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Coorong Investigations Project: *Ruppia* habitat changes in response to augmented South East Flows scenarios and a regulating structure

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

THE UNIVERSITY OF WESTERN AUSTRALIA

Executive Summary

Reduced water flow to the Coorong (South Australia) has previously led to marked increases in salinity and decline in the coverage of *Ruppia tuberosa*. The Department of Environment, Water and Natural Resources (DEWNR) *Coorong Investigations Project* has been examining the technical and implementation feasibility of two potential management measures that could maintain and enhance the ecology of the Coorong by improving the volume, security, level and quality of water in the Coorong South Lagoon (CSL). The management strategies under consideration include i) augmenting the (under construction) South-East Flow Restoration Project (SEFRP) to provide additional flows to the Coorong via Salt Creek, and ii) a flow regulating structure (or "weir") between the Coorong North Lagoon (CNL) and the CSL; this has been identified as a potential engineering measure that may improve conditions for *R. tuberosa*, and biota dependent upon *R. tuberosa*, by maintaining suitable water levels for it to complete its life-cycle. The aim of this assessment was to run a recently developed habitat model for the Coorong in order to assess the sensitivity of habitat extent to different Coorong Regulator installation and SEFRP (including augmentation) scenarios, as being considered under the DEWNR *Coorong Investigations Project*.

The model TUFLOW-FV was used to simulate the hydrodynamics of the Coorong (including the CNL and CSL), and was dynamically coupled with the biogeochemical / ecological model AED2, which was used to predict *R. tuberosa* habitat extent at high spatial resolution. For this specific application, several scenarios were tested including simulations assessing different SEFRP flows as planned under the SEFRP augmentation assessment, and the impact of flow-regulating structures located across Parnka Point or at The Needles, plus other options. In total 16 main simulations are reported on, with a focus on the potential changes to *R. tuberosa* habitat, in addition to the driving environmental factors.

Overall, analysis of the changes in several regions of the lagoon for each of the life-stages highlight that the interactions between the management measures and environmental conditions that may impact *R. tuberosa* becomes complicated, making it difficult to conclusively recommend a long-term management policy based on the simulations conducted, however various useful findings have been identified.

For the base-case simulation (capturing 2014-2015 conditions) the results highlighted year to year variability in the extent of suitable habitat, and this can vary substantially based on the combination of starting conditions (e.g., summer salinity), barrage flows, and Salt Creek inputs. Notable findings from the SEFRP and regulator scenario simulations include:

- Differences in habitat caused by inter-annual variability between the 2014 and 2015 conditions was generally more significant than the impact of the weir or SEFRP flow variations, at least for the range of water level and salinity impacts assessed; conclusions made as to the impact of the Salt Creek flows and the flow regulator should be considered in this context.

- Additional water entering the CSL via Salt Creek in all cases tended to improve the overall extent of habitat available, based on the conditions in the 2 years assessed. Timing and magnitude of flow changed the over area of suitable habitat with higher flows coming earlier being the most suitable.

- Increasing Salt Creek flows would tend to allow further build-up of nuisance *Ulva* biomass in the southern reaches within the Coorong, overlapping in areas of otherwise suitable flowering habitat, due to a decline in salinity.

- When Salt Creek flows were high (40-70GL), the presence of a flow regulation device such as a weir between the CNL and CSL (at either Parnka Pt or across The Needles, set at 0.6mAHD) was predicted to decrease the overall suitability for *R. tuberosa*. However, when a low Salt Creek flow scenario was run with a low weir (0.4mAHD), then a slight improvement occurred.

- The weir at 0.6mAHD was predicted to have limited effect on conditions for the adult stage of the plant (and in fact would improve plant habitat in the shallower Parnka Region), however, would decrease the overall suitability of conditions for flowering (and potentially seed germination to a lesser extent).

- Whilst the different weir positions tested did impact CSL salinity and water level, the changes that were evident were due to implementation options rather than position per se, and the changes did not have a significant effect on the overall amount of suitable habitat. Whilst some habitat changes between The Needles and Parnka Pt emerged when the weirs were positioned differently, they were offset by spatial differences in the extent of the decline, such that there was limited overall difference. Also, the particularly high salinities (>70g/L) that occurred in the Needles to Parnka region when a weir was located at The Needles occurred mostly after the plant would have been expected to complete its lifecycle.

- Simulations run with a lower sill (at 0.4mAHD), or earlier culvert closure time (Aug) also led to a changes in the area for flowering, with 0.4m better than 0.6m, and Aug worse that Sept; these results suggest that alternate weir configurations and timings that wouldn't limit flowering would be able to be identified, and the timing of water inputs is important.

The results highlight that the interactions between the management measures and environmental conditions that impact upon *R. tuberosa* habitat suitability becomes complicated when looking over the various life-cycle stages and regions of the Coorong, making it difficult to conclusively recommend a long-term management policy from the present simulation set. As a further caveat for the present analysis, the study has simulated two growing seasons for each scenario. In some cases, the measures being assessed, if implemented, would have a long-term impact on the salinity and nutrient budgets across the lagoon. Depending on the variability in barrage flows and oceanographic conditions, the time frame for a management action to have its full effect and for a health bed to emerge may take many years and this long-term effect has not been captured in the assessments undertaken here. In addition, simulations also do not consider carry over effects associated with the status of the seed-bank, or other (non-environmental) stressors experienced by *R. tuberosa*.

The results do not all necessarily agree with the conventional wisdom which suggests that holding the water level higher for longer in the CSL will give *R. tuberosa* a greater chance to complete its life-cycle. This is primarily because the habitat model used here is based on the recent information coming out of the *Optimising Ruppia Habitat* project where it was identified the extent to which water depth would be a limitation on flowering success. It may be that the choice of sill heights for this assessment at 0.6 and 0.4 mAHD were too high, and further simulations could potentially find an optimum. Nonetheless, the results have indicated the weir may negatively impact the overall habitat suitability by limiting the available area where established plants can flower. In contrast, the ORH simulation with a small weir at 0.4 mAHD did see a benefit, suggesting that when the Salt Creek flows were low, and exhibit a different delivery regime, then management could seek to make a positive impact on flowering habitat.

To better address this uncertainty three areas for ongoing work are recommended:

- further simulations are recommended to find an optimum flow regulator physical configuration and operational regime that promotes all plant life-stages (at least for sexual reproduction), exploring a wider range of barrage and Salt Creek flows, and their timing;
- further assessment of the CSL biogeochemical dynamics;
- ongoing assessment of the ecological basis for the *R. tuberosa* HSI algorithms, including assumptions as to the requirements for successful flowering in particular.

CONTRIBUTORS

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Contents

Background

Reduced water flow to the Coorong (South Australia) has led to marked increases in salinity that have led to numerous undesirable ecological impacts, including a reduction in the extent of *Ruppia tuberosa*, hereafter *Ruppia* (Paton et al., 2015). The hydrodynamic-biogeochemical model TUFLOW-FV – AED2 was previously used under the Coorong, Lower Lakes and Murray Mouth (CLLMM) Recovery Project's *Optimising Ruppia Habitat Management Action* to simulate the high-resolution dynamics of hydrodynamics, water clarity (light and turbidity), nutrients and filamentous algae in the Coorong, in order to undertake a habitat assessment of *Ruppia* (Collier et al., 2017). The model predicted maps of high- and low-quality habitat allowing for an assessment of where conditions would be "suitable" under any given hydro-biogeochemical conditions by adopting a "Habitat Suitability Index" (HSI) approach. This assessment introduced extensions to previous *Ruppia* modelling approaches by resolving the various environmental sensitivities for different stages of the *Ruppia* life-cycle. The model was run for 2014, 2015 and 2016, and demonstrated that the hydrodynamic complexity of the system, and different requirements of each life phase, make it difficult to generalize about flow conditions that would lead to optimum overall habitat availability. In general, the results showed that the interaction of water level, salinity and filamentous algae were the main drivers that could lead to changes in the overall area and location of good quality *Ruppia* habitat.

The Department of Environment, Water and Natural Resources (DEWNR) *Coorong Investigations Project* is examining the technical and implementation feasibility of two potential management measures that could maintain and enhance the ecology of the Coorong by improving the volume, security, level and quality of water in the Coorong South Lagoon. The management strategies under consideration include augmenting the (under construction) South-East Flow Restoration Project (SEFRP) to provide additional flows to the Coorong via Salt Creek. Previous hydrologic studies undertaken by DEWNR have indicated that on average volumes from the drainage network into the Coorong increase by approximately 26 GL/yr from the current under construction SEFRP, and an additional 15 GL/yr on average from augmentation of SEFRP. These volumes are expected to decrease the salinity of lagoon water, particularly during the summer (BMT WBM, 2017).

In addition to the SEFRP Augmentation, the *Coorong Investigations Project* is investigating the potential for a flow regulating structure (or "weir") between the North and South Coorong; this has been identified as a potential engineering measure that may improve conditions for *Ruppia*, and biota dependent upon *Ruppia*, by maintaining suitable water levels for *Ruppia* to complete its life-cycle.

The specific benefit of different SEFRP flow and weir options require investigation, particularly in the context of the requirements of different life-stages of *Ruppia* (e.g. seed germination, adult growth or flowering), to ascertain the level of benefit, or otherwise, that may be expected. The aim of this report is therefore to present the results from the AED2 *Ruppia* habitat model for the Coorong, as applied to assess the sensitivity of habitat extent to different Coorong flow regulator and SEFRP (including augmentation) scenarios, as being considered under the DEWNR *Coorong Investigations Project*. This project complements a number of investigations related to improving the condition of *Ruppia* and the Coorong ecosystems more generally, and outputs of this report should be considered in combination with those investigations.

Model Approach & Scenarios

The model TUFLOW-FV was used to simulate the hydrodynamics, and this was coupled with the ecological model AED2 for simulation of nutrients, algae and habitat. TUFLOW-FV hydrodynamics has been validated for the system separately by BMT WBM (2017) and Collier et al. (2017). The model simulations run by Collier et al. (2017) also simulated turbidity (including particle resuspension and sediment redistribution), inorganic and organic nutrients, chlorophyll *a* (chl-a), and filamentous algae (*Ulva*); the validation of these components occurred by comparing model outputs against observed data for the period from 2014-2016 at multiple locations within the domain. These years were chosen based on recent data availability for validation (Mosley et al. 2017; Frahn and Gehrig, 2015), and also spanned a range of conditions including water levels that experienced a sharp decline resulting in poor *Ruppia* habitat, which a weir could be expected to improve.

For this specific application, the extent of the modelled domain is shown in Figure 1, and scenarios tested included simulations whereby structures regulating flow were located across Parnka Point or at The Needles, as depicted in Figure 2. In total 16 main simulations are reported on, as described next. Note that whilst the *Coorong Investigations Project* is investigating ecological outcomes for the Coorong South Lagoon (CSL), this assessment covers the entire Coorong in order to ensure there are no adverse impacts to the Coorong North Lagoon (CNL).

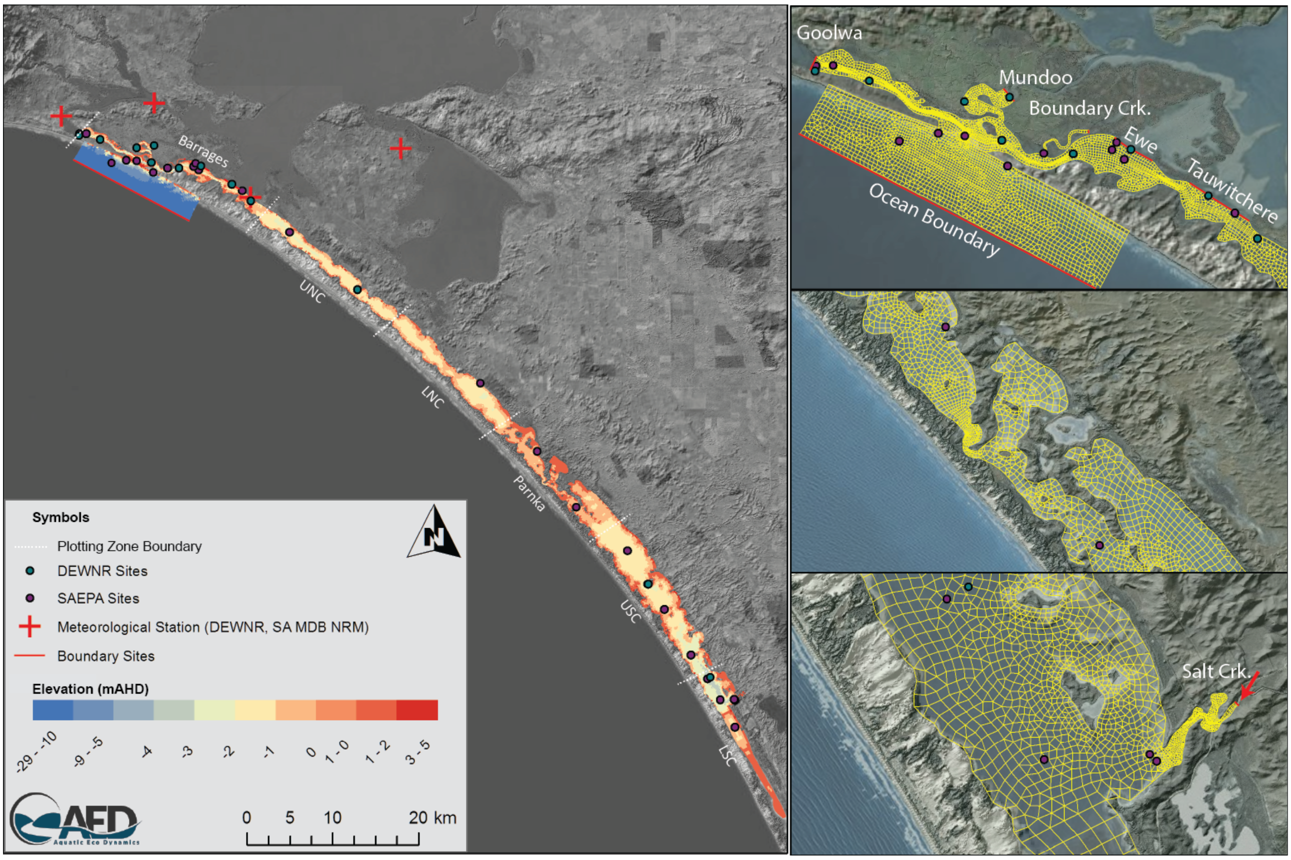

Figure 1: Outline of the simulated model domain, indicating the model mesh, analysis regions, and monitoring sites.

For this assessment, a base-case 3-year simulation was run using actual environmental conditions for the period from 2014-2016; this simulation was consistent with the validation simulations of the "*Optimising Ruppia Habitat*" project (Collier et al., 2017). A set of 18-month "what-if" scenarios were then run over the period Apr 2014 - Dec 2015, with each scenario therefore capturing two growing seasons, and capturing the potential for "carry-over" effects from one winter/spring to the next summer/autumn. These scenarios compared the sensitivity of habitat quality to: a) weir locations being situated at The Needles or Parnka Point (Figure 2), b) weir sill heights and culvert closure timing, and c) different volumes of freshwater inputs from Salt Creek (Figure 3), as summarised in Table 1.

It is important to note that there may be additional longer-term "carry-over" effects that were not possible to be considered in these scenarios. Furthermore, the assessment also does not consider the current (starting) condition of *Ruppia* populations within Coorong, nor additional factors that may limit its recovery (e.g. sulfidic sediments). In addition, it was not possible to investigate all factors that may influence habitat availability for *Ruppia* and that may change in response to management interventions (e.g. geomorphology, sediment characteristics).

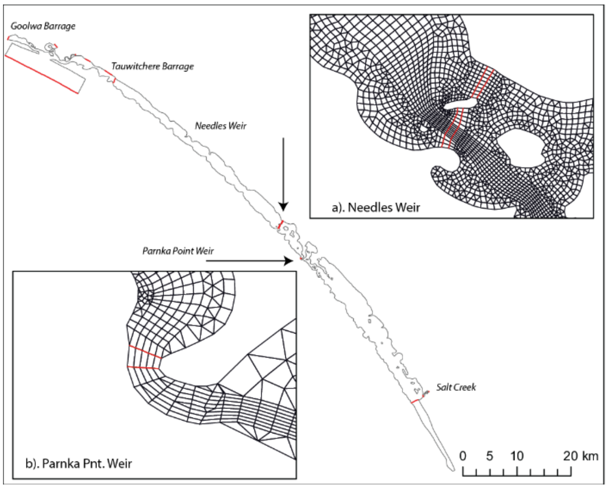

Figure 2: Weir locations and specifications.

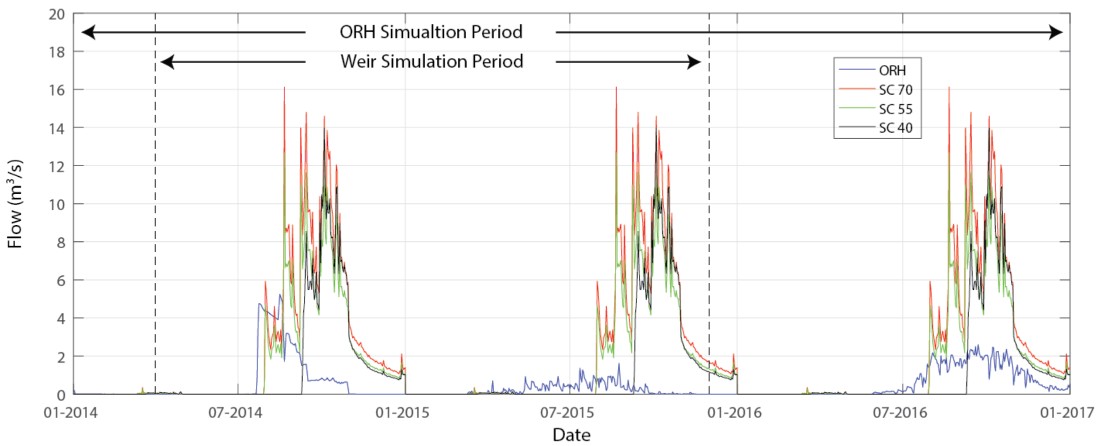

Figure 3: Salt Creek inflow for the actual (ORH) and SEFRP scenarios (40, 55 and 70GL per year).

Table 1: Details of model simulations undertaken, summarising key differences between them.

Simulation	Description	Barrage Flow (GL)	Annual Salt Creek Flow (GL) 2014/2015(/2016)	Weir Configuration (mAHD)	Initial Coorong State
2014 – 2016/ **0**	**ORH** : Base Case 2014-2016	2014: 919.3 2015: 754.9 2016: 5694.8	18.8 / 6.6 / 19.7	N/A	Interpolated 01/1/2014 data
2014 – 2015/ **1**	**NoWeir SC40** : 2014-2015 No-Weir simulation		40 / 40	N/A	Interpolated 31/4/2014 data
2	**Parnka SC40** : As 1, but Parnka Weir			0.6 culverts close 1-Sep	
3	**Needles SC40** : As 1, but Needles Weir				
4	**NoWeir SC70** : Base Case 2014-2015 No-Weir simulation		70 / 70	N/A	
5	**Parnka SC70** : As 4, but Parnka Weir			0.6 culverts close 1-Sep	
6	**Needles SC70** : As 4, but Needles Weir				
7	**NoWeir SC55** : Base Case 2014-2015 No-Weir simulation		55 / 55	N/A	
8	**Parnka SC55** : As 7, but Parnka Weir			0.6 culverts close 1-Sep	
9	**Needles SC55** : As 7, but Needles Weir				
10	**Needles SC70 Sill 0.4m**: As 6, but Needles Weir @ 0.4m		70 / 70	0.4 culverts close 1-Sep	Interpolated 31/4/2014 data
11	**Parnka SC40 HighSalinity**: As 2, but high initial salinity		40 / 40	0.6 culverts close 1-Sep	Increased x2 in the Sth Lagoon
12	**NoWeir SC40 HighSalinity**: As 1, but high initial salinity			N/A	
13	**Parnka SC40 Aug**: As 2, but culverts closed in Aug			0.6 culverts close 1-Aug	Interpolated 31/4/2014 data
14	**ORH Parnka:** As 0, but Parnka Weir @ 0.4m		18.8 / 6.6	0.4 culverts close 1-Sep	Interpolated 01/1/2014 data
15	**Parnka SC55J:** As 5, but with SC flow entering July.		55 / 55	0.6 culverts close 1-Sep	Interpolated 31/4/2014 data

Results

Results from the model include hydrodynamic, biogeochemical and habitat related measures, across the domain over the multi-year simulation period. To enable interpretation of the scenarios, a summary of the key results is presented by grouping scenarios relevant to specific questions that are related to the sensitivity of habitat to weir and/or SE flows:

- *Effect of weir location*
  - Scenarios 0, 7, 8 and 9
  - Figures 4-13
- *Effect of Salt Creek flows, with and without weir*
  - Scenarios 1,4,7 (no weir) and 2,5,8 (Parnka weir)
  - Figures 14-18
- *Effect of weir sill height*
  - Scenarios 4, 6, 10, 12
  - Figures 19-23
- *Effect of weir culvert closure time*
  - Scenarios 1, 2 , 13 and 15
  - Figures 24-28
- *Effect of initial salinity (starting conditions)*
  - Scenarios 2, 11 and 12
  - Figures 29-33

For each grouping indicated above, water level and salinity changes are compared, followed by variation in habitat suitability (HSI) and the total suitable area (A^{HSI}). Where relevant, the results of the light and nutrient conditions are also presented. Note that, in order to facilitate comparisons, some scenarios are repeated between groups. Detailed maps of each scenario's *Ruppia* habitat and environmental controls are shown in the Appendix (Figures A1-A14).

To assist in building an overall summary of the effect of the different scenarios on conditions within the Coorong, a summary section is provided at the end of the results showing width-averaged results of *Ruppia* HSI and Ulva biomass (Figure 34 & 35). Quantitative summaries of habitat area are also listed as tables in the Appendix (Tables A1-A4).

Effect of Weir Location: *Water level*

For the scenarios investigated, the modelling results suggest:

- The water level during closure of the culverts is increased by the weir by approximately 20-40cm
- The water level is maintained ~10cm (30-50cm total increase) higher in the CSL when the weir was at Parnka Pt compared to The Needles; note this is due to higher flow rate capacity of the culverts for water flow configured at the Needles relative to the Parnka culverts, and is not related directly to the position chosen.

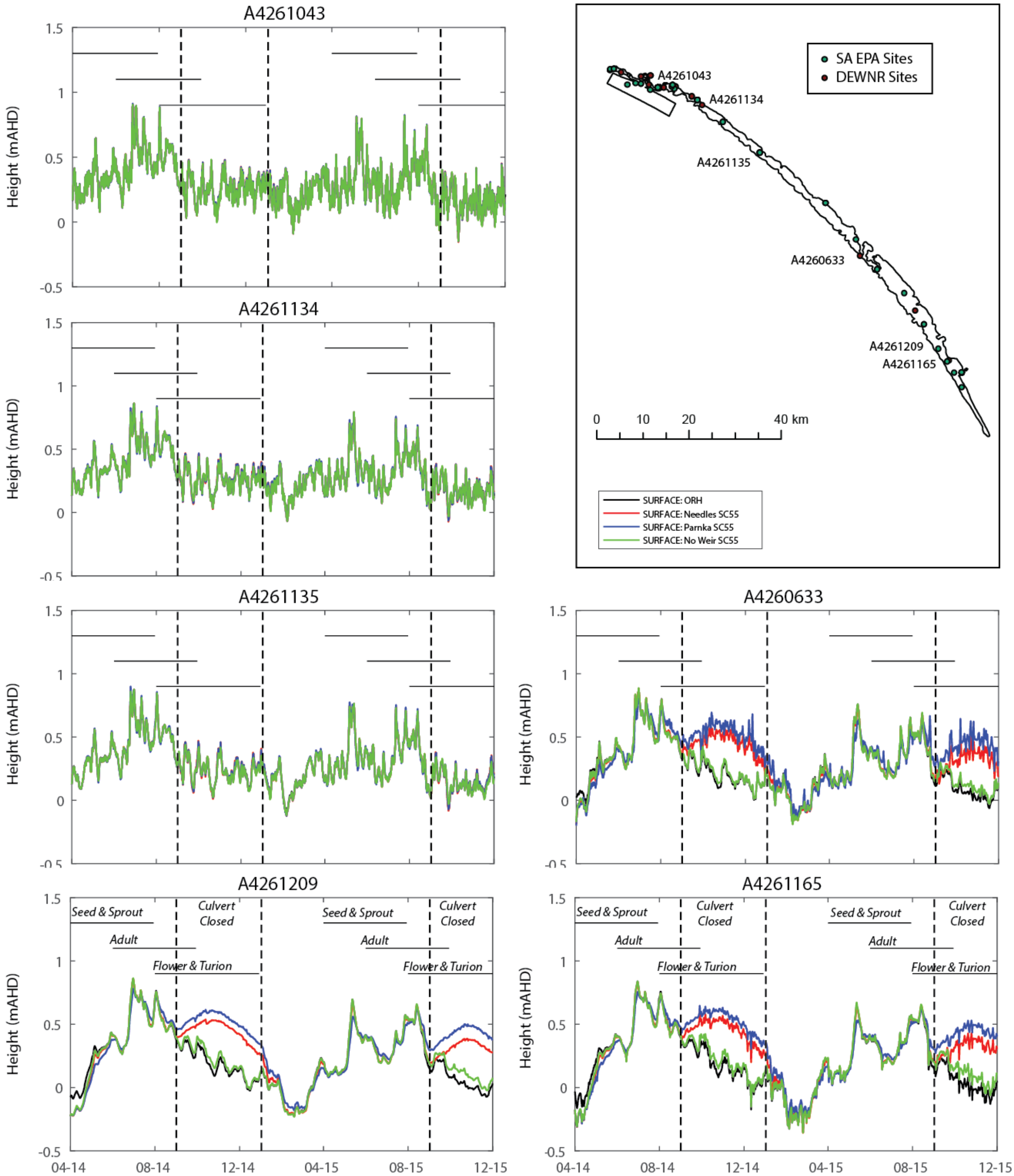

Figure 4: Comparison of predicted water levels at various monitoring stations within the Coorong for scenarios comparing the effect of weir location (scenarios 0,9,8,7). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD in scenarios 8 & 9, and Salt Creek flow was 55GL in scenarios 7, 8 & 9.

