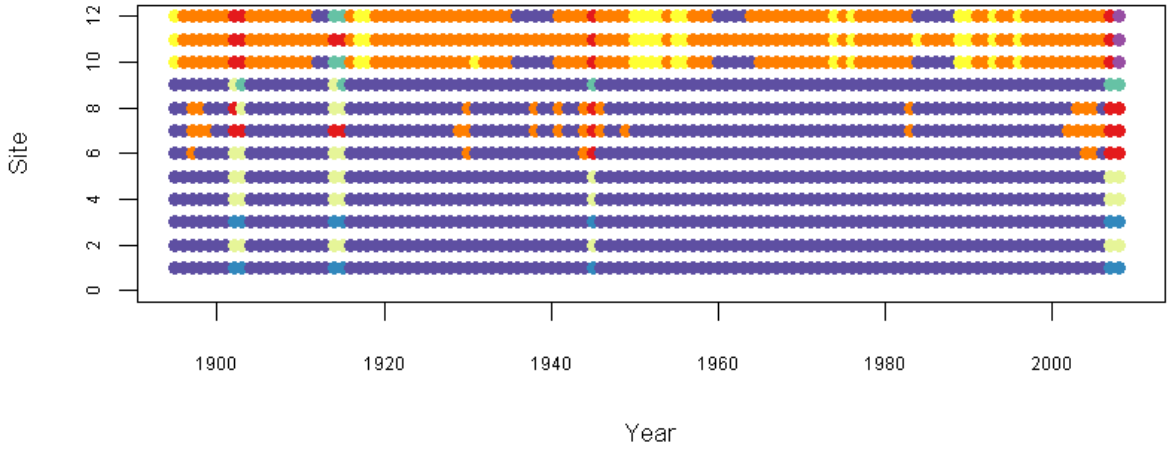

Figure A.3. Example of distribution of states for each site-year under the Baseline scenario

Each bar shows the distribution of the states within each site across the 114-year model run. Sites are numbered from north to south (e.g. Monument Road = Site 1 and Salt Creek = Site 12). The changes in the bar colours represent the transitions between states. For each bar, colours represent the following states: dark blue = Estuarine/Marine, light blue = Marine, light green = Unhealthy Marine, dark green = Degraded Marine, yellow = Healthy Hypersaline, orange =Average Hypersaline, red = Unhealthy Hypersaline and purple = Degraded Hypersaline.

A.4 Mapping the ecosystem states of the Coorong for seminal years

The distribution of ecosystem states in the Coorong is mapped for a number of seminal years in Figure A.4. For each year, the focal study sites of CLLAMMecology are colour-coded to show the relative spatial extent of each ecosystem state. A key outlining the colour-coding for each of the eight ecosystem states is given below the figure. The years were chosen to represent a mix of dry years, wet years, the year of Ramsar-listing and the last year of simulation. An inset map provides a magnified view of the Murray Mouth region for each panel.

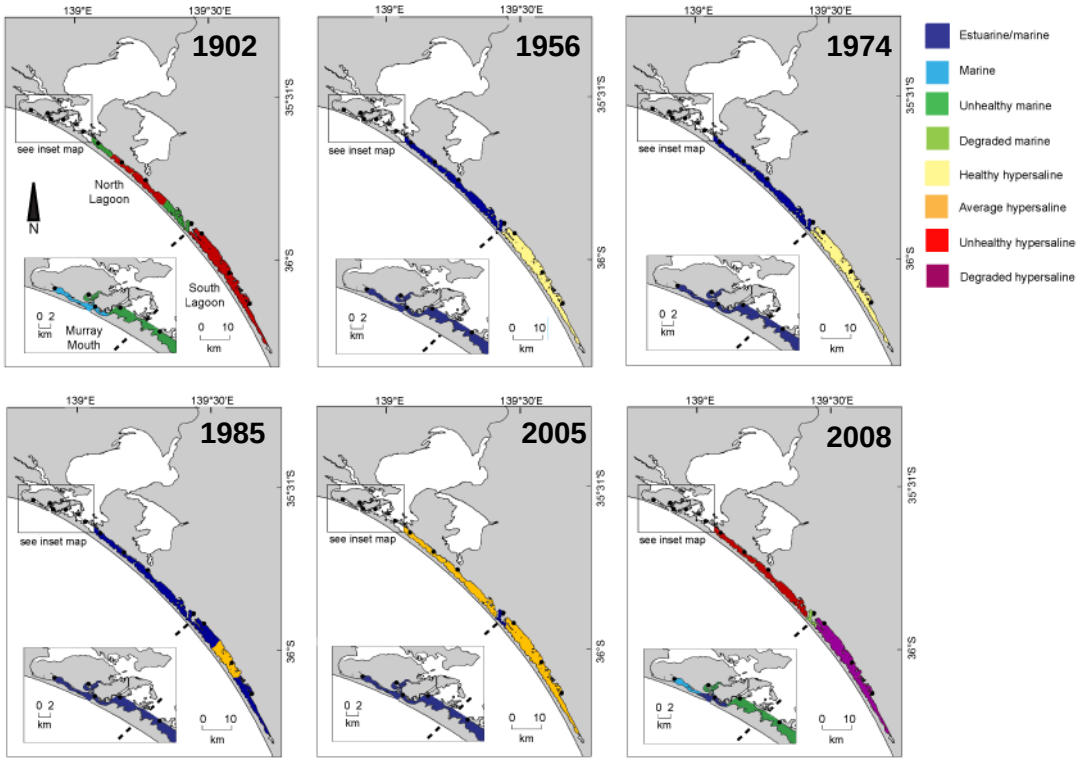

Figure A.4. Example of mapping the distribution of states for seminal years under the Baseline scenario

The dotted lines indicate boundaries between the three regions. Dots indicate the locations of the focal sites. Names of regions are only listed in panel a, but apply to all other panels as well. Each colour represents a different state (with corresponding states and colours shown in the legend).