Effect of Weir Location: *Salinity*

For the scenarios investigated, the modelling results suggest:

- Salinity in the CSL is modestly increased by ~10ppt during closure of the weir culverts, but recovers to the base case within 1-2 months when the culverts are opened again.
- Salinity in the CSL is slightly lower with the weir at The Needles, compared to Parnka Pt.
- The CNL has lower salinities with a weir in place, regardless of its location.

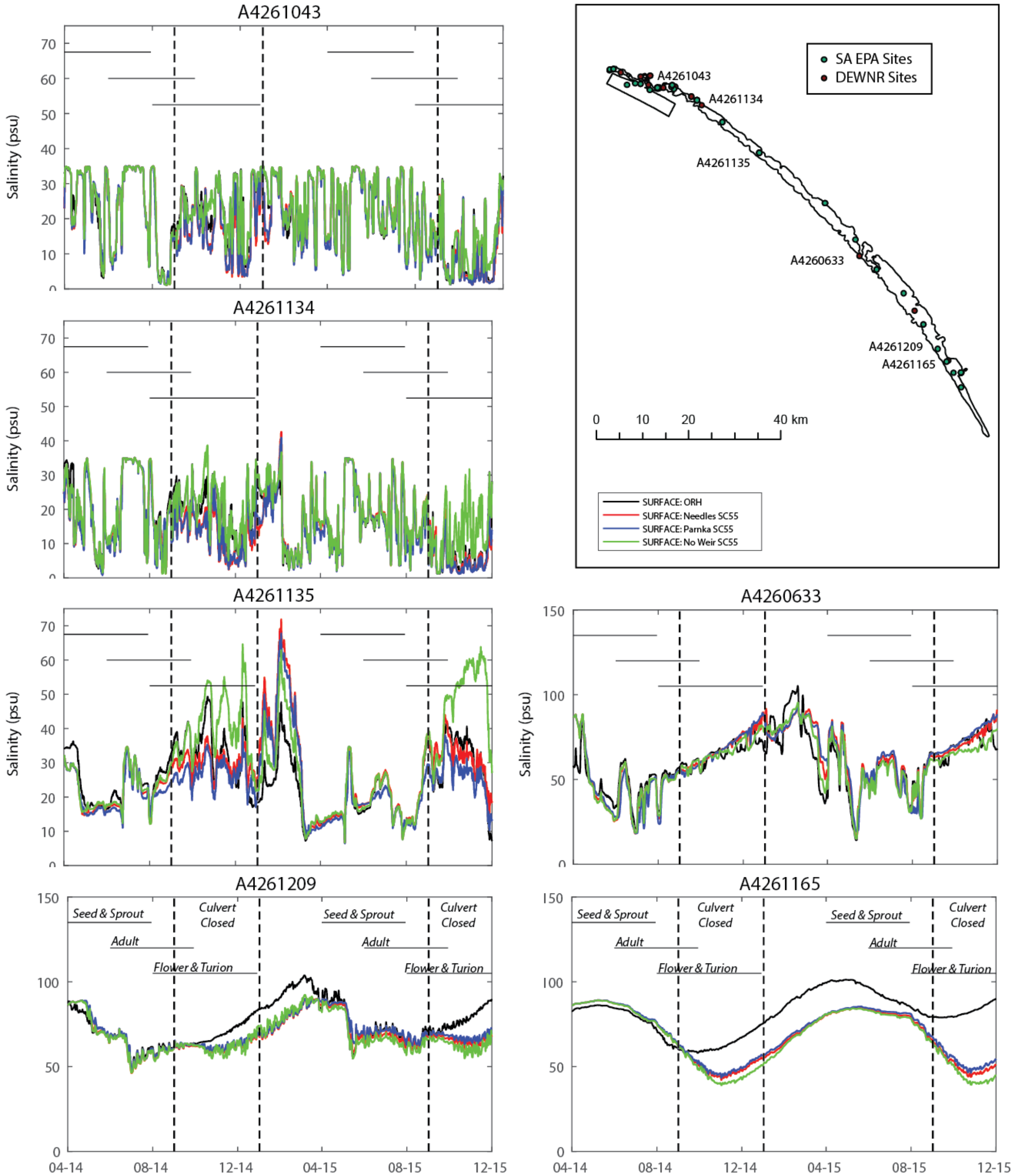

Figure 5: Comparison of predicted water levels at various monitoring stations within the Coorong for scenarios comparing the effect of weir location (scenarios 0,9,8,7). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD in scenarios 8 & 9, and Salt Creek flow was 55GL in scenarios 7, 8 & 9.

Effect of Weir Location: *Light*

For the scenarios investigated, the modelling results suggest:

- The mean light available to the benthos was variable in the scenarios, with reduction in water clarity under the scenarios compared to ORH, and a slight reduction with the weirs in place. The reduction, however, was small compared to the light tolerance of *Ruppia*, as adopted in the habitat model.
- Changes in water clarity brought about by the weir are not likely to play a role in shifting habitat quality.

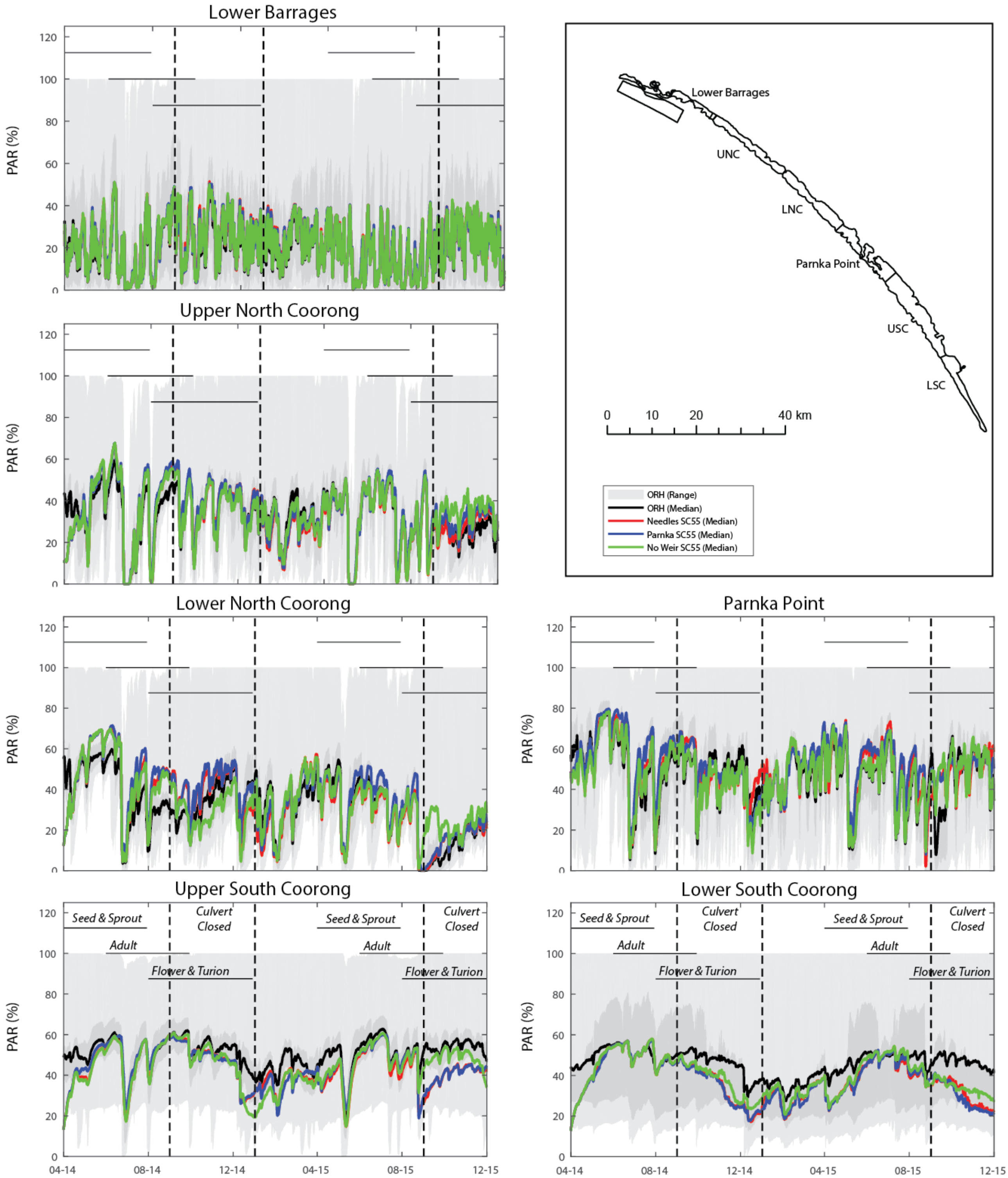

Figure 6: Comparison of predicted benthic light (% surface irradiance) at various monitoring stations within the Coorong for scenarios comparing the effect of weir location (scenarios 0,9,8,7). Weir sill height was 0.6mAHD in scenarios 8 & 9, and Salt Creek flow was 55GL in scenarios 7, 8 & 9.

Effect of Weir Location: *Nitrogen*

For the scenarios investigated, the modelling results suggest:

- Presence of a weir had limited effect on TN in the CSL, but did tend to increase the nitrogen level in the PR lower CNL, particularly in the 2nd growing season.

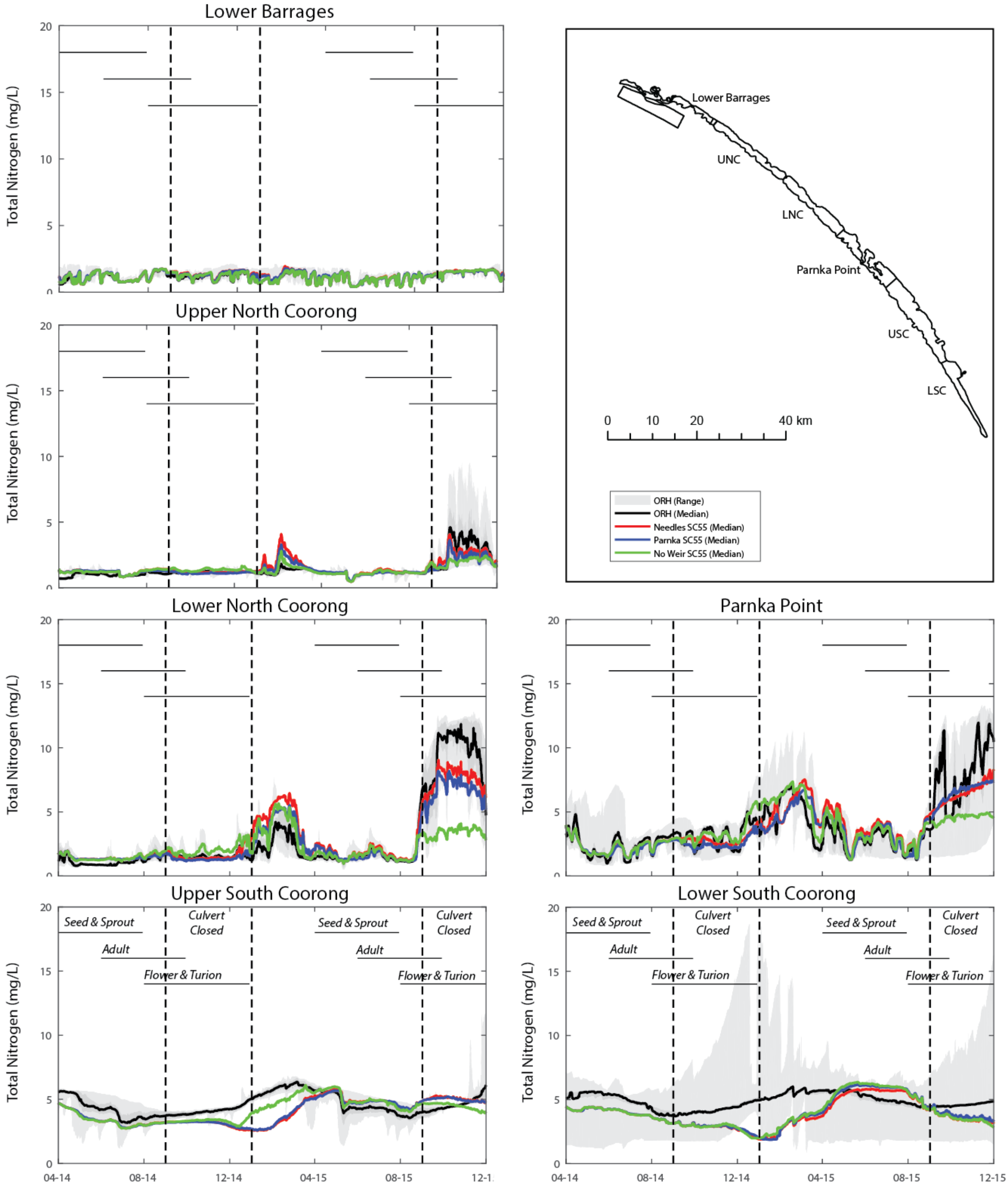

Figure 7: Comparison of predicted nitrogen at various monitoring stations within the Coorong for scenarios comparing the effect of weir location (scenarios 0,9,8,7). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD in scenarios 8 & 9, and Salt Creek flow was 55GL in scenarios 7, 8 & 9.

Effect of Weir Location: *Ruppia Habitat Area*

For the scenarios investigated, the modelling results suggest:

- The total area of suitable habitat under Scenario 1 is 3,780 Ha (1,100 in the CNL, 1,400 in the PR and 1,200 in the CSL) in 2014, which was higher than the ORH base case of 3,690 (see Appendix for data tables).
- The total area of habitat was predicted to reduce with either of the weirs in place. This was a decline of 10-22% for the sexual life-cycle, and a decline of up to 64% for the asexual life-cycle. See maps over page.
- The declines were predominantly due to a 11-14% decline in habitat suitable for flowering and a large decline in the suitability of turion production for sexual and asexual, respectively. Flowering habitat was partly impacted by excess nuisance algal production in the lower region of the CNL, but was predominantly impacted by the water level height regime reducing the otherwise good quality habitat by limiting the likelihood for flowers to reach the surface.
- Seed germination was also negatively impacted (2-15%) by the weir, with a larger impact when it was situated at Parnka Pt.

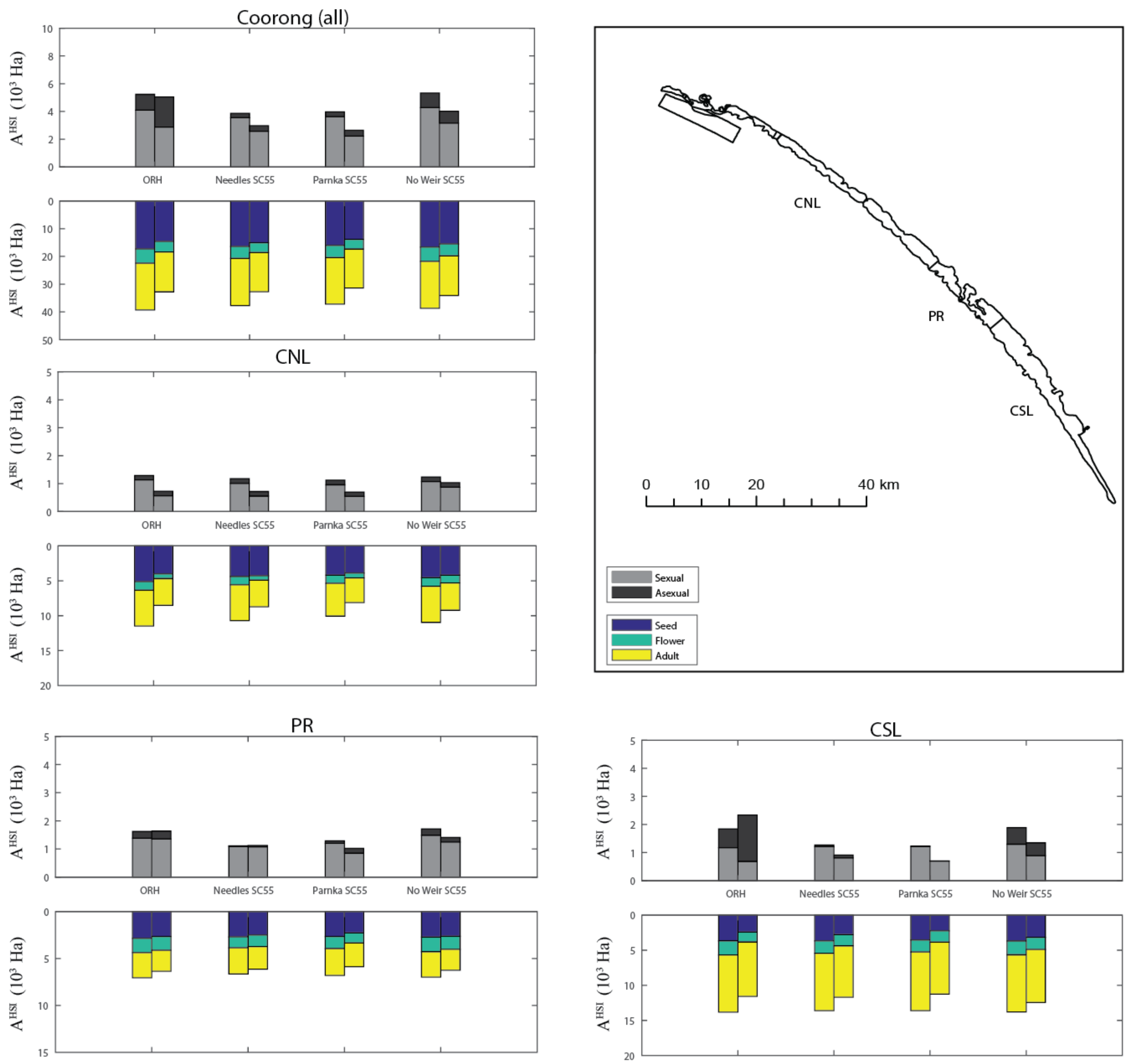

Figure 8: Comparison of the predicted suitable *Ruppia* habitat area, A^{HSI}, within 3 regions of the Coorong and for the total domain, for scenarios comparing the effect of weir presence and location (scenarios 0,9,8,7). Grey and black results indicate the overall suitable habitat where *Ruppia* would be likely to complete its sexual and asexual life-cycle, respectively, and the blue, green and yellow columns indicate the magnitude of the three most important life-stages. The left and right columns for each scenario indicate the 2014 and 2015 results, respectively. Note for these simulations the weir sill height was 0.6mAHD at Parnka Point (scenarios 8&9), and Salt Creek flow was 55GL in scenarios 7, 8 & 9.

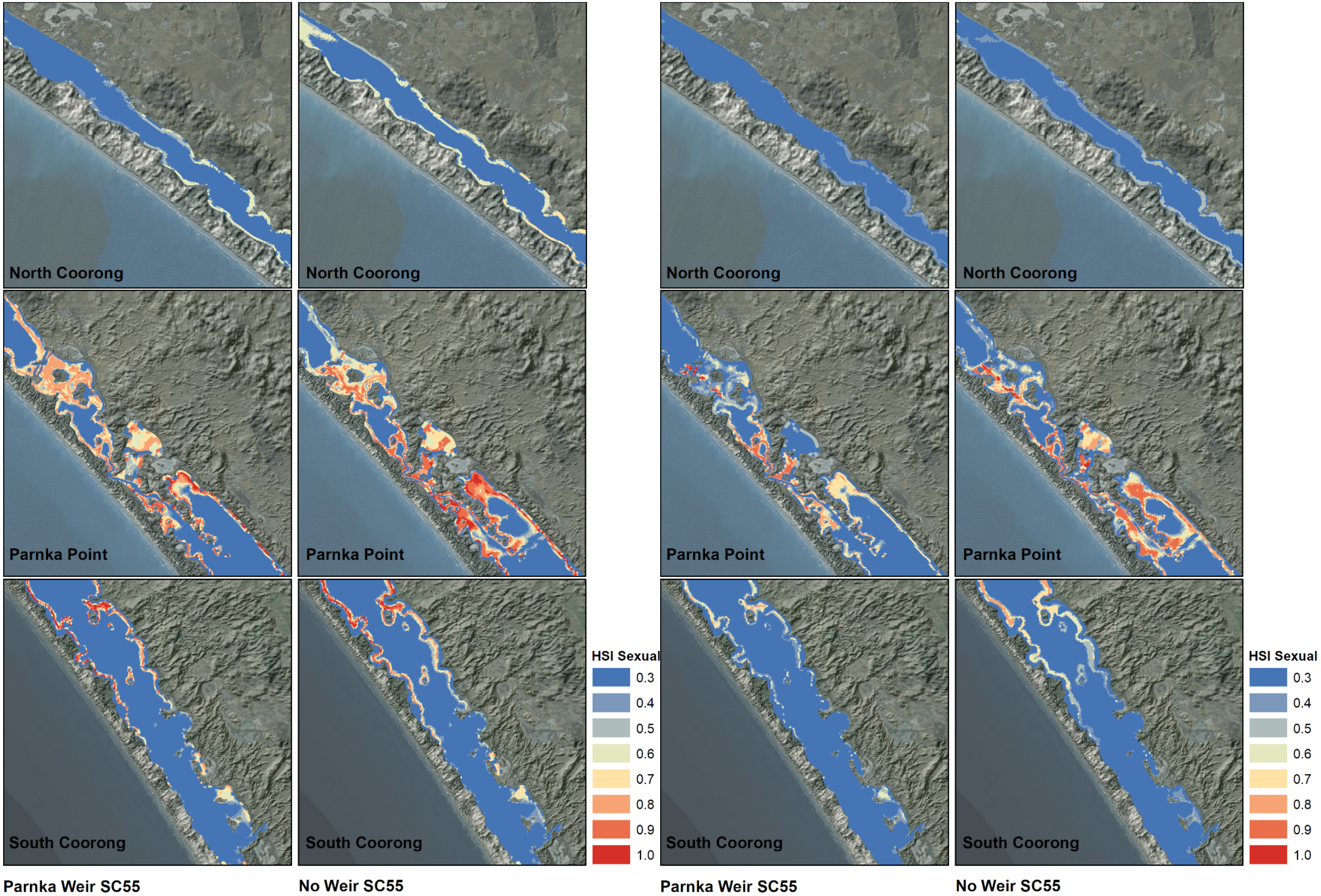

Figure 10: Comparison of Sexual life-cycle HSI for 2014 (left) and 2015 (right) showing conditions with and without a weir (scenario 8 & 7).

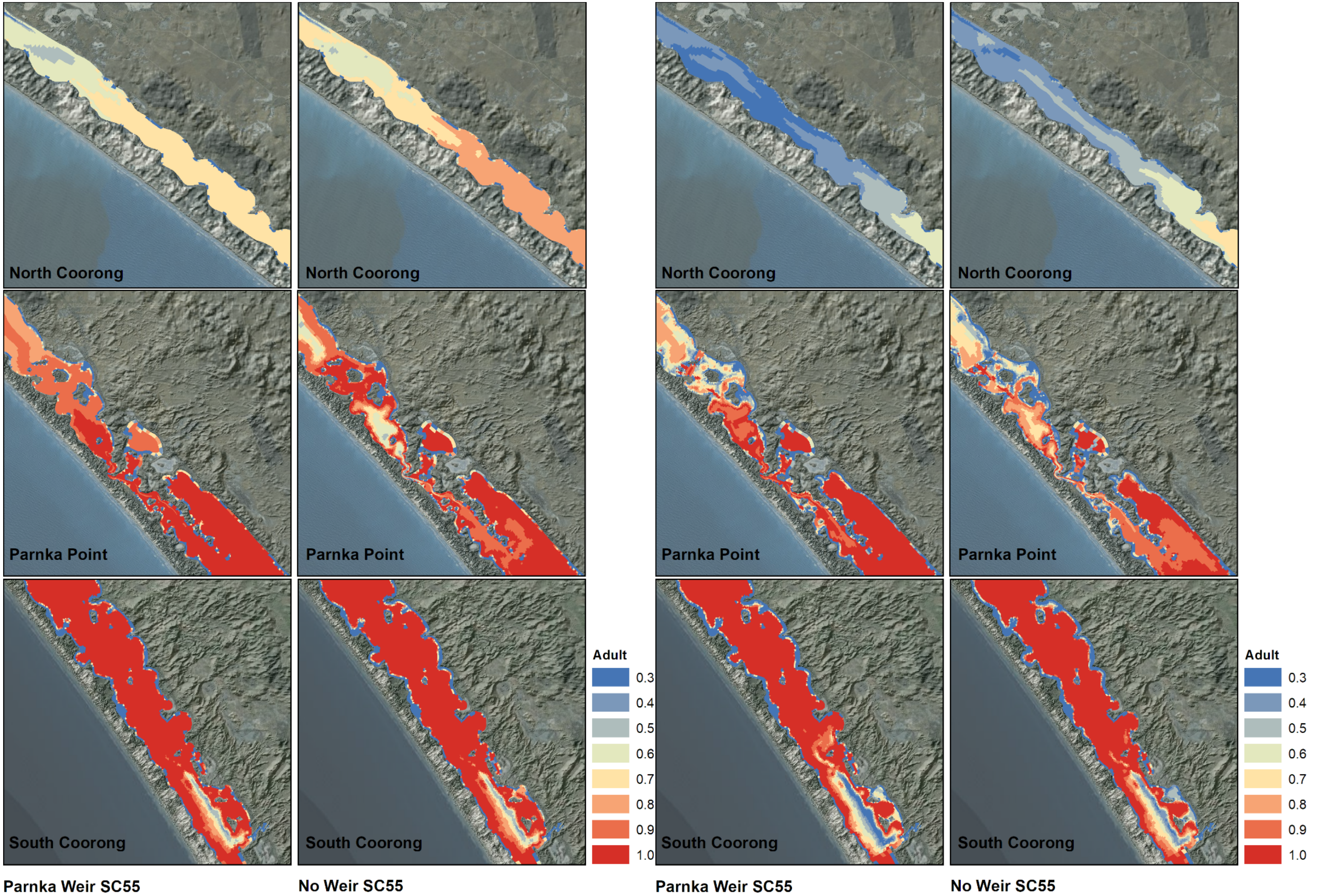

Figure 10: Comparison of Adult HSI for 2014 (left) and 2015 (right) showing conditions with and without a weir (scenario 8 & 7).

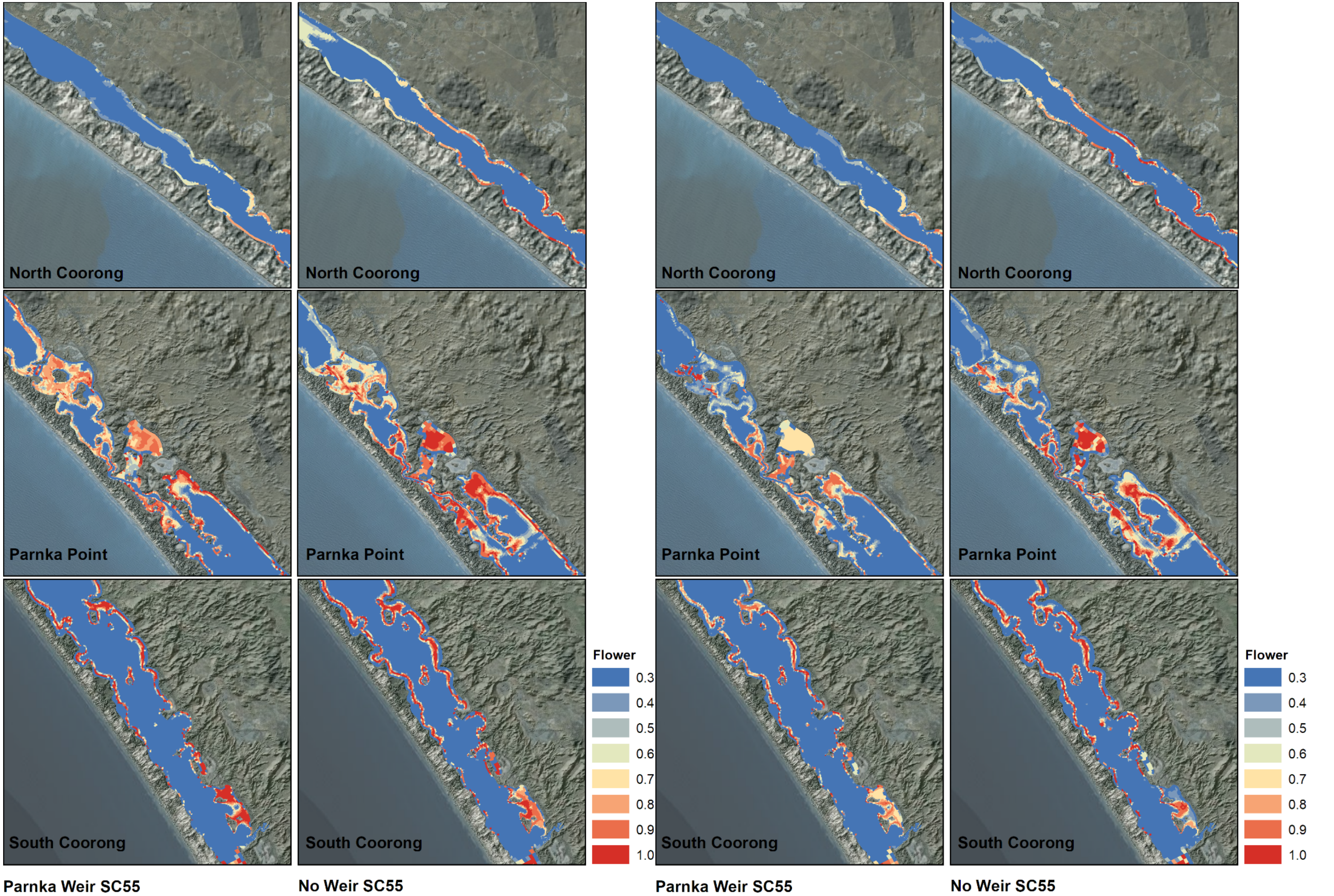

Figure 11: Comparison of Flower HSI for 2014 (left) and 2015 (right) showing conditions with and without a weir (scenario 8 & 7).

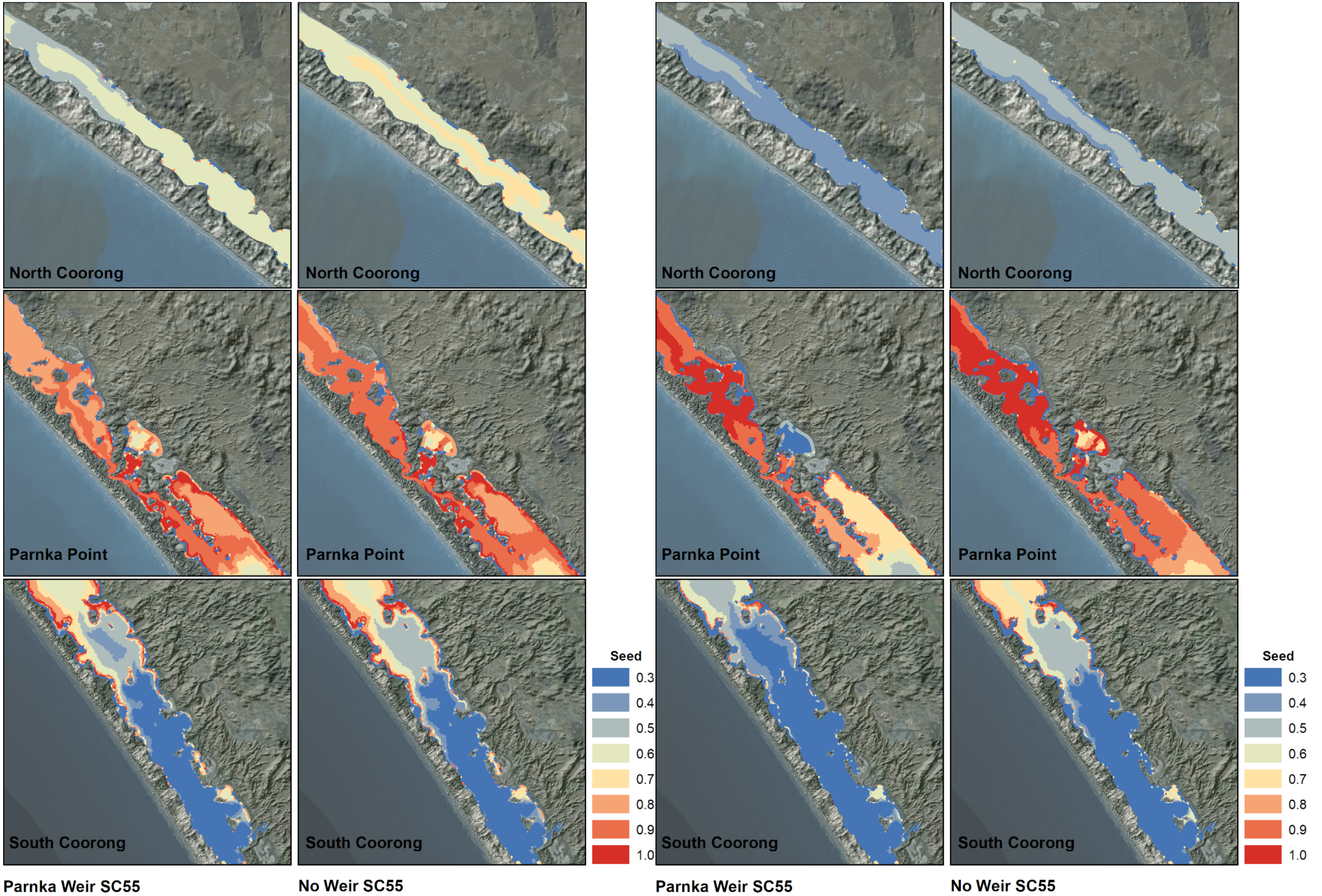

Figure 12: Comparison of Seed HSI for 2014 (left) and 2015 (right) showing conditions with and without a weir (scenario 8 & 7).

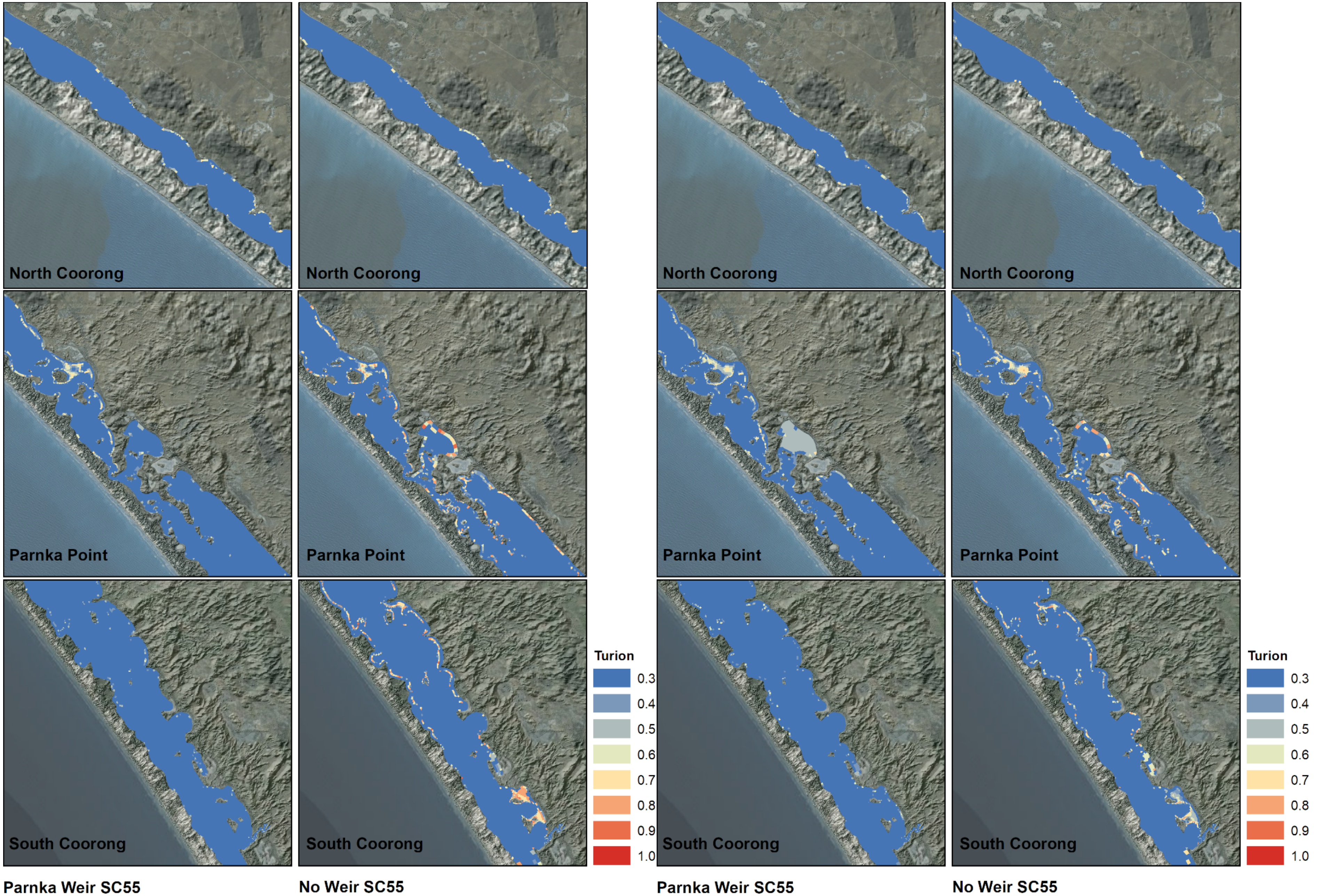

Figure 13: Comparison of Turion HSI for 2014 (left) and 2015 (right) showing conditions with and without a weir (scenario 8 & 7).

Effect of Salt Creek flows with and without weir: *Water level*

For the scenarios investigated, the modelling results suggest:

- Without a weir in place, the magnitude of SE flows has a minor effect on CSL water level.
- With the (Parnka) weir in place water levels increased by up to 40cm once the culverts closed, with an extra 10-12cm of rise for each 15GL increase in the SE flow amount.

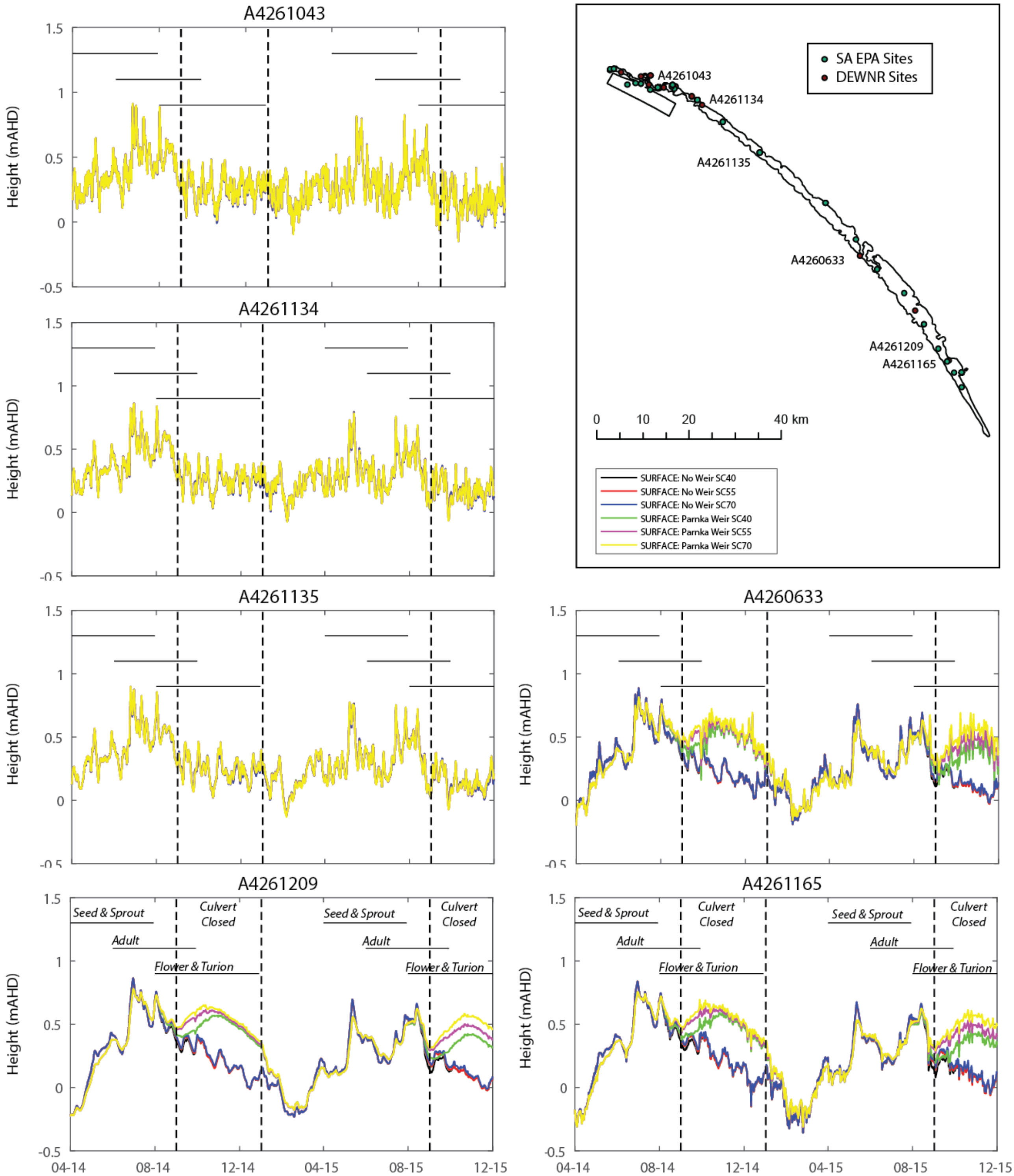

Figure 14: Comparison of predicted water levels at various monitoring stations within the Coorong for scenarios comparing the effect of Salt Creek inflows (scenarios 1,4,7 & 2,5,8). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD in scenarios 2, 5 & 8, and Salt Creek flow varied from 40-70GL.

Effect of Salt Creek flows with and without weir: *Salinity*

For the scenarios investigated, the modelling results suggest:

- Salinity in the CNL and CSL are both impacted by flows of 40, 55 and 70GL; the CSL experiences a decline, whereas the CNL experienced higher levels.
- On the CSL, the SC flows decreased the salinity, and with the regulator they were raised towards a similar level as unregulated flow conditions.
- Salinity in the CNL is notably higher with no weir in place; therefore higher SE flows push more salt toward the mouth, and create a higher export rate of material from the CSL.

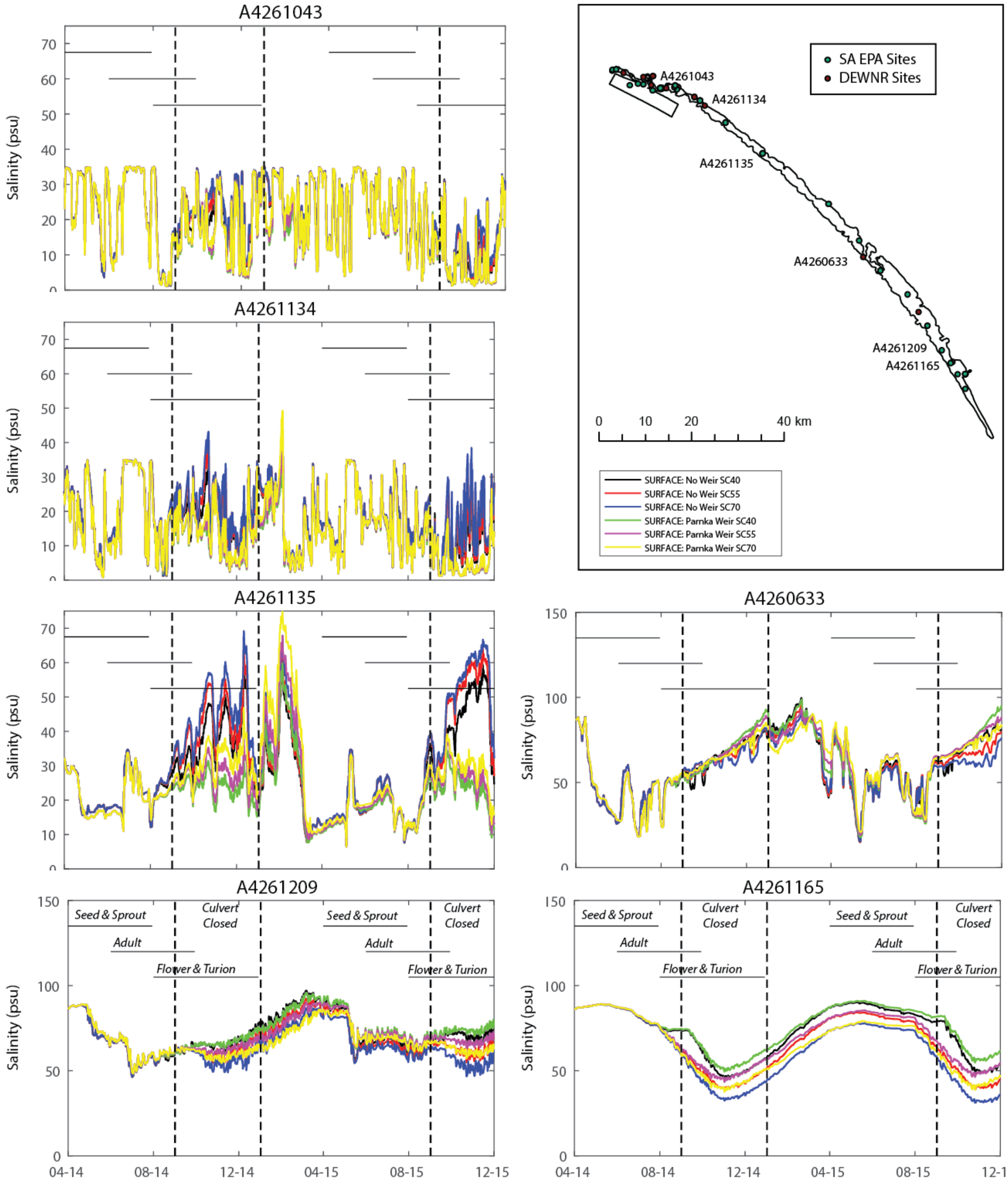

Figure 15: Comparison of predicted salinity at various monitoring stations within the Coorong for scenarios comparing the effect of Salt Creek inflows (scenarios 1,4,7 & 2,5,8). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD in scenarios 2, 5 & 8, and Salt Creek flow varied from 40-70GL.

Effect of Salt Creek flows with and without weir: *Light*

For the scenarios investigated, the modelling results suggest:

- No consistent trend in the light climate occurs due to the SC flow; both increases and decreases occurred since the 2014 and 2015 years showed different responses to Salt Creek inflow magnitude.

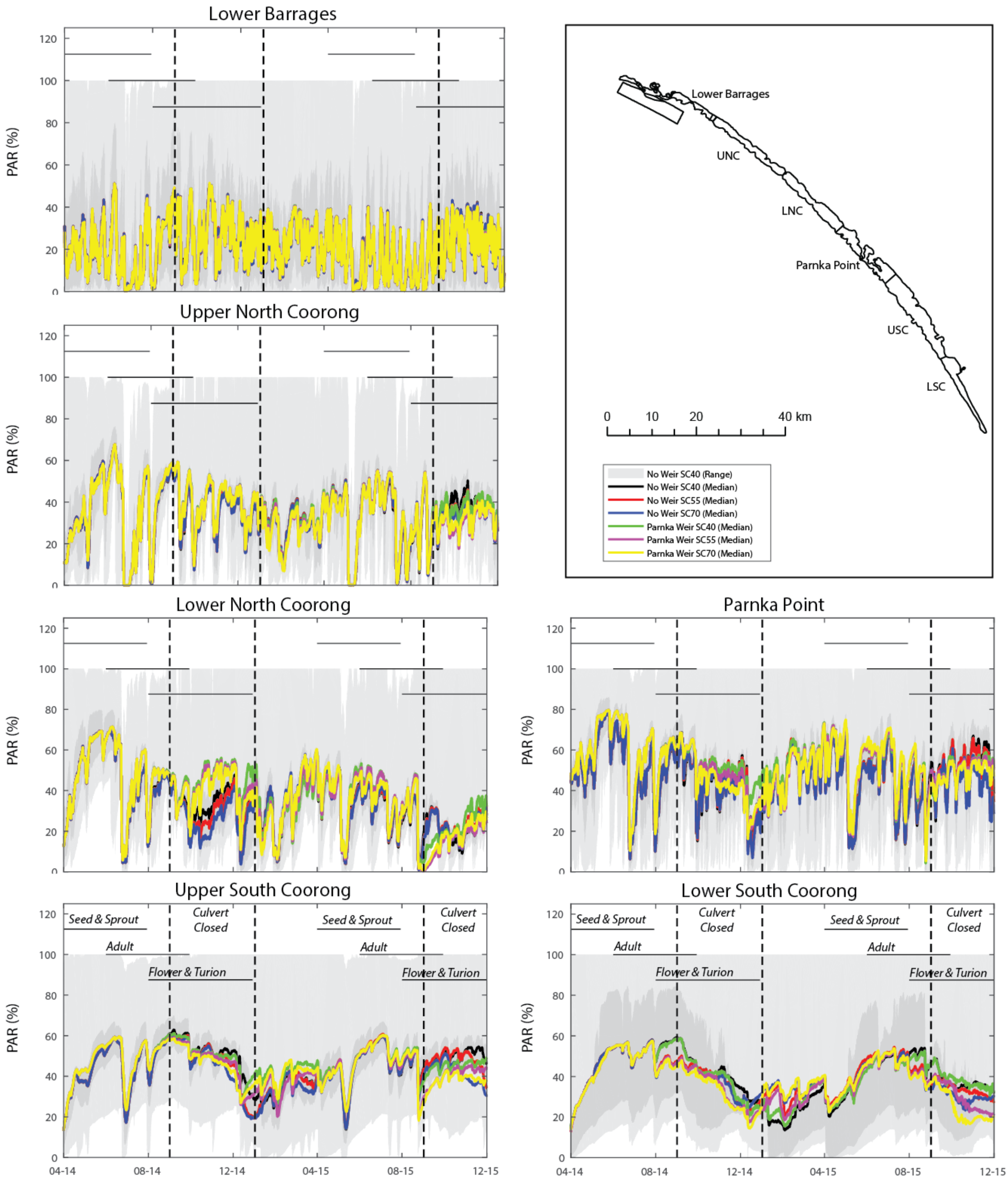

Figure 16: Comparison of predicted benthic light (% surface irradiance) for various regions within the Coorong for scenarios comparing the effect of Salt Creek inflows (scenarios 1,4,7 & 2,5,8). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD in scenarios 2, 5 & 8, and Salt Creek flow varied from 40-70GL.

Effect of Salt Creek flows with and without weir: *Nitrogen*

For the scenarios investigated, the modelling results suggest:

- Based on the assumptions for Salt Creek nutrient levels (~1.7mg/L), all scenarios that increase inputs from Salt Creek are predicted to dilute the nutrient levels of the CSL.
- Notably, the Salt Creek flow of 70GL had the largest dilution of TN and this was more significant with the weir present; the higher dilution with the weir up is not expected, given the salinity dilution is higher without the weir, and is thought to be related to the relative effect of dissolved nutrient flux and resuspension being lower with a deeper CSL. There is also an increase in the export of TN to the CNL with the weir, as indicated in the Lower North Coorong panel.

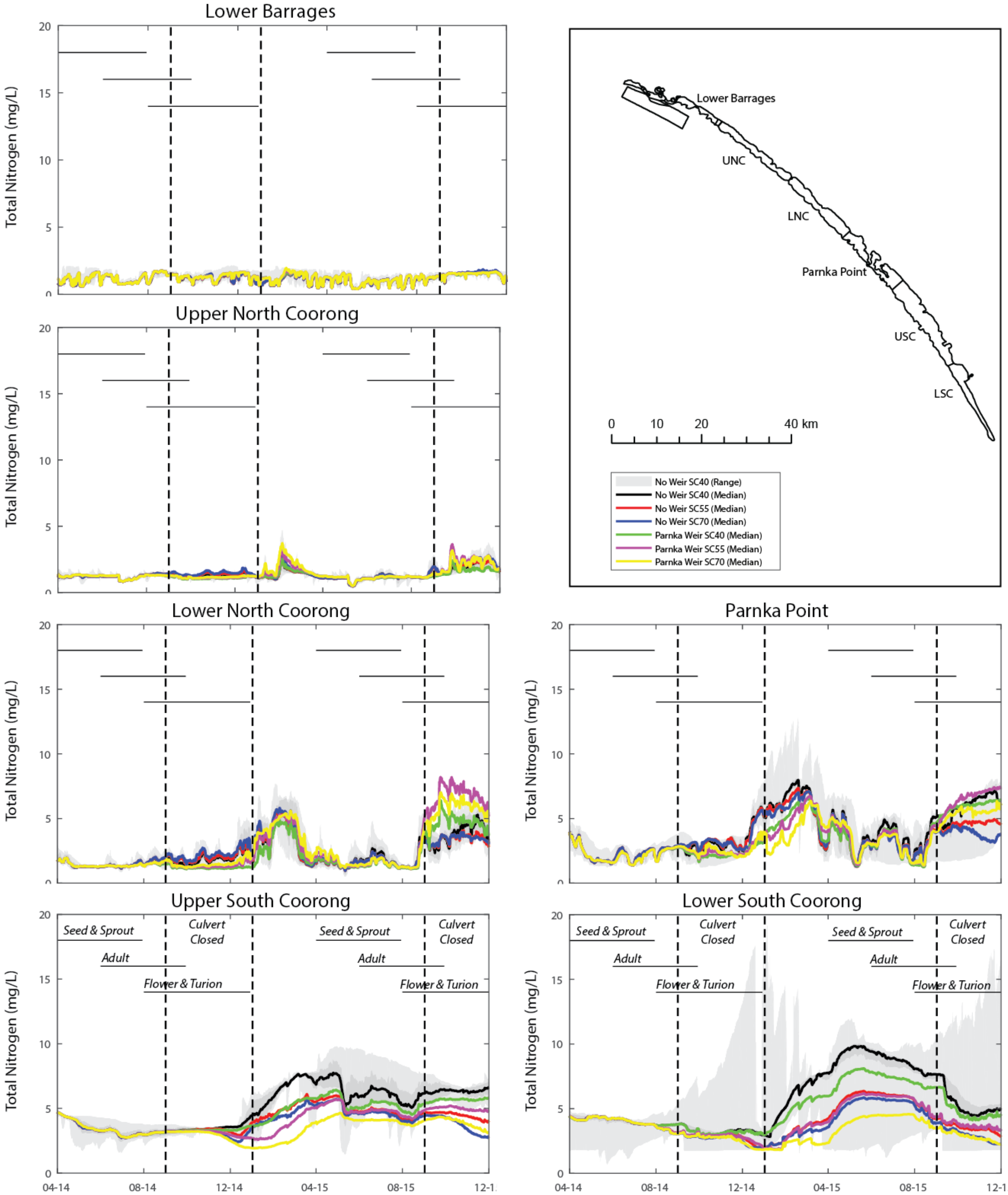

Figure 17: Comparison of predicted nitrogen for various regions within the Coorong for scenarios comparing the effect of Salt Creek inflows (scenarios 1,4,7 & 2,5,8). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD in scenarios 2, 5 & 8, and Salt Creek flow varied from 40-70GL.

Effect of Salt Creek flows with and without weir: *Ruppia Habitat Area*

For the scenarios investigated, the modelling results suggest:

- An increase in South East Flows relative to ORH conditions improved the quality of overall habitat in the Coorong by changing the relative suitability of habitat for flowering and seed germination (Tables A1-A4).
- The total area of suitable habitat was highest under the SC70 (no weir) but benefits became less sensitive to changes in SE flow between from 55 and 70GL.
- The weir negatively impacted the habitat in all SEFRP flow scenarios to a similar extent (however note in Figure 23 in the next section, a 0.4m weir improved conditions when Salt Creek flows were as low as in ORH conditions) (Tables A1-A4).

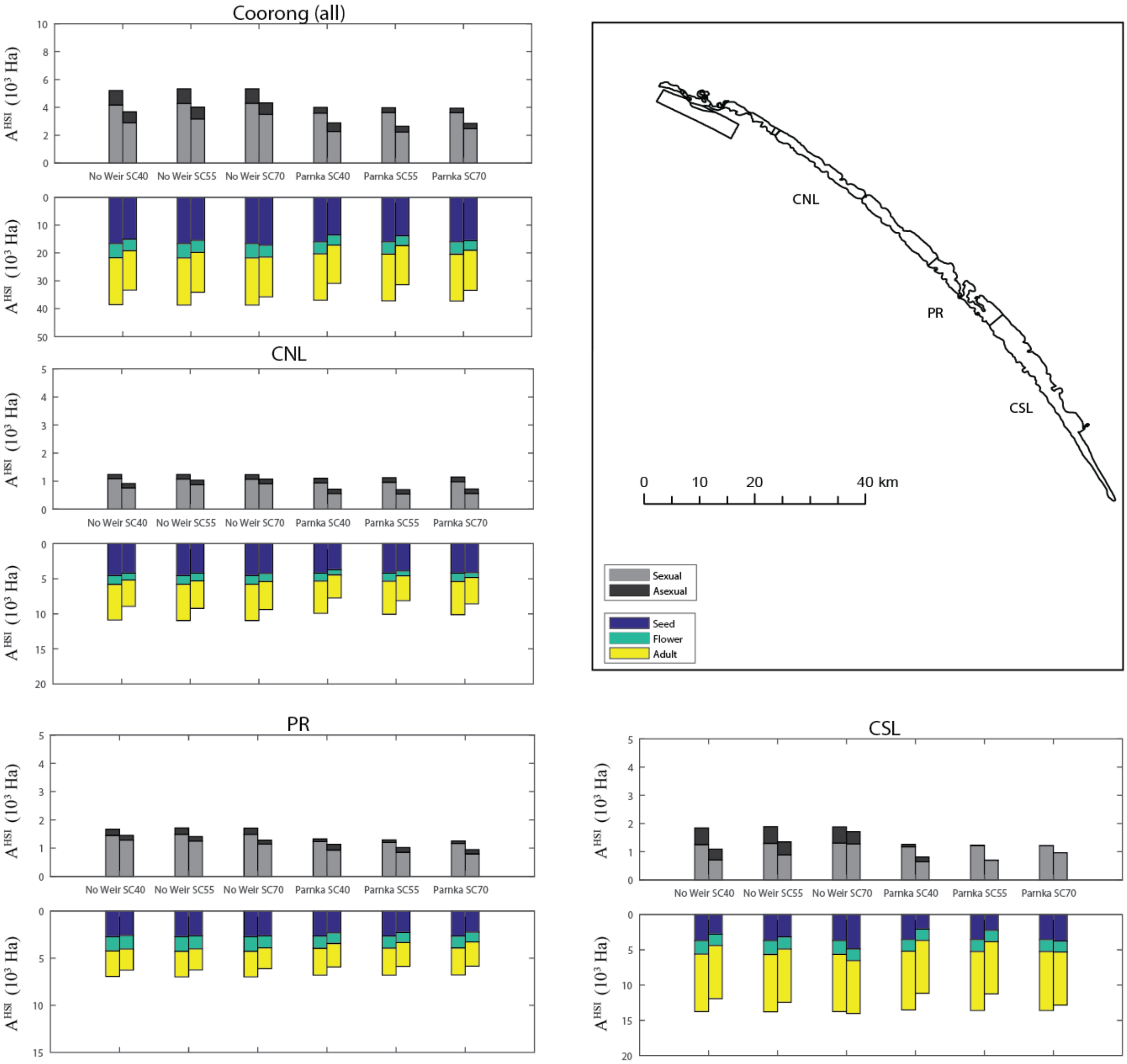

Figure 18: Comparison of the predicted suitable *Ruppia* habitat area, A^{HSI}, within 3 regions of the Coorong and for the total domain, for scenarios comparing the effect of Salt Creek inflows (scenarios 1,4,7 & 2,5,8). Grey and black results indicate the overall suitable habitat where *Ruppia* would be likely to complete its sexual and asexual life-cycle, respectively, and the blue, green and yellow columns indicate the magnitude of the three most important life-stages. The left and right columns for each scenario indicate the 2014 and 2015 results, respectively. Note for these simulations the weir sill height was 0.6mAHD at Parnka Point (scenarios 2, 5 & 8), and Salt Creek flows tested varied from 40-70GL.

Effect of weir sill height: *Water level*

For the scenarios investigated, the modelling results suggest:

- The effect of the sill at 0.4mAHD relative to 0.6mAHD, manifested in a 10-20cm reduction in water level over the period when the culverts were closed.

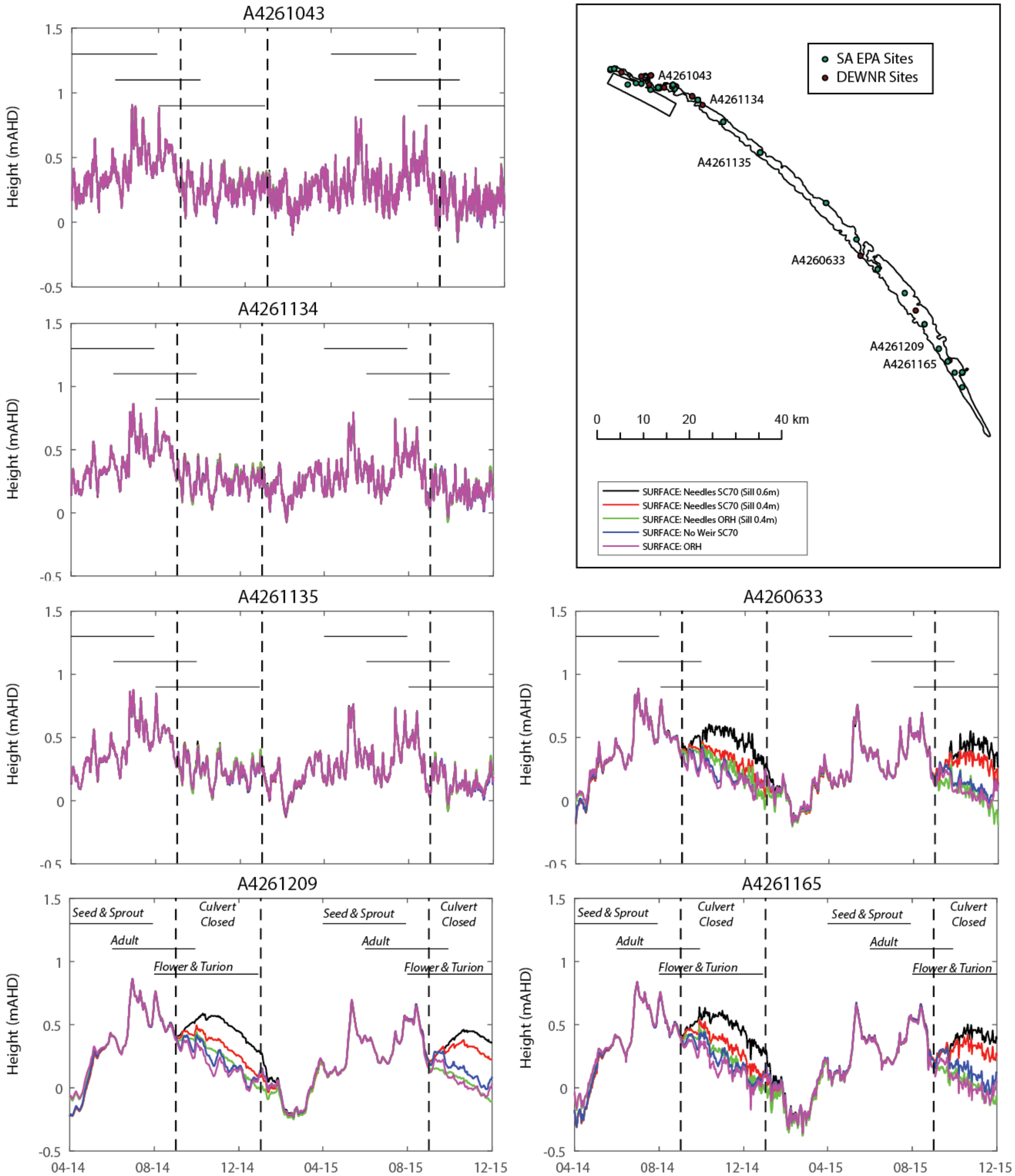

Figure 19: Comparison of predicted water level at various monitoring stations within the Coorong for scenarios comparing the sill height of the weir (scenarios 4, 6, 10, 14, 0). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.4mAHD and 0.6mAHD, and Salt Creek flow was 70GL.

Effect of weir sill height: *Salinity*

For the scenarios investigated, the modelling results suggest:

- The effect of the sill at 0.4mAHD relative to 0.6mAHD, manifested in a relatively modest reduction in salinity (~5g/L), due to the lower volume of lagoon water relative to the inflowing water.
- The change in salinity occurred over the latter half of the flowering window.
- Both simulations with a weir present had a higher salinity in the CSL when the culverts were closed relative to the case with no weir.

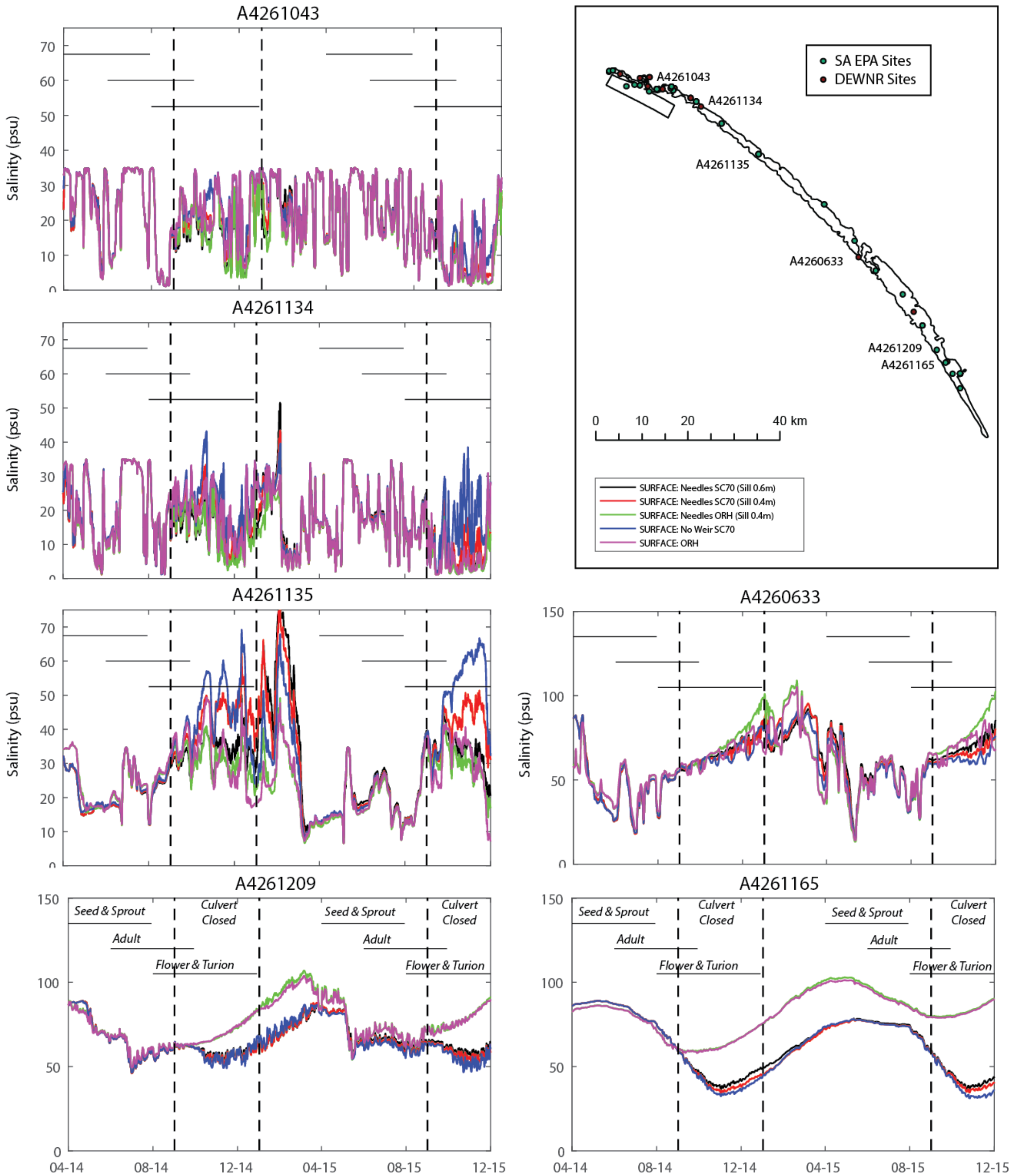

Figure 19: Comparison of predicted salinity at various monitoring stations within the Coorong for scenarios comparing the sill height of the weir (scenarios 4, 6, 10, 14, 0). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.4mAHD and 0.6mAHD, and Salt Creek flow was 70GL.

Effect of weir sill height: *Light*

For the scenarios investigated, the modelling results identified no significant changes.

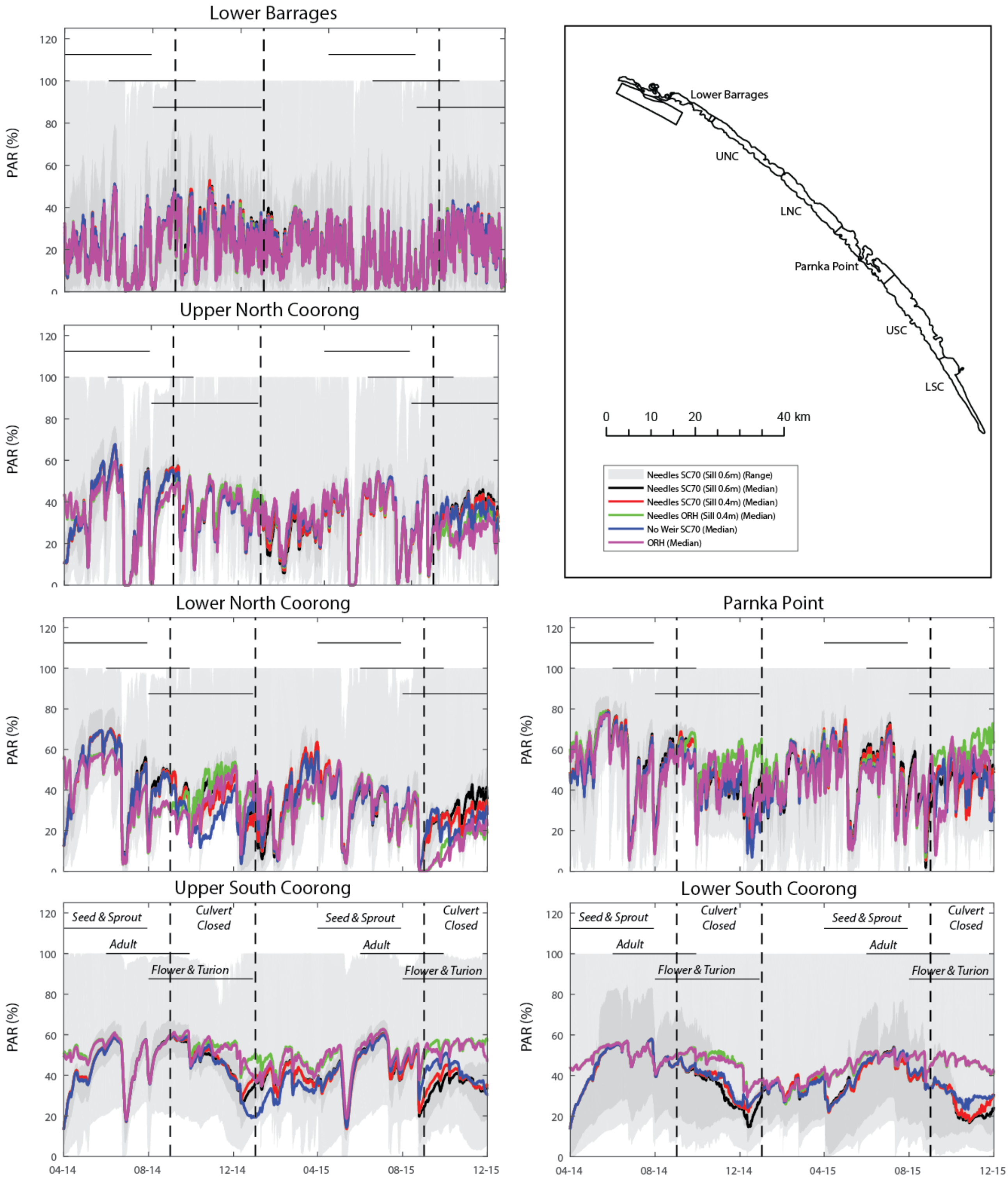

Figure 19: Comparison of predicted benthic light availability at various monitoring stations within the Coorong for scenarios comparing the sill height of the weir (scenarios 4, 6, 10, 14, 0). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.4mAHD and 0.6mAHD, and Salt Creek flow was 70GL.

Effect of weir sill height: *Nitrogen*

For the scenarios investigated, the modelling results identified no significant changes.

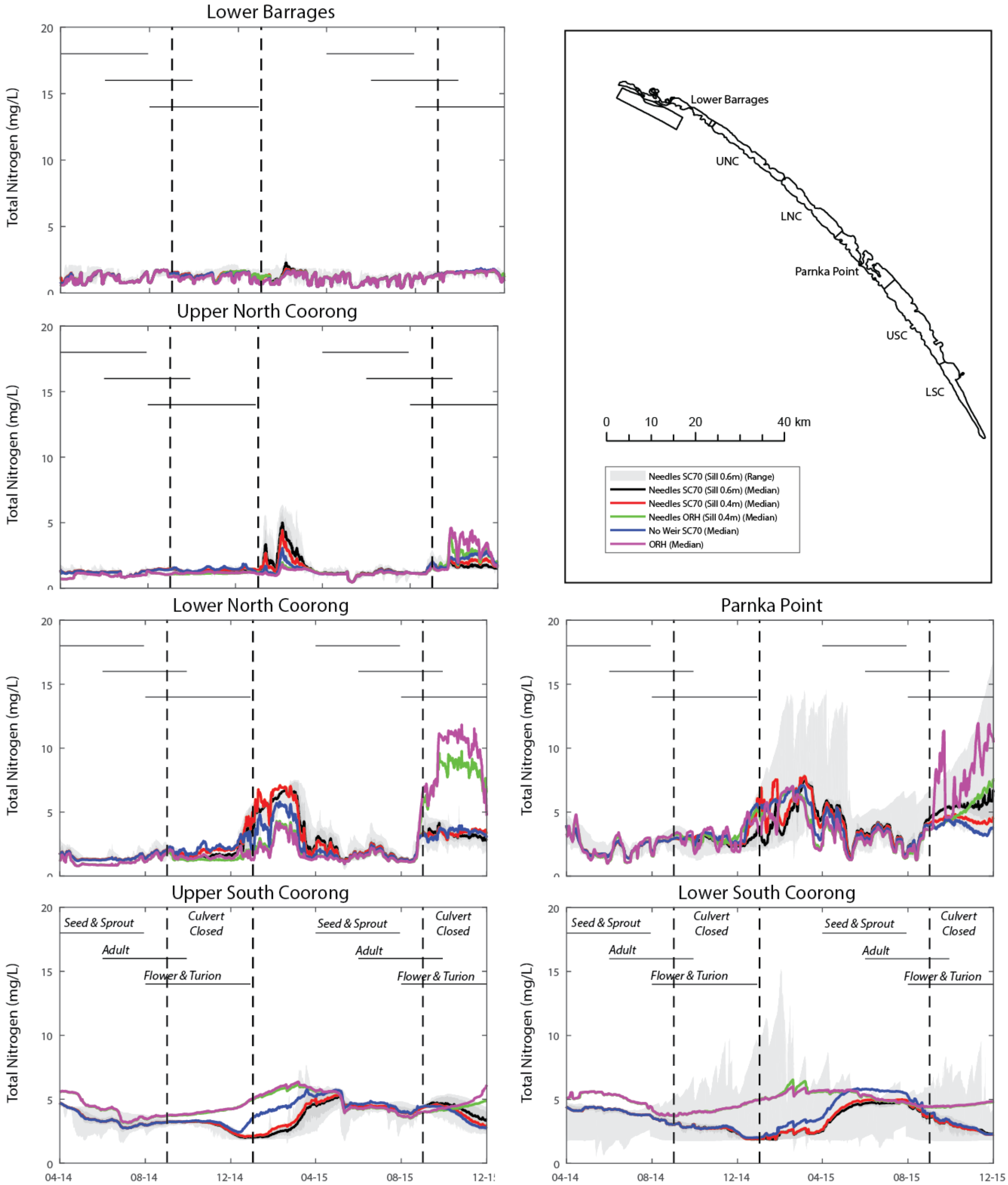

Figure 19: Comparison of predicted nitrogen at various monitoring stations within the Coorong for scenarios comparing the sill height of the weir (scenarios 4, 6, 10, 14, 0). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.4mAHD and 0.6mAHD, and Salt Creek flow was 70GL.

Effect of weir sill height: *Ruppia Habitat Area*

For the scenarios investigated, the modelling results suggest:

- The total area of suitable habitat was predicted to be higher when the sill was lowered from 0.6 to 0.4mAHD, with a 7% increase for sexual and 64% increase in asexual; but this was not as high as for No Weir SC70 (Table A1-A4).
- The main difference caused by lowering the sill was the improvement in conditions for flowering.
- The improved area was in the Parnka Region, and CSL.

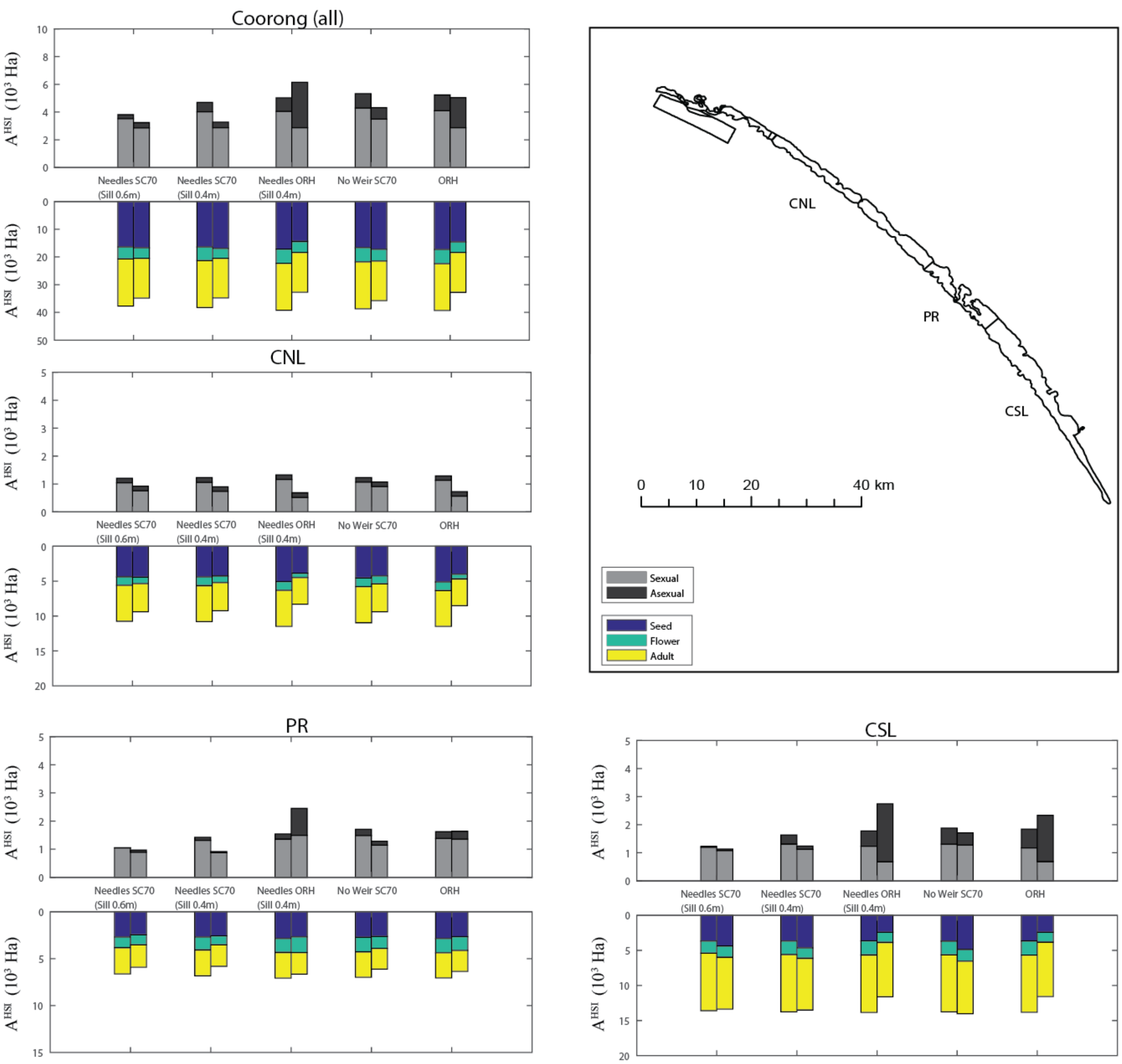

Figure 23: Comparison of the predicted suitable *Ruppia* habitat area, A^{HSI}, within 3 regions of the Coorong and for the total domain, for scenarios comparing the effect of sill height (scenarios 6, 10, 12 with no weir conditions 4 & 0). Grey and black results indicate the overall suitable habitat where *Ruppia* would be likely to complete its sexual and asexual life-cycle, respectively, and the blue, green and yellow columns indicate the magnitude of the three most important life-stages. The left and right columns for each scenario indicate the 2014 and 2015 results, respectively. Note for these simulations the weir sill height was 0.4mAHD and 0.6mAHD at Needles, and Salt Creek flows were 70GL, or as in ORH.

Effect of weir culvert closure time: *Water level*

For the scenarios investigated, the modelling results suggest:

- The effect of changing the culvert closure time from Sept to Aug in 2014 prevented the extent of water level decline, allowing 0.6m AHD to be maintained more consistently.

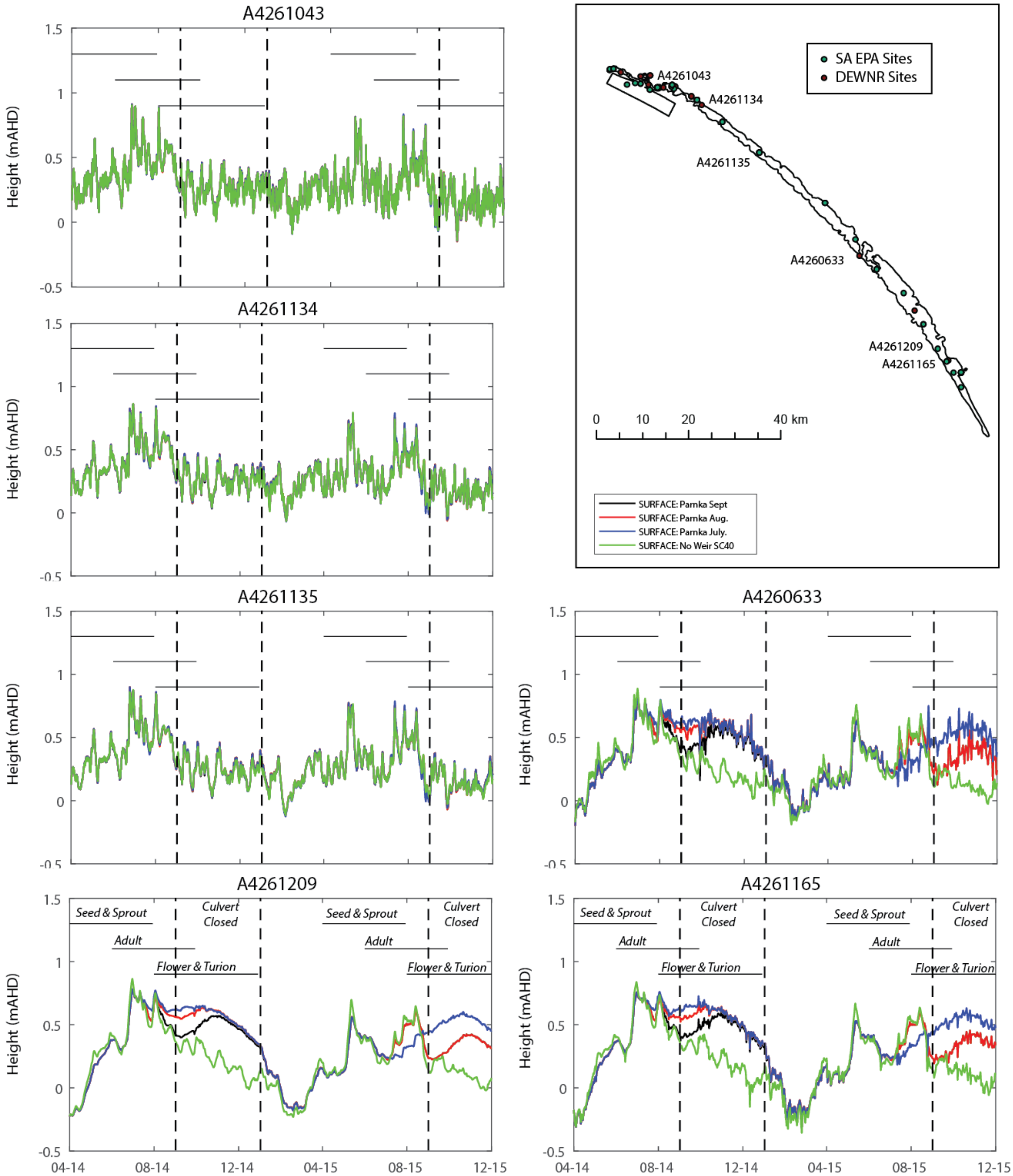

Figure 24: Comparison of predicted water level at various monitoring stations within the Coorong for scenarios comparing the effect of weir closure timing (scenarios 1,2,13, 15). Dashed lines indicate the standard period of closure of the weir culverts from 1 Sept to 31 Jan (scenarios 1,2); red line closure time was 1 Aug (scenario 13). Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL for all three scenarios.

Effect of weir culvert closure time: *Salinity*

For the scenarios investigated, the modelling results suggest:

- There was only an insignificant change to salinity brought about by changing the culvert closure time.

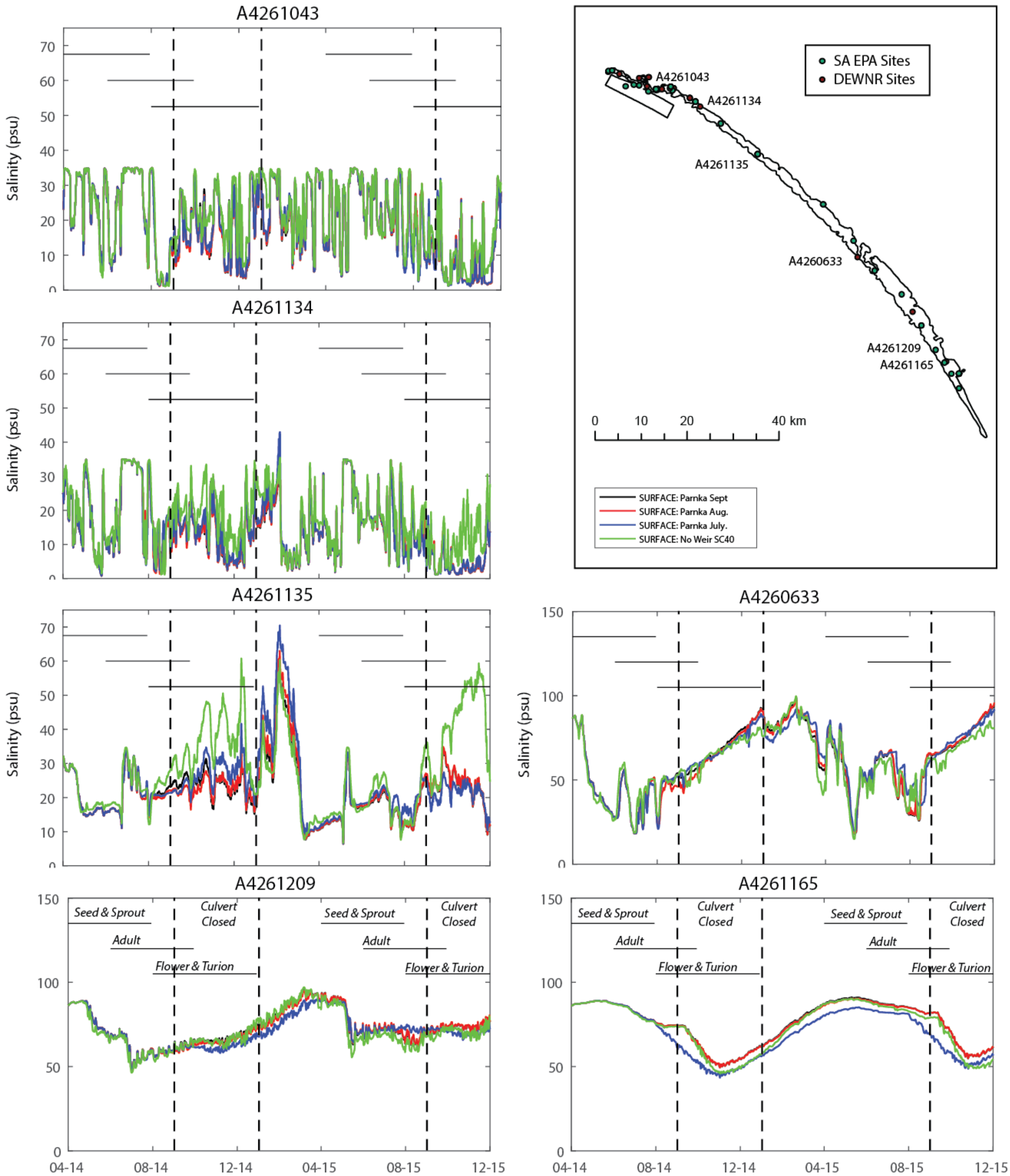

Figure 25: Comparison of predicted salinity at various monitoring stations within the Coorong for scenarios comparing the effect of weir closure timing (scenarios 1,2,13,15). Dashed lines indicate the standard period of closure of the weir culverts from 1 Sept to 31 Jan (scenarios 1,2); red line closure time was 1 Aug (scenario 13). Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL for all three scenarios.

Effect of weir culvert closure time: *Light*

For the scenarios investigated, the modelling results identified no significant changes.

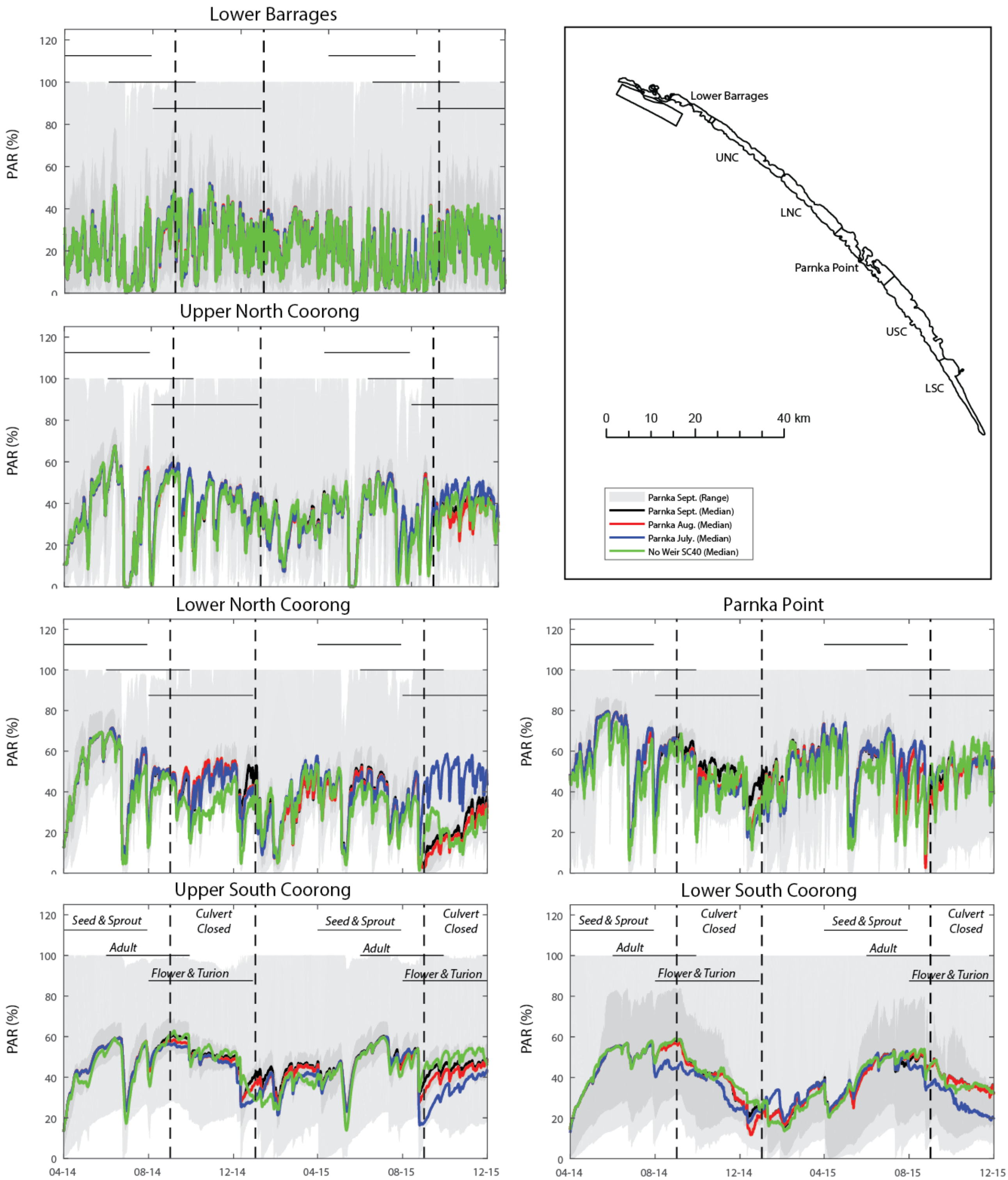

Figure 26: Comparison of predicted benthic light availability at various monitoring stations within the Coorong for scenarios comparing the effect of weir closure timing (scenarios 1,2,13,15). Dashed lines indicate the standard period of closure of the weir culverts from 1 Sept to 31 Jan (scenarios 1,2); red line closure time was 1 Aug (scenario 13). Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL for all three scenarios.

Effect of weir culvert closure time: *Nitrogen*

For the scenarios investigated, the modelling results suggest:

- Earlier closure of the culverts led to a reduction in the build of nitrogen in the CSL; the assumed Salt Creek inputs had a TN of ~1.7 mg/L which at times is lower than ambient water in the CNL which ranges from 1.5-5mg/L.

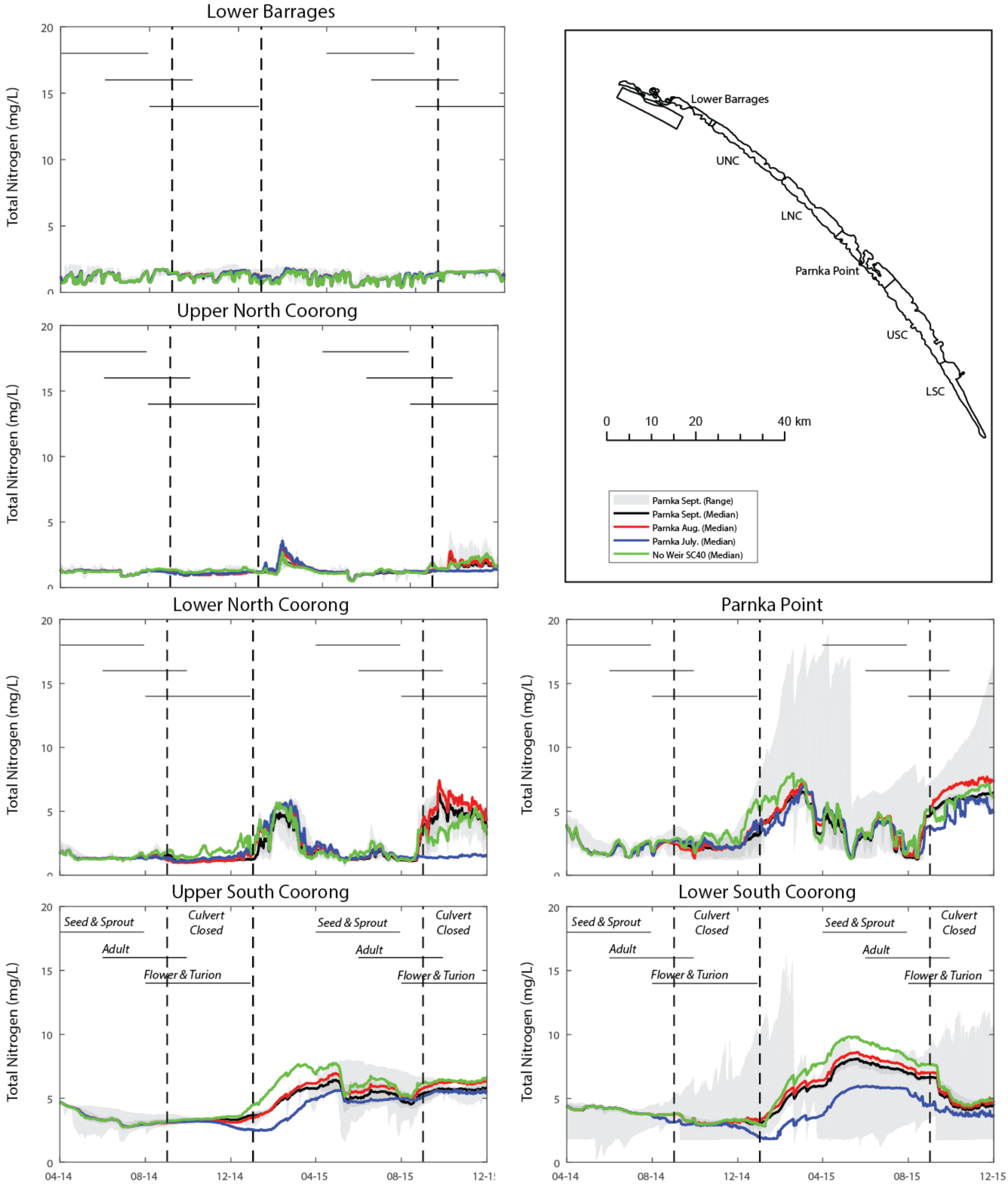

Figure 27: Comparison of predicted nitrogen at various monitoring stations within the Coorong for scenarios comparing the effect of weir closure timing (scenarios 1,2,13,15). Dashed lines indicate the standard period of closure of the weir culverts from 1 Sept to 31 Jan (scenarios 1,2); red line closure time was 1 Aug (scenario 13). Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL for all three scenarios.

Effect of weir culvert closure time: *Ruppia Habitat Area*

For the scenarios investigated, the modelling results suggest:

- The total area of suitable habitat was predicted to be slightly larger when the culverts on the Parnka weir were closed earlier in August, instead of September, with an increase for sexual and asexual habitat.
- The main difference caused by closing earlier was the improvement in conditions for flowering.
- The impact of weir closure time on hydrodynamics and consequently *Ruppia* habitat highlights the need for a structure that has the capability to adapt to the hydrological conditions occurring in a given growing season.
- Moving the start of the Salt Creek flow earlier to July (Parnka SC40 July) also improved the *Ruppia* conditions in the CNL and CSL growing regions relative to the default SC40 inflow regime (where flows started in August)

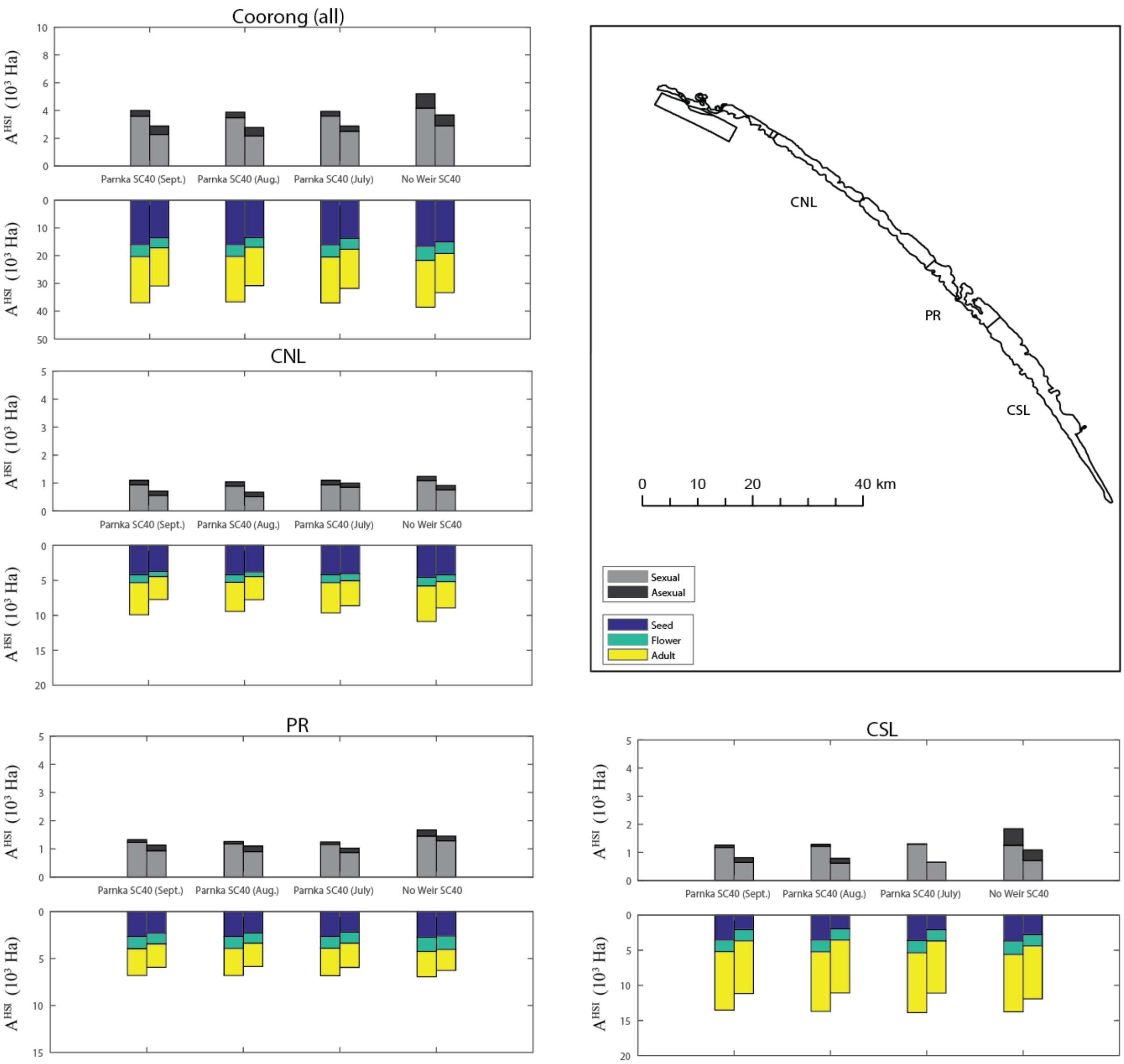

Figure 28: Comparison of the predicted suitable *Ruppia* habitat area, A^{HSI}, within 3 regions of the Coorong and for the total domain, for scenarios comparing the effect of closure timing of culverts from Sept to Aug (scenarios 2, 13 compared to 1) and Salt Creek timing (scenario 15). Grey and black results indicate the overall suitable habitat where *Ruppia* would be likely to complete its sexual and asexual life-cycle, respectively, and the blue, green and yellow columns indicate the magnitude of the three most important life-stages. The left and right columns for each scenario indicate the 2014 and 2015 results, respectively. Note for these simulations the weir sill height was 0.6mAHD at Parnka, and Salt Creek flows were 40GL.

Effect of initial salinity (starting conditions): *Water level*

For the scenarios investigated, the modelling results suggest:

- The effect of starting with higher salinity does not effect the water levels.

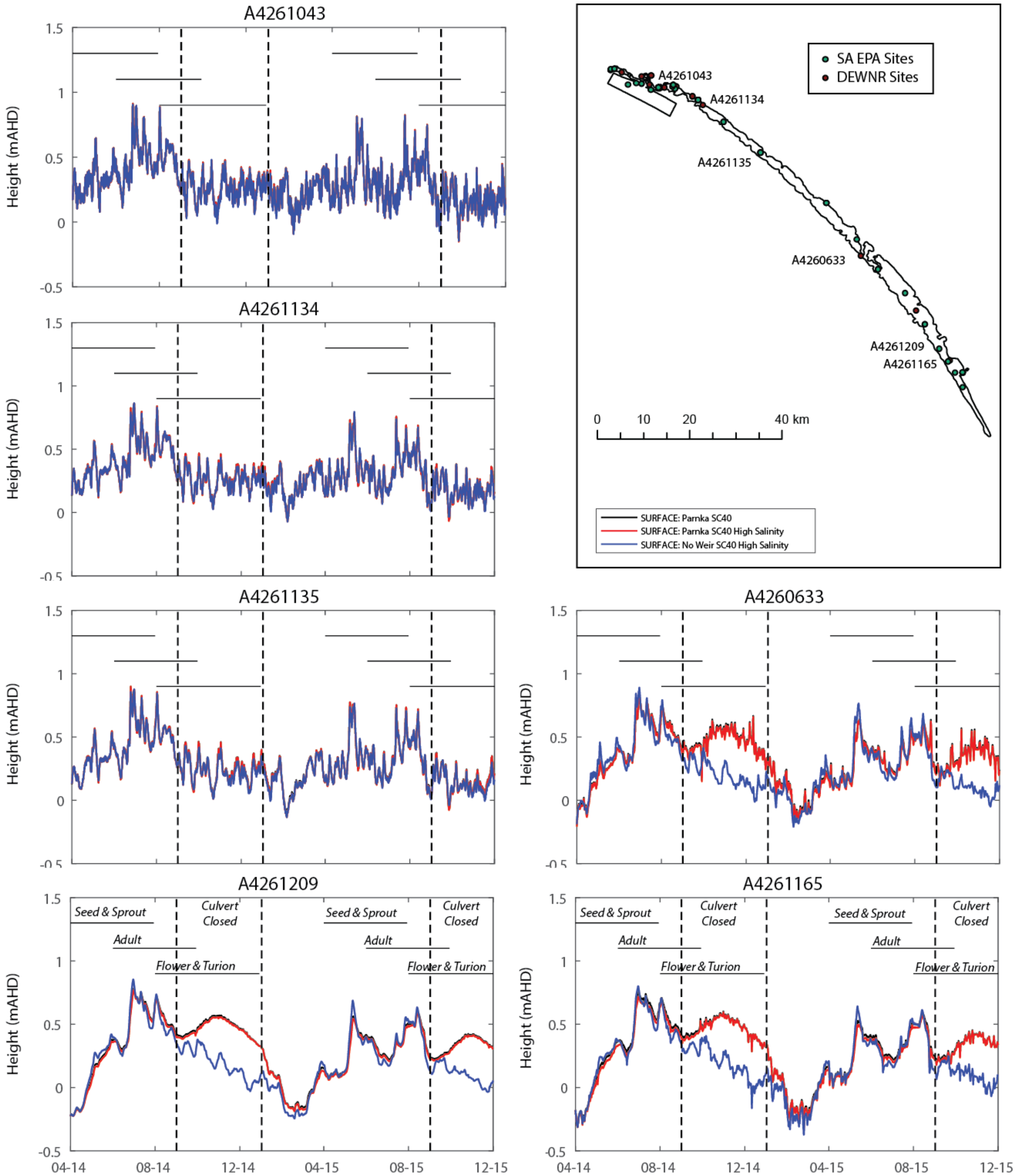

Figure 29: Comparison of predicted water level at various monitoring stations within the Coorong for scenarios comparing the effect of changing the initial salinity (scenarios 2,11,12). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL.

Effect of initial salinity (starting conditions): *Salinity*

For the scenarios investigated, the modelling results suggest:

- The effect of starting with higher salinity (with and without the weir) considerably impacts the summer and winter salinity over the simulation period.

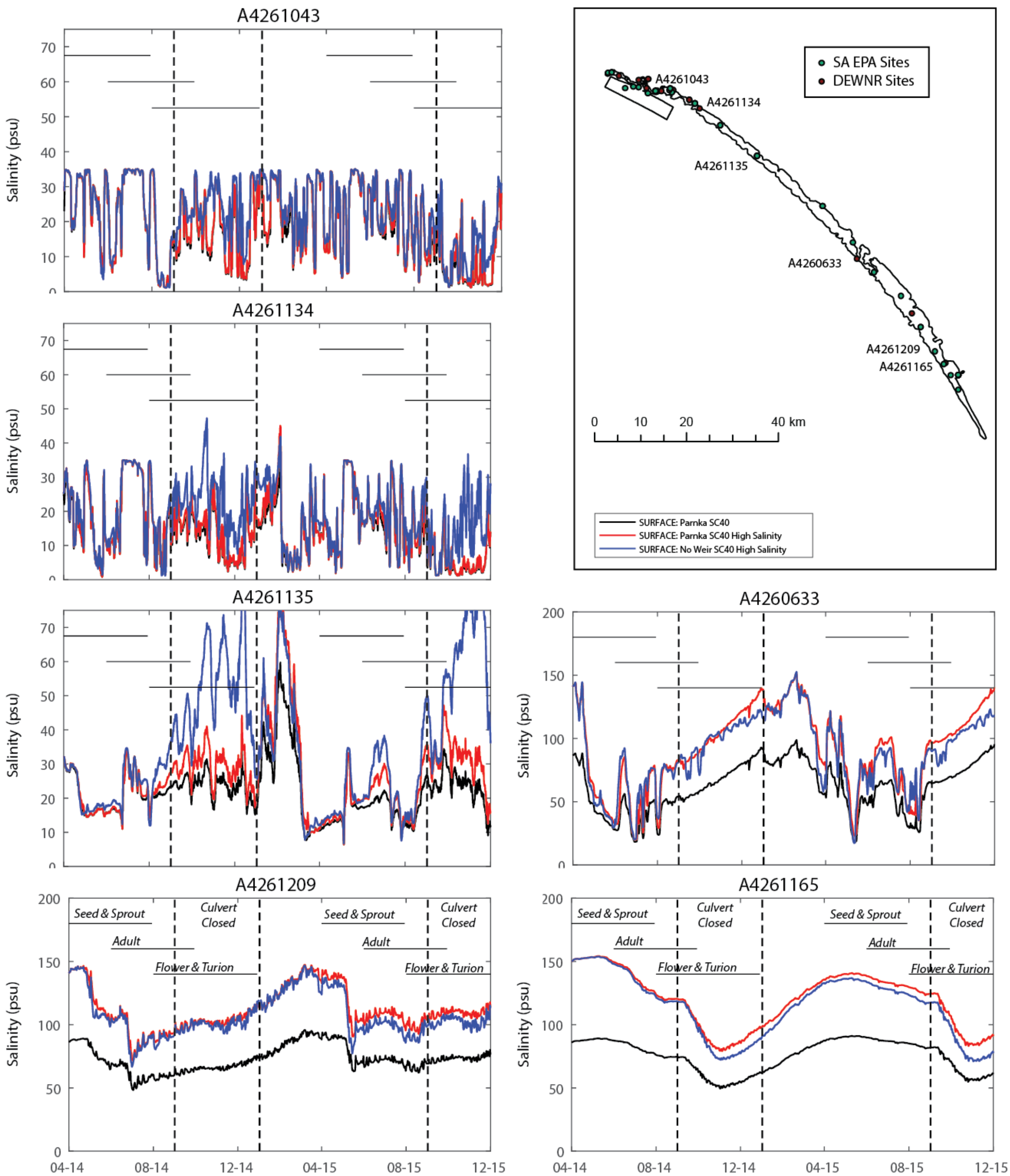

Figure 30: Comparison of predicted salinity at various monitoring stations within the Coorong for scenarios comparing the effect of changing the initial salinity (scenarios 2,11,12). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL.

Effect of initial salinity (starting conditions): *Light*

For the scenarios investigated, the modelling results identified no significant changes.

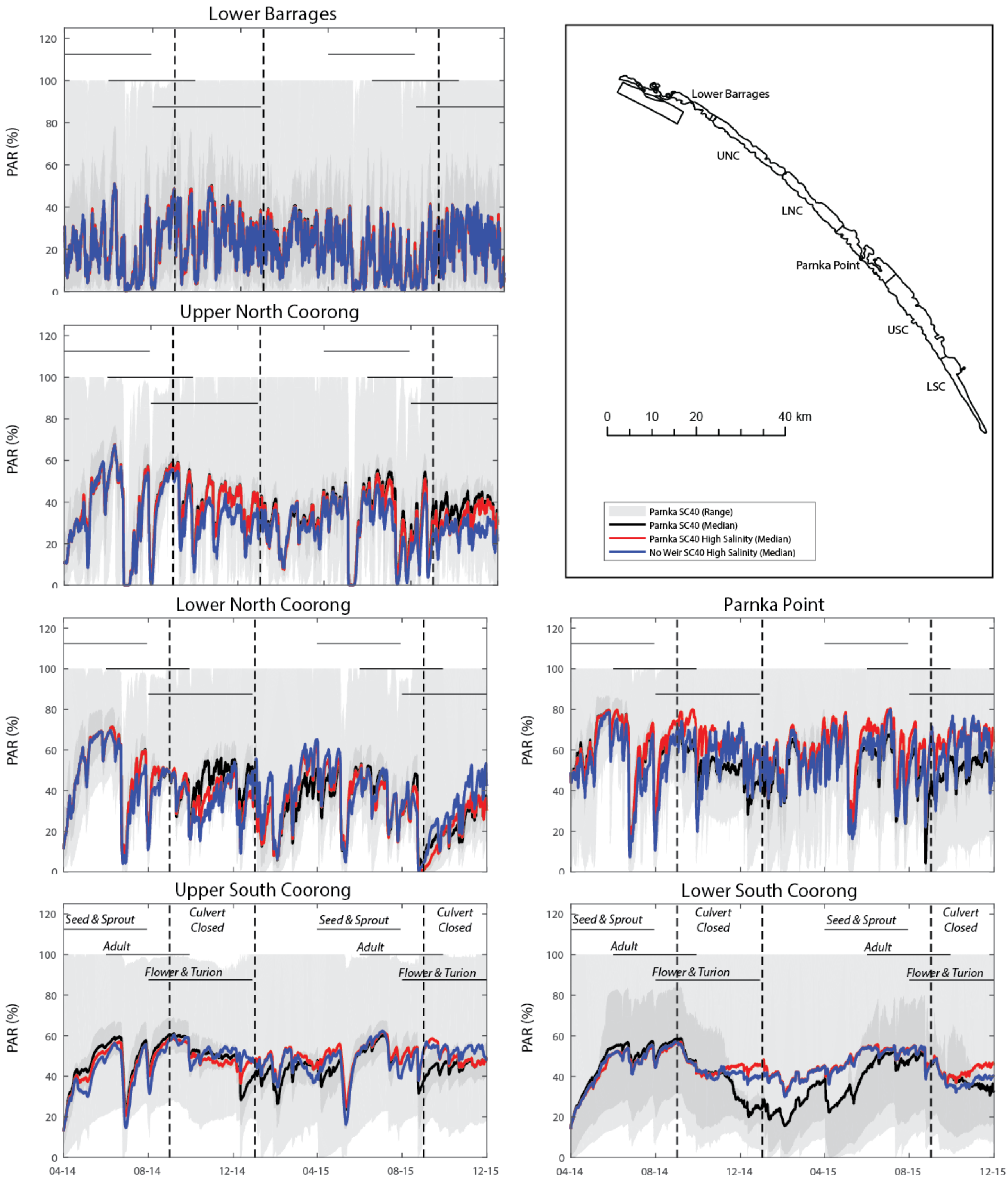

Figure 31: Comparison of predicted benthic light availability at various monitoring stations within the Coorong for scenarios comparing the effect of changing the initial salinity (scenarios 2,11,12). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL.

Effect of initial salinity (starting conditions): *Nitrogen*

For the scenarios investigated, the modelling results identified no significant changes; slight changes are evident due to the impact of salinity on *Ulva* growth and other biogeochemical reactions.

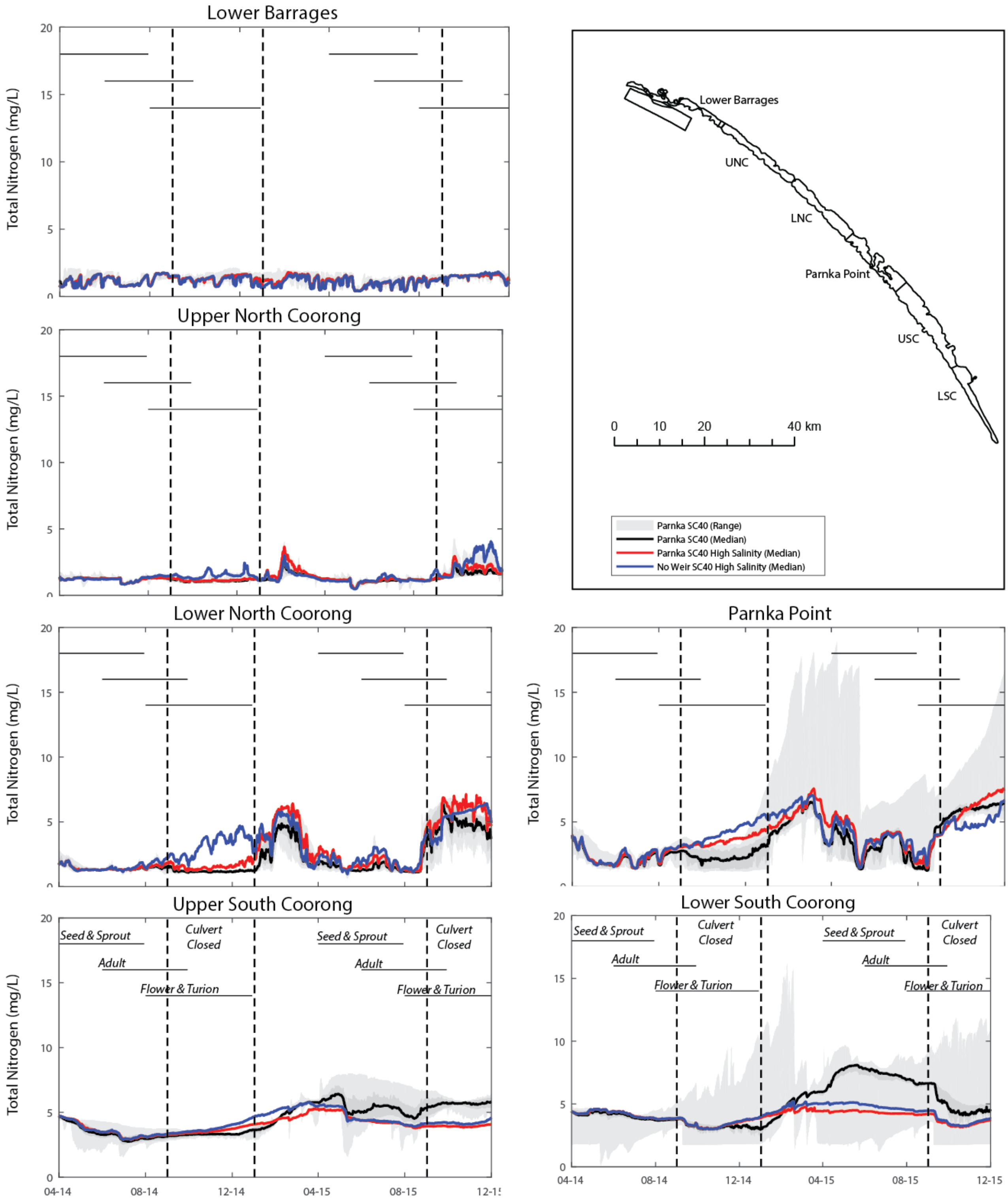

Figure 32: Comparison of predicted nitrogen at various monitoring stations within the Coorong for scenarios comparing the effect of changing the initial salinity (scenarios 2,11,12). Dashed lines indicate the period of closure of the weir culverts from 1 Sept to 31 Jan. Weir sill height was 0.6mAHD, and Salt Creek flow was 40GL.

Effect of initial salinity (starting conditions): *Ruppia Habitat Area*

For the scenarios investigated, the modelling results suggest:

- The total area of suitable habitat was substantially impacted by having a higher starting salinity, with higher predicted extent of habitat suitable for asexual production, and reduced area for sexual reproduction.
- With a higher salinity, the no weir scenario still performed better than with weir present.
- Relative to the standard 2014 starting salinity, the Parnka region has similar suitability, however the CSL was significantly reduced, with the flowering and seed production stages reduced considerably (Tables A1-A4).

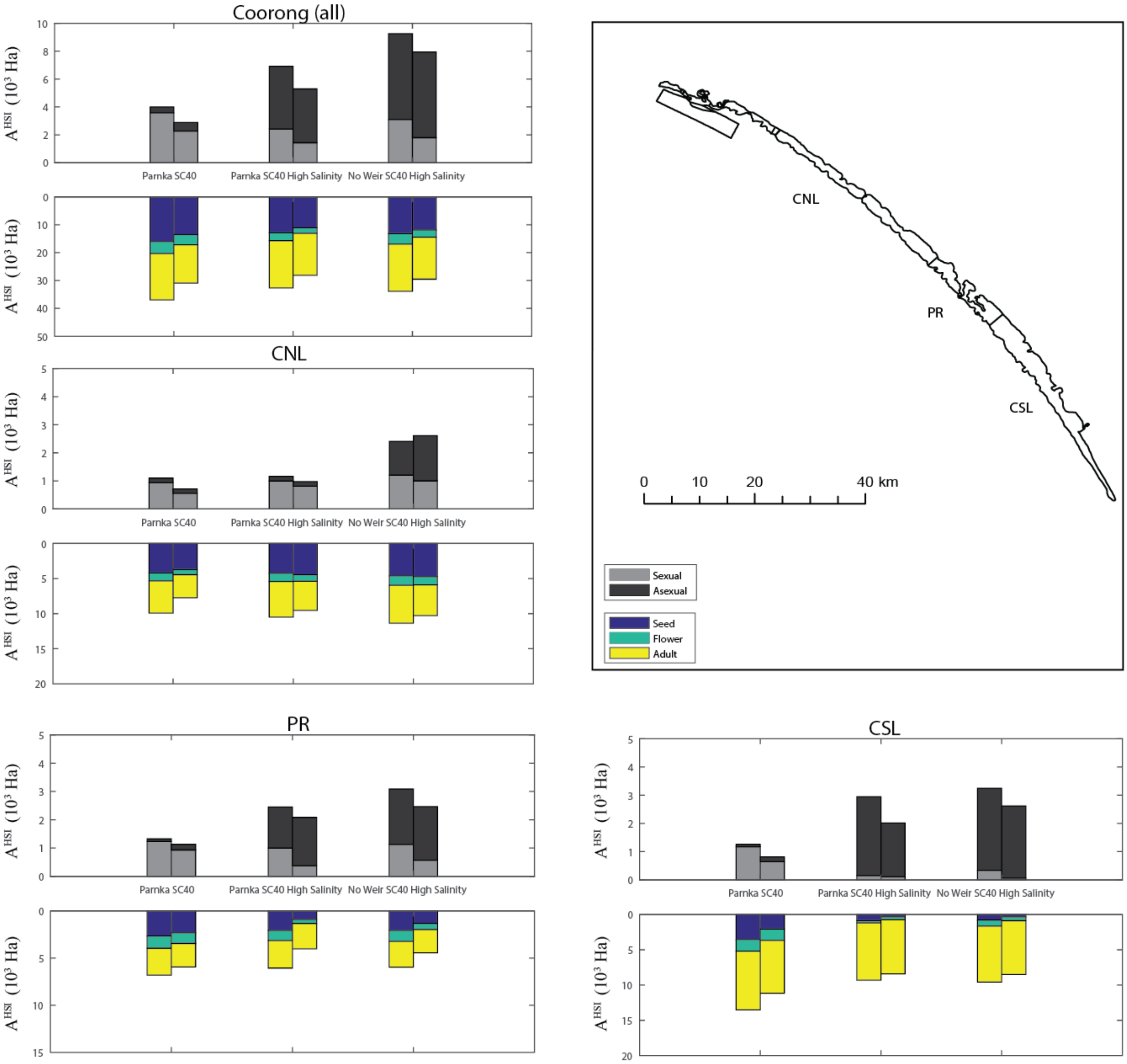

Figure 33: Comparison of the predicted suitable *Ruppia* habitat area, A^{HSI}, within 3 regions of the Coorong and for the total domain, for scenarios comparing the effect of the starting salinity level (scenarios 2,11,12). Grey and black results indicate the overall suitable habitat where *Ruppia* would be likely to complete its sexual and asexual life-cycle, respectively, and the blue, green and yellow columns indicate the magnitude of the three most important life-stages. The left and right columns for each scenario indicate the 2014 and 2015 results, respectively. Note for these simulations the weir sill height was 0.6mAHD at Parnka (scenarios 2,11), and Salt Creek flows were 40GL.

Summary of *Ruppia* HSI and Ulva biomass variation

Figures 34 and 35 provide further detail illustrating how the scenarios drive a change in the distribution of suitable habitat for Ruppia and Ulva along the length of the Coorong. For more detailed plots of spatial variation, readers are referred to summary map plots provided in the Appendix for each scenario.

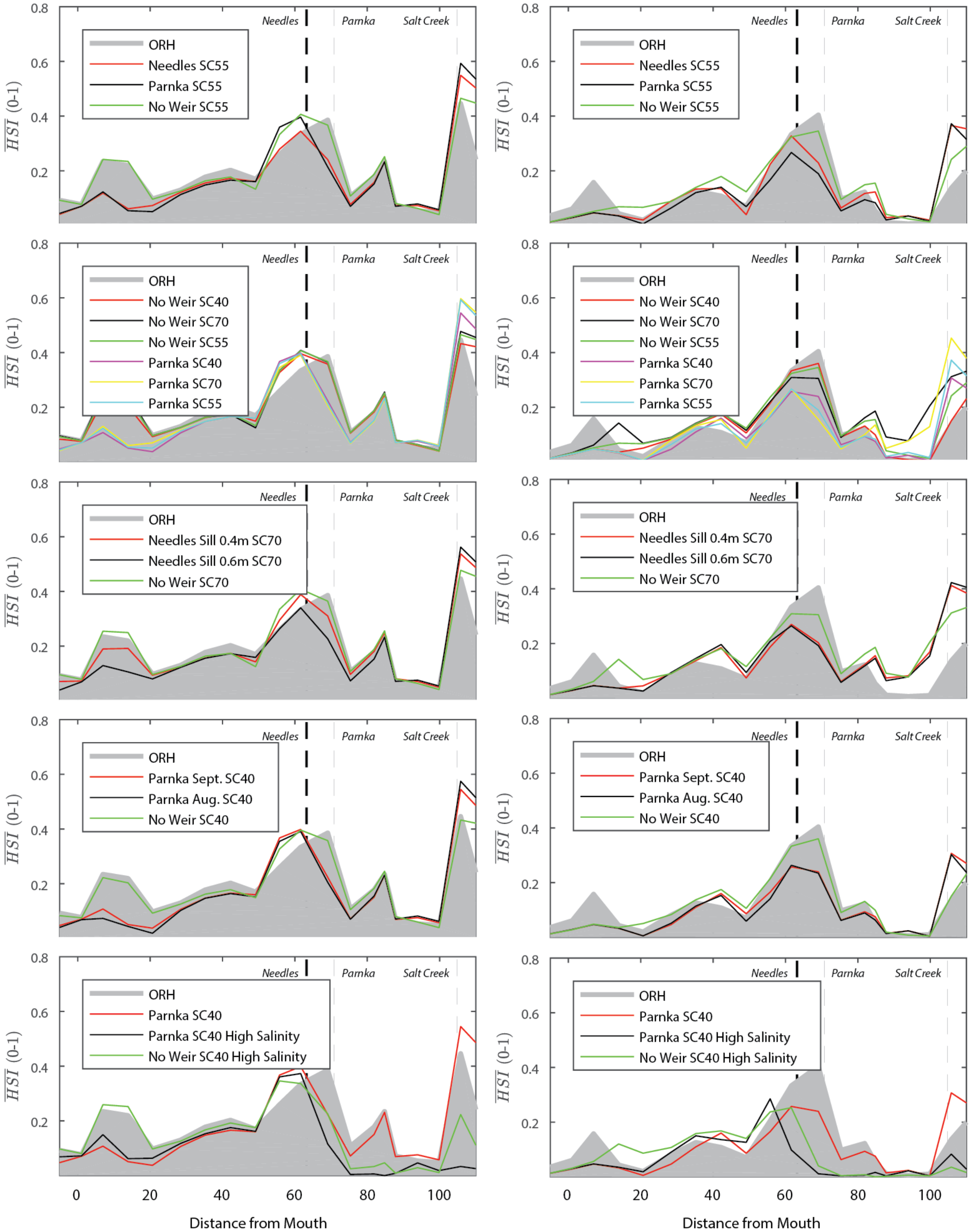

Figure 34: Comparison of *Ruppia HSI* along the Coorong, for the five scenario groups, and 2014 (left) and 2015 (right) conditions.

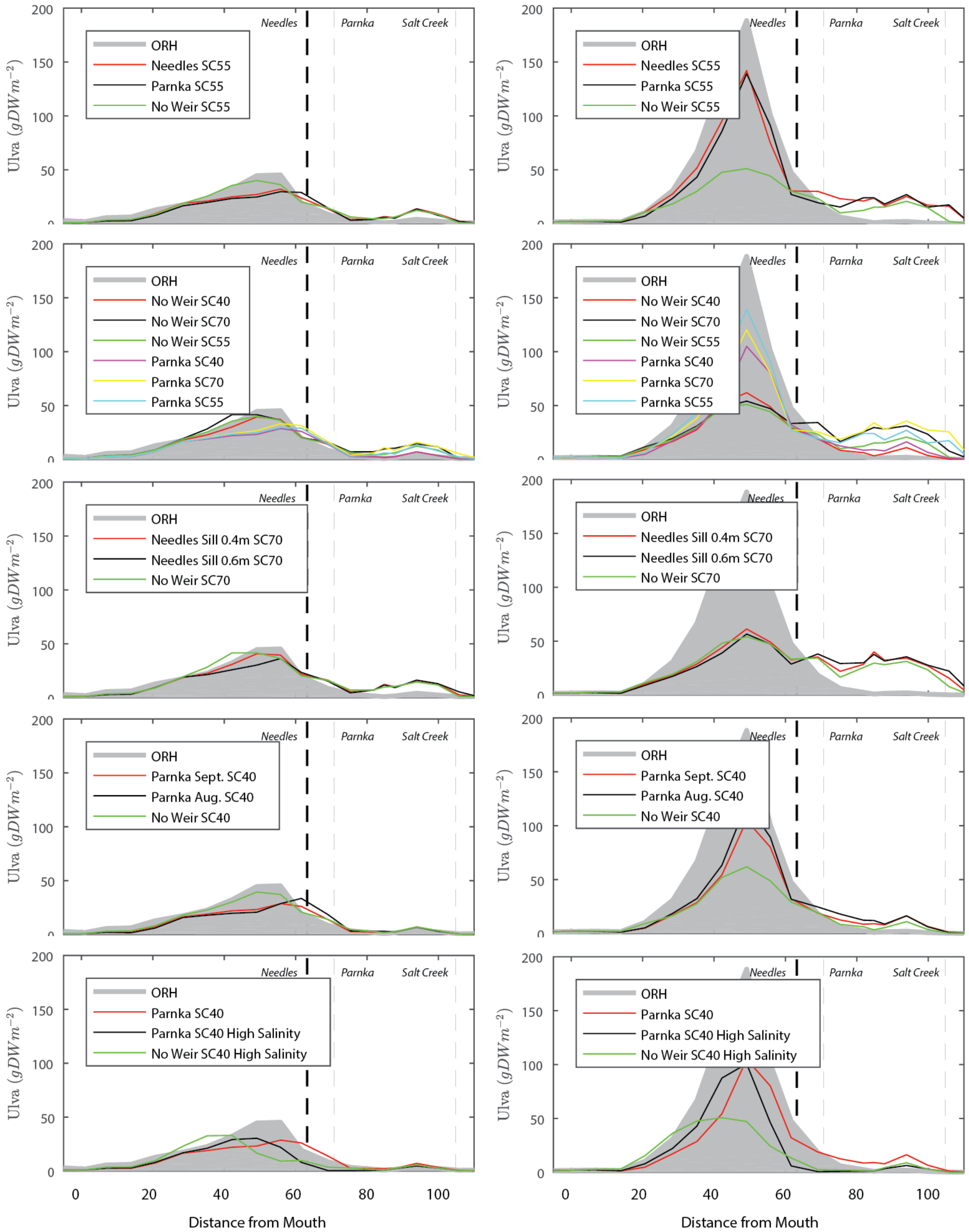

Figure 35: Comparison of the width-averaged *Ulva* biomass along the Coorong, for the five scenario groups, and 2014 (left) and 2015 (right) conditions.

Summary of Findings

Year to year variability in the extent of suitable habitat is notable, and varies based on the combination of starting conditions, barrage flows, and Salt Creek inputs. Differences in habitat caused by inter-annual variability between the 2014 and 2015 conditions was generally more significant than the impact of the weir or SEFRP flow variations, at least for the range of water level and salinity conditions assessed. The largest changes observed were brought about by changing the starting salinity, highlighting that the long-term drivers of Coorong hydrology are an important determinant of habitat quality. It is highlighted in Paton et al. (2015) that recovery of *Ruppia* beds does require several years of consistent conditions of suitable habitat before plants recover. Conclusions made as to the impact of the Salt Creek flows and the flow regulator should be considered in this context.

Across all the scenarios tested, the 2014 conditions led to a higher area of habitat than for 2015, regardless of the presence of the weir or the magnitude of Salt Creek inflow (Figure 36a). Furthermore, the question of whether the management measures would act consistently in both years is worth assessing, since the background hydro-climatological conditions in each year could determine the relative benefit of any given intervention, and also consider that 2015 will be impacted by carry-over impacts from spring flows in 2014. Interestingly, the results in Figure 36b highlight that the direction of the change in the first growing season (2014 conditions) vs the 2nd growing season (2015 conditions) was generally correlated, but not always; in some cases a benefit was noted under 2014 conditions and a decline was noted under 2015 conditions and vice versa. Of particular note in Figure 36b, is that only 4 points appear in the upper-right quadrant, indicating that of all the simulation and region combinations assessed (15 simulations x 3 regions = 45), very few led to a consistent improvement over and above the No Weir SC40 case (scenario 1 in Table 1). Findings from analysis of differences between the scenarios are explored further below in order to better understand the drivers.

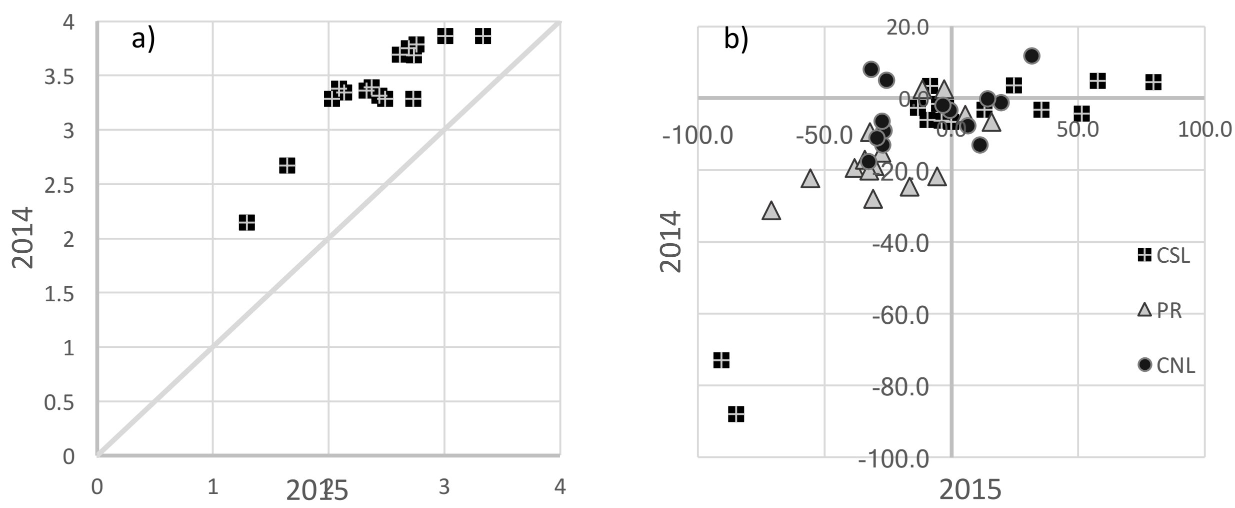

Figure 36: Comparison of the sexual life-cycle habitat between the 2014 and 2015 growing seasons for each scenario, showing: a) total habitat area (x10^3 Ha), and b) relative benefit of intervention in each region (% improvement in area, computed relative to scenario 1: No Weir, SC40).

- Additional water entering the CSL via Salt Creek in all cases tended to improve the overall extent of habitat available, based on the conditions in the 2 years assessed. The extra flows did not significantly change the water level without a weir in place, but improved the salinity. The points in the upper right quadrant of Figure 36b relate to higher Salt Creek inflows indicating that higher SC flows improved conditions. The timing of the flow was identified to have an effect, with earlier introduction of water improving habitat conditions, particularly for flowering and seed germination.

- Increasing Salt Creek flows did tend to allow build-up of *Ulva* biomass further south within the Coorong, potentially overlapping with areas of otherwise suitable flowering habitat. In areas that *Ulva* extended into, the expansion in area appeared to have less to do with nutrient availability and was based on the reduction in the salinity brought about by freshwater inflows due to the salinity tolerance of *Ulva*. In fact, for the scenarios tested, the SEFRP flows served to dilute nutrient levels in CSL and encourage more exprt to the CNL, though this is based on limited data for configuring the inflow nutrient loads, and this may not be the case for extra SEFRP water or the augmented water added into the Salt Creek flows.

- Overall, the presence of a weir (at either Parnka Pt or across The Needles, set at 0.6mAHD) was predicted to decrease the overall suitability for *Ruppia*.

- Whilst the choice of weir position did impact CSL salinity and water level, the position did not have a significant effect on the overall extent of suitable habitat. One concern is the development of high-salinity patch of water between The Needles and the Parnka constriction when the weir is place at the former. Whilst some habitat differences between The Needles and Parnka Pt emerged when the weirs were positioned differently, the changes were offset by spatial differences in the extent of the decline, such that there was limited overall difference. Also, the particularly high salinities (>70g/L) that occurred in the Needles to Parnka region occurred mostly after the plant would have been expected to complete its lifecycle.

- Notably, the weir was predicted to have limited effect on conditions for the adult stage of the plant (and in fact would improve plant habitat in the Parnka Region), but would decrease the overall suitability of conditions for flowering (and seed germination to a lesser extent). Even in the scenarios run with a high initial starting salinity (e.g. as may be expected after an extended drought), then the presence of a weir at 0.6mAHD did not significantly improve conditions relative to SEFRP augmentation alone. Whilst the lower CNL did have significantly higher limitation of flowering due to Ulva when the weir was in place, the primary driver for the decline in area for flowering was due to water level limitation, with previously good habitat in the Parnka Region becoming too deep for flowers to reach the surface.

- The extra scenario run with a lower sill (at 0.4mAHD), or earlier culvert closure time (Aug) also led to a change in the area for flowering, with 0.4m better than 0.6m, and Aug worse than Sept; these results suggest that alternate weir configurations and timings that wouldn't limit flowering would be able to be identified. Notably, in the simulation run with ORH (low) flows coming through Salt Creek, a weir with a sill height 0.4m (Scenario 14) provided a slight improvement in conditions relative to the base ORH simulation

(Scenario 0). It should be highlighted that in these simulations a 0.6 m structure was used to represent an operational gate, not a target water level for the CSL and further work is recommended to identify optimum operational targets.

Visualising the habitat maps and the change tables in the Appendix highlight that the interactions between the management measures and environmental conditions that may impact *Ruppia* becomes complicated when looking over the various life-cycle stages, making it difficult to conclusively recommend a long-term management policy from the present simulation set. Whilst the study has simulated two growing seasons for each scenario, in many cases the measures being assessed would have a long-term impact on the salinity and nutrient budgets across the lagoon. Depending on the variability in barrage flows and oceanographic conditions, the time frame for a management action to have its full effect may take many years and this long-term effect has not been captured in the assessments undertaken here. In addition, simulations also do not consider carry over effects associated with the status of the seed-bank, or other (non-environmental) stressors experienced by *Ruppia*, and therefore don't account for the lag-time that would occur in reality for a healthy bed to emerge.

The results do not all necessarily agree with the conventional wisdom which suggests that holding the water level higher for longer in the CSL will give *Ruppia* a greater chance to complete its life-cycle (Paton et al. 2015). With this in mind, the structures proposed for this assessment were initially designed to maintain 0.2 m AHD at the end of December, and the results show they achieve this. However, the habitat model used here suggests those conditions are sub optimal and this is due to the present habitat model being based on further information coming out of the *Optimising Ruppia Habitat* project (Collier et al., 2017), and in particular the consideration of the limitation of water depth on flowering success. It may be that the choice of sill heights for this assessment at 0.6 and 0.4 mAHD was too high, and further simulations could potentially find an optimum. Nonetheless, the results have indicated the weir may negatively impact the overall habitat suitability by limiting the available area where established plants can flower. In contrast, the ORH simulation with a small weir at 0.4 mAHD did see a benefit, suggesting that when the Salt Creek flows were low, and exhibit a different delivery regime, then management could seek to make a positive impact on flowering habitat.

Therefore, uncertainty remains in aspects of the model predictions and further work is recommended for the ongoing use of the model to support decision-making within the Coorong within the context of flow modification (both through SEFRP augmentation and installation of a flow regulator). To address this uncertainty three major recommendations for ongoing work are:

- further simulations are recommended to find an optimum flow regulator physical configuration and operational regime that promotes all plant life-stages, (at least for sexual reproduction), exploring a wider range of barrage and Salt Creek flows, and their timing.
- further assessment of the CSL biogeochemical dynamics, including:
    - better characterisation of the range of input nutrient loads from different SEFRP and augmentation scenarios;
    - nutrient loads from sediment vs recycling, and links to Ulva accumulation;
- ongoing assessment of the ecological basis for the *Ruppia* HSI algorithms, including:
    - Improved surveys to capture the spatial extent of both *Ulva* and *Ruppia* is suggested to provide a higher level of confidence to validate model predictions;

- ongoing assays assessing the eco-physiological response of different *Ruppia* life-stages to environmental conditions. In particular, a range of studies on adult plant growth have been undertaken but the present results indicated that the seed and flowering phases, where less information is available, are the most sensitive life-stages.

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Appendix

Figures A1-A16: Output results.
Tables A1-A4: Summary data on habitat area.

Simulation 0: (00_012_ORH_2014_2016)

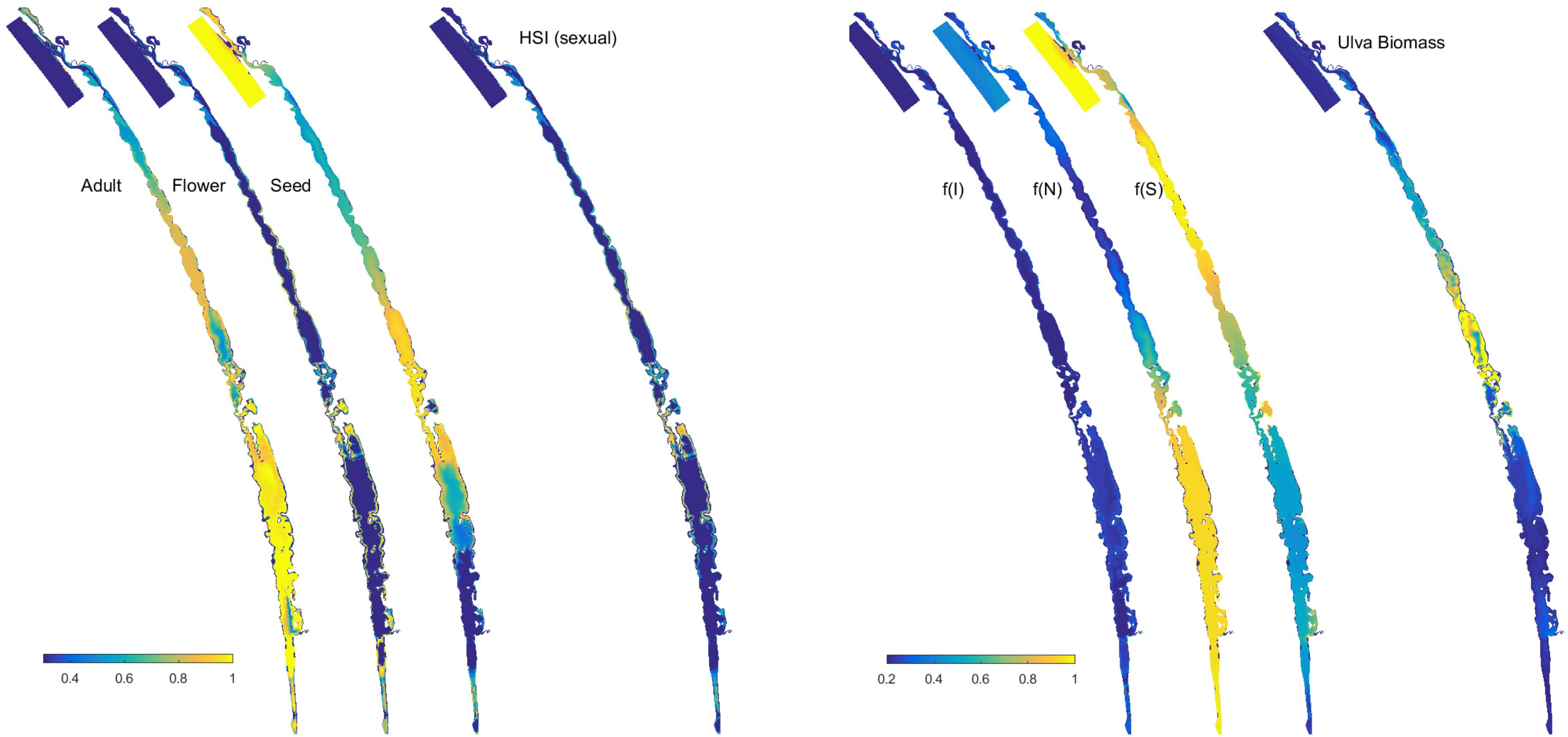

Figure A1: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 1: (01_012_Weir_3_SC40_noWeir)

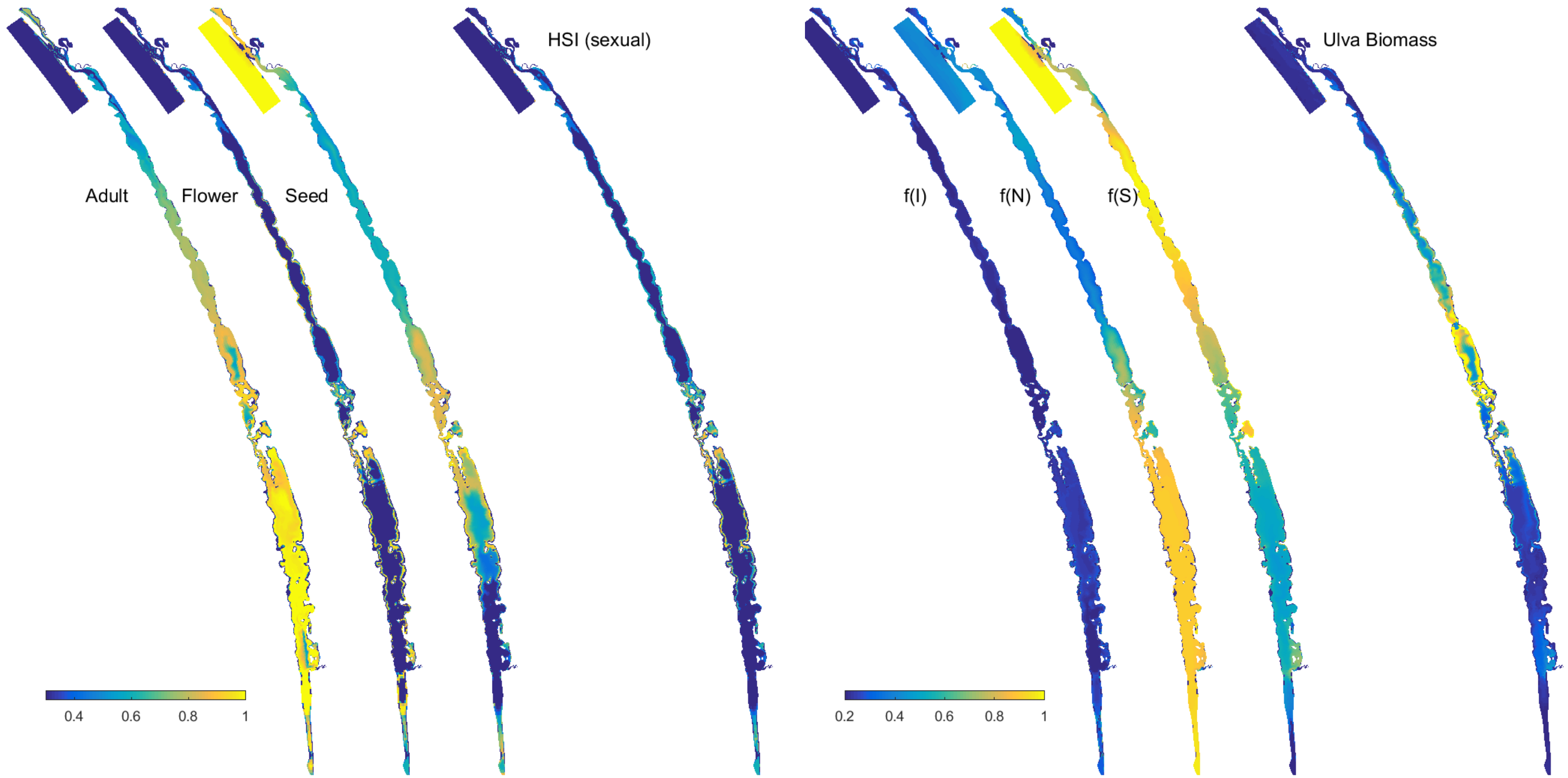

Figure A2: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 2: (02_013_Weir_2_SC40_Parnka_Fixed_TS)

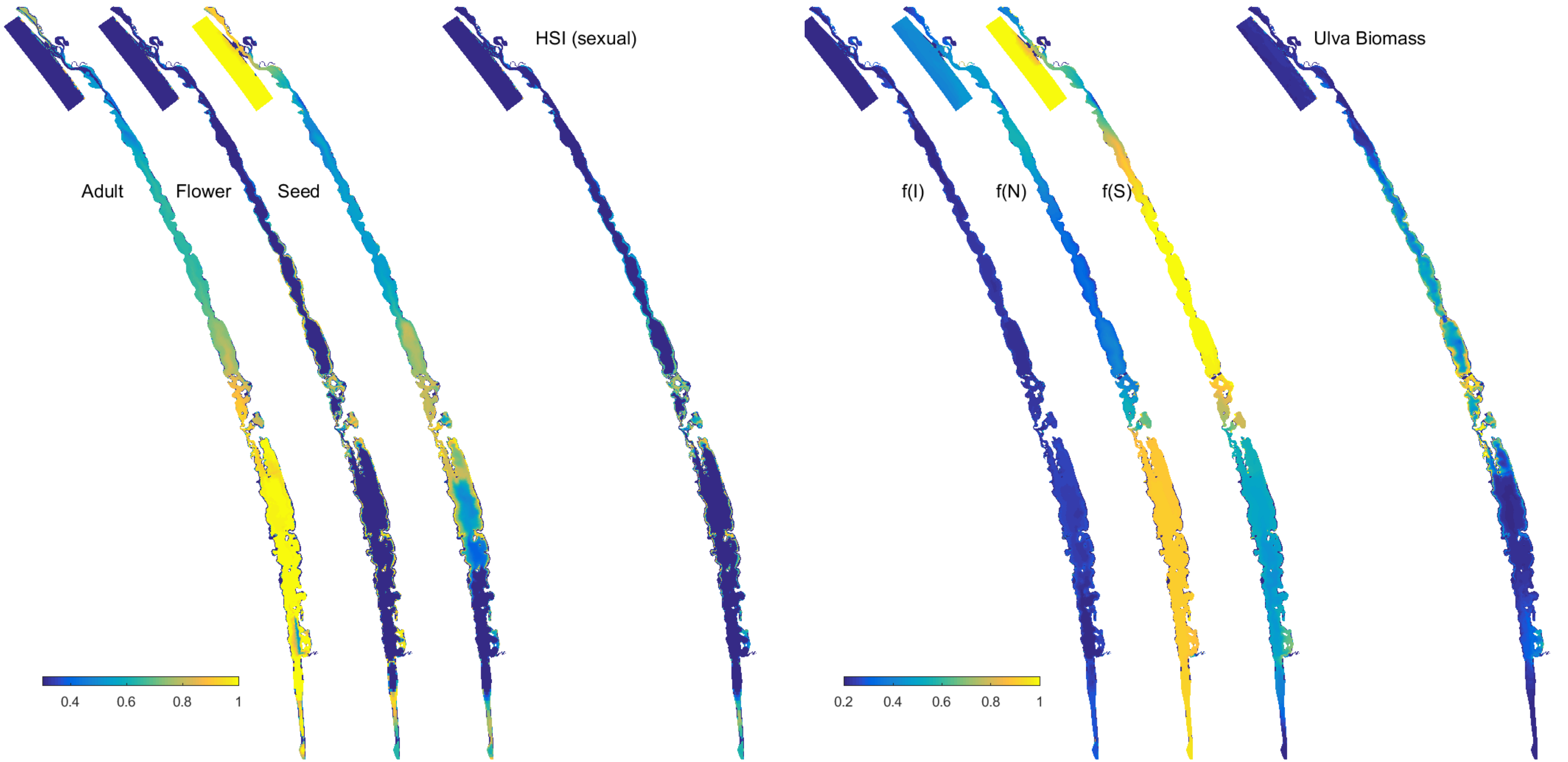

Figure A3: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 3: (03_013_Weir_1_SC40_Needles)

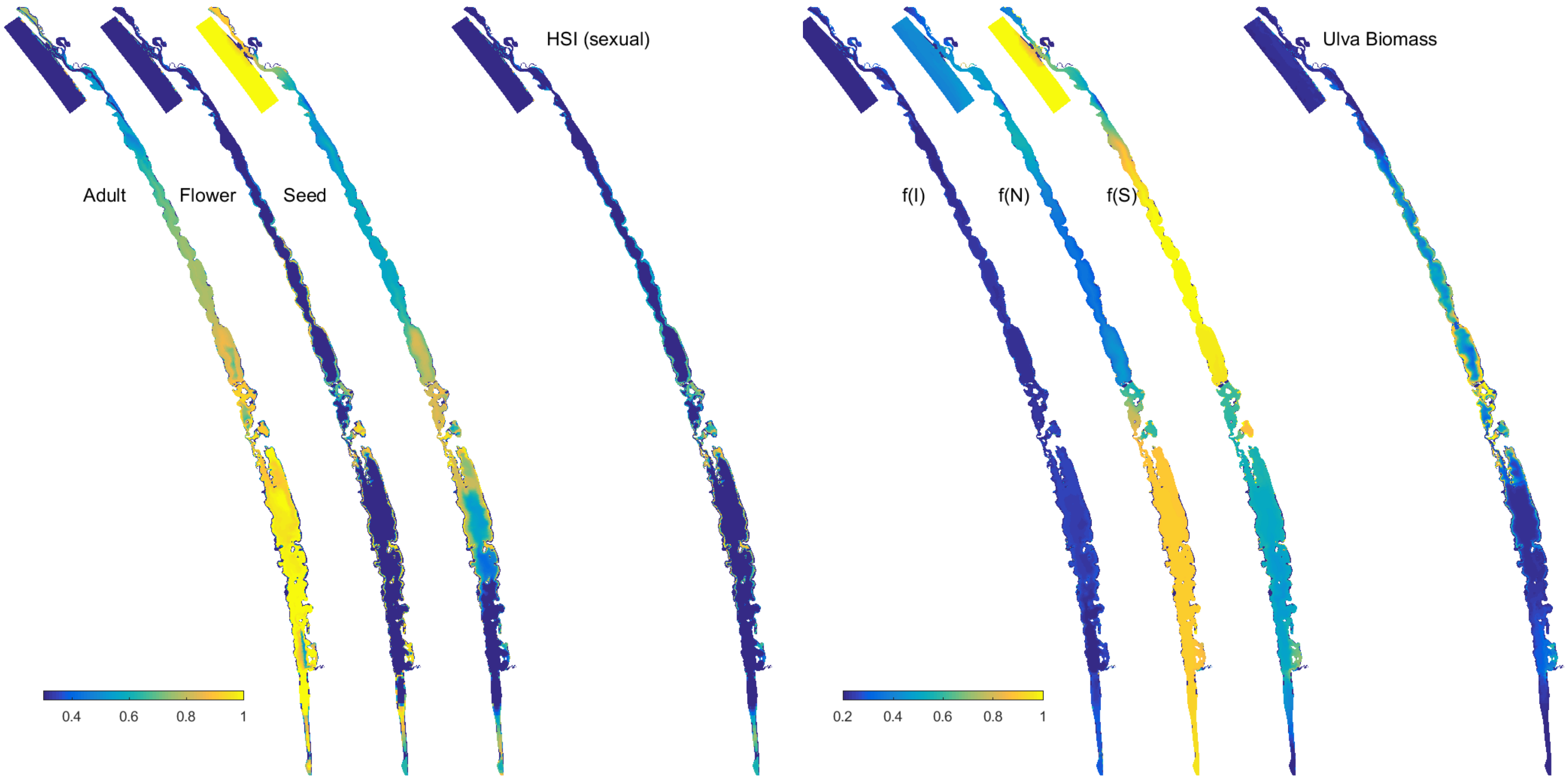

Figure A4: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 4: (04_012_Weir_6_SC70_noWeir)

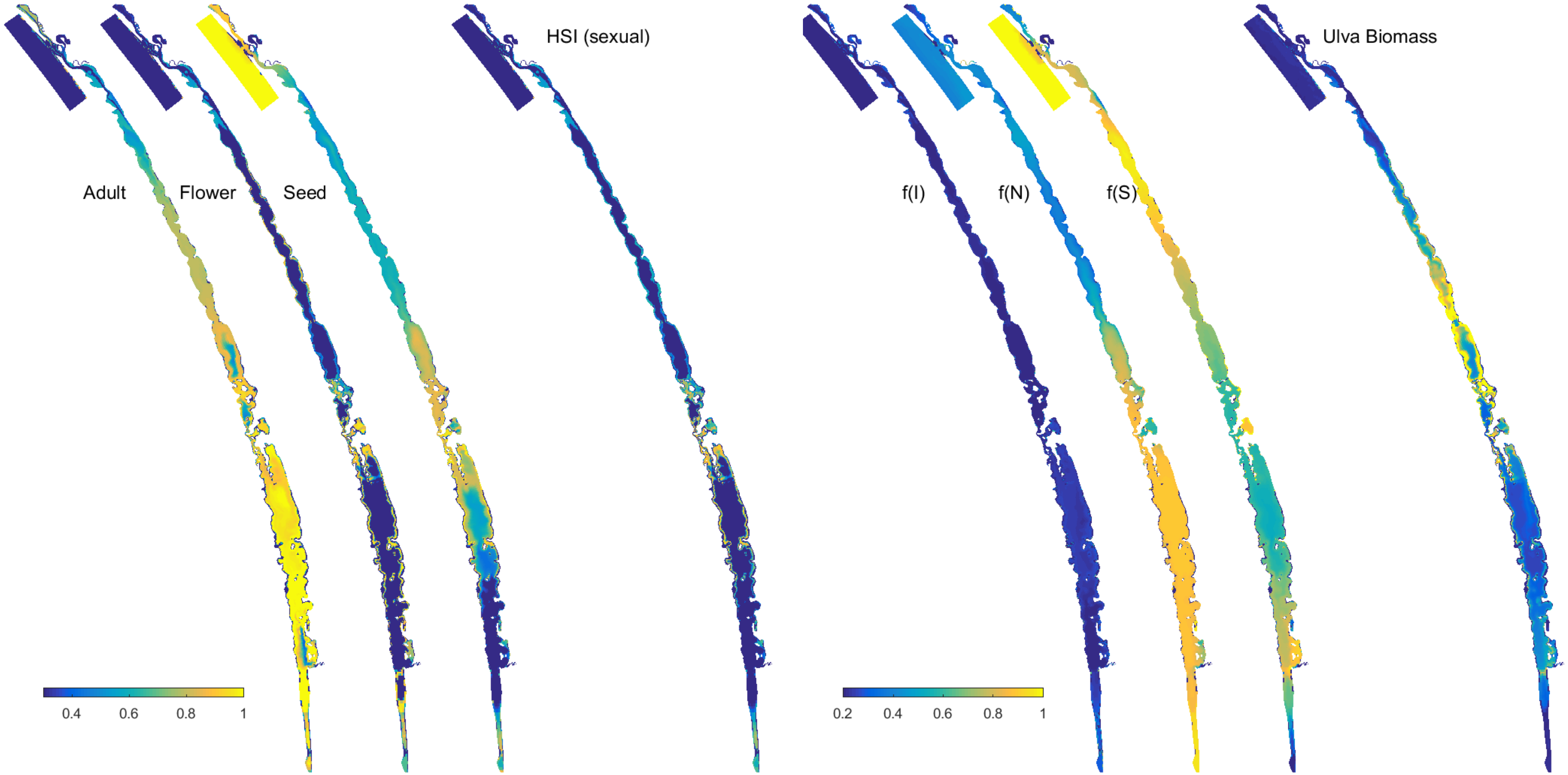

Figure A5: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 5: (05_013_Weir_5_SC70_Parnka)

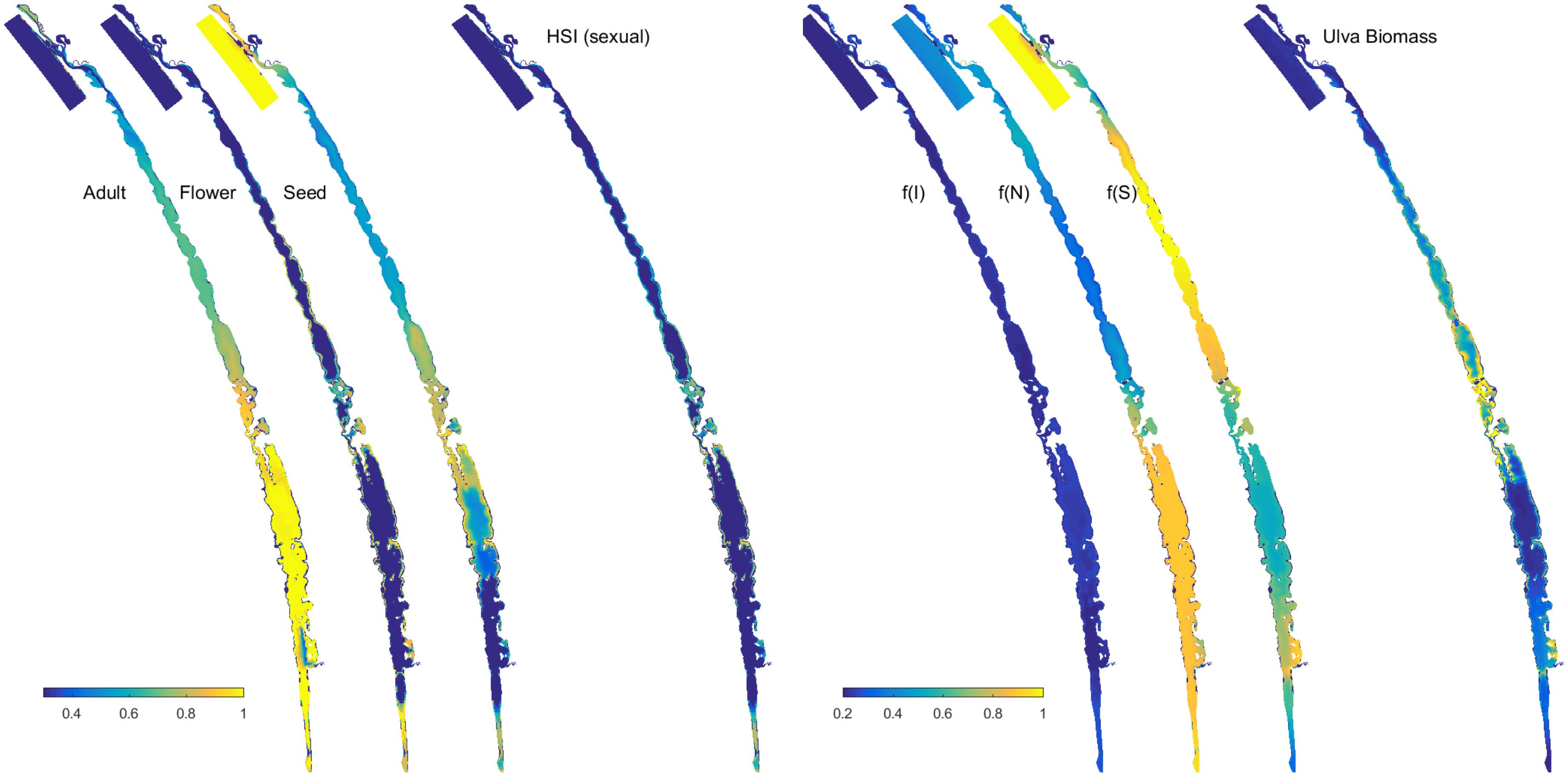

Figure A6: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 6: (06_013_Weir_4_SC70_Needles)

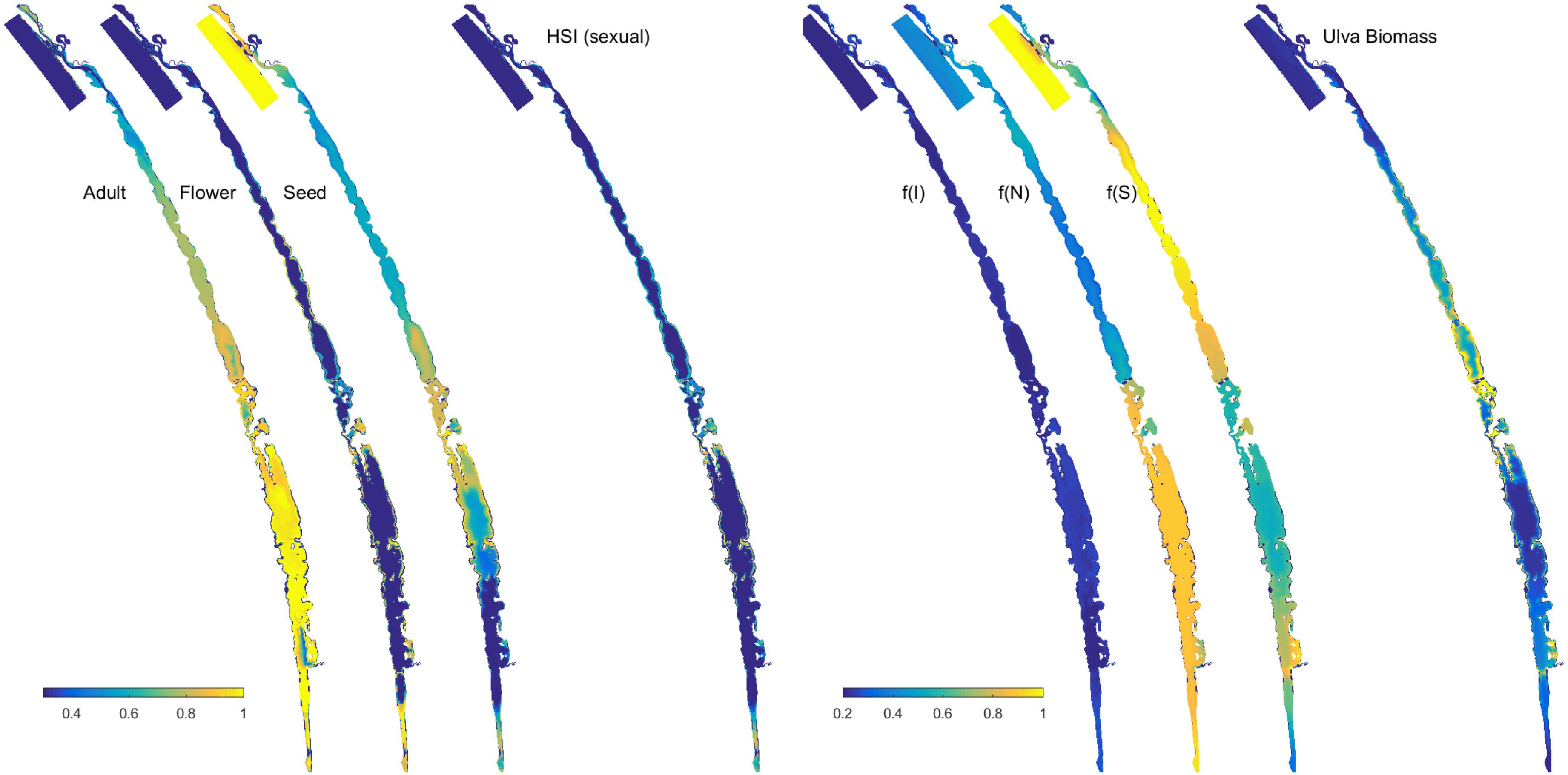

Figure A7: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 7: (07_013_Weir_9_SC55_noWeir)

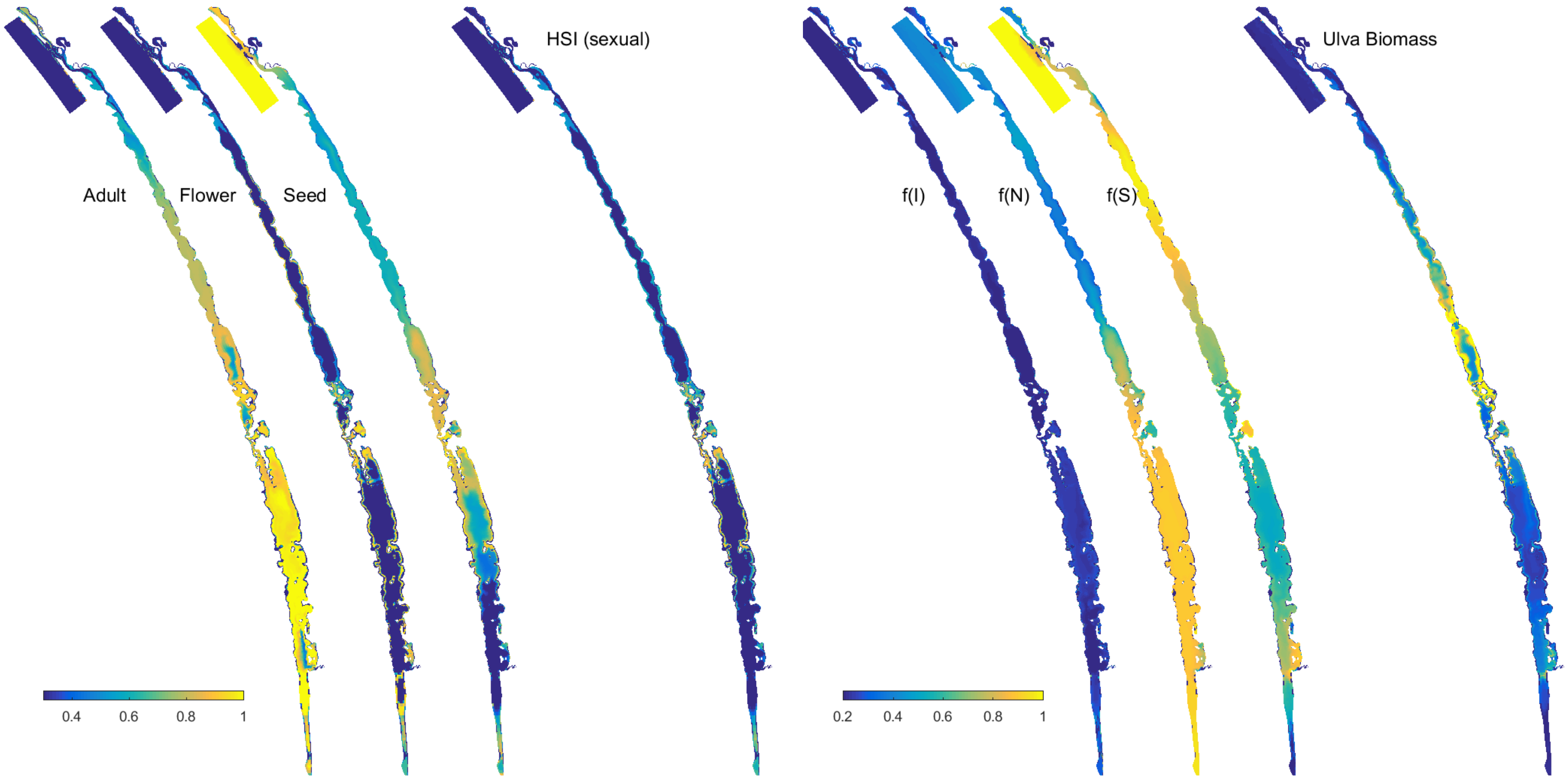

Figure A8: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 8: (08_013_Weir_8_SC55_Parnka)

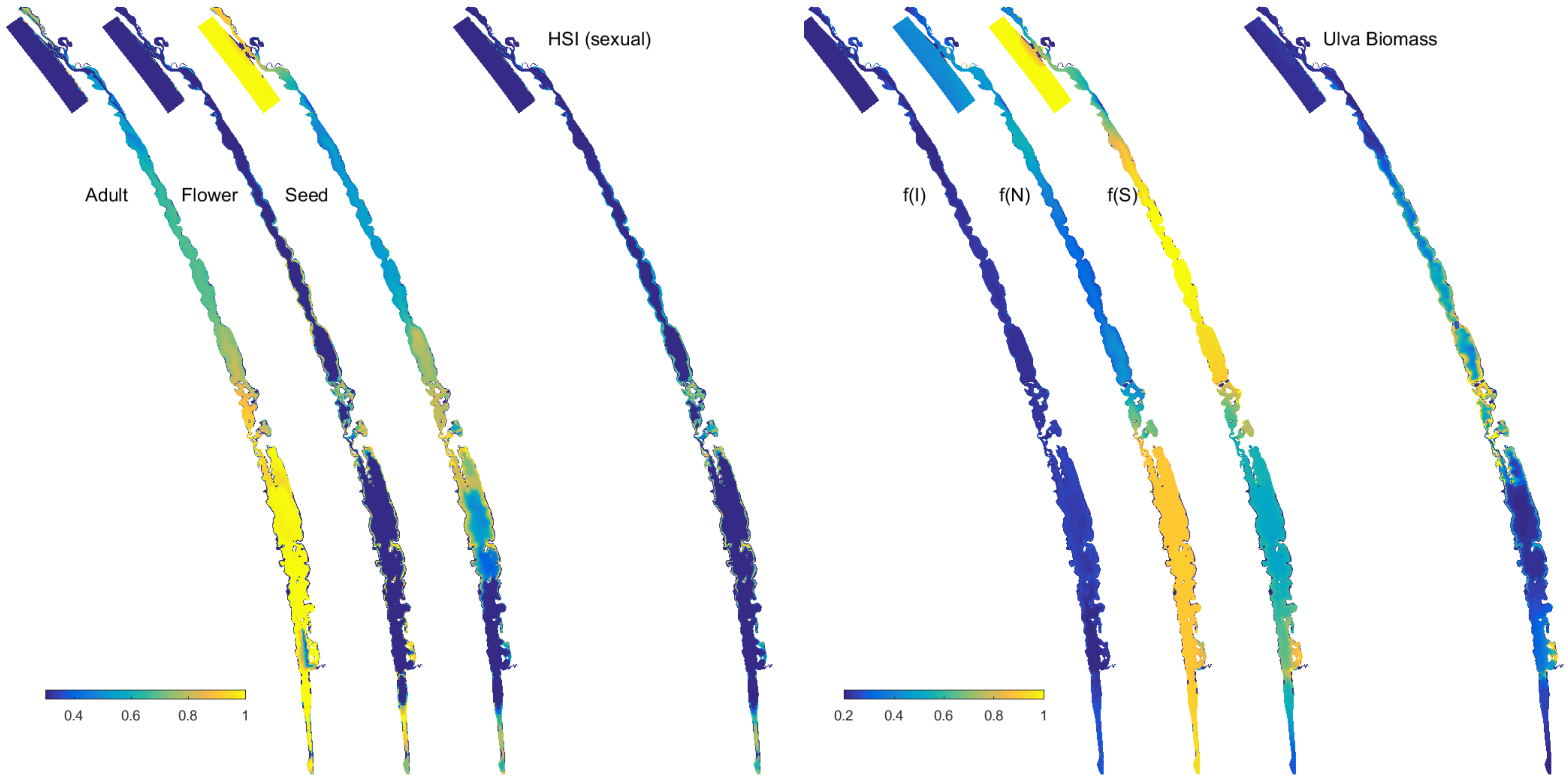

Figure A9: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 9: (09_013_Weir_7_SC55_Needles)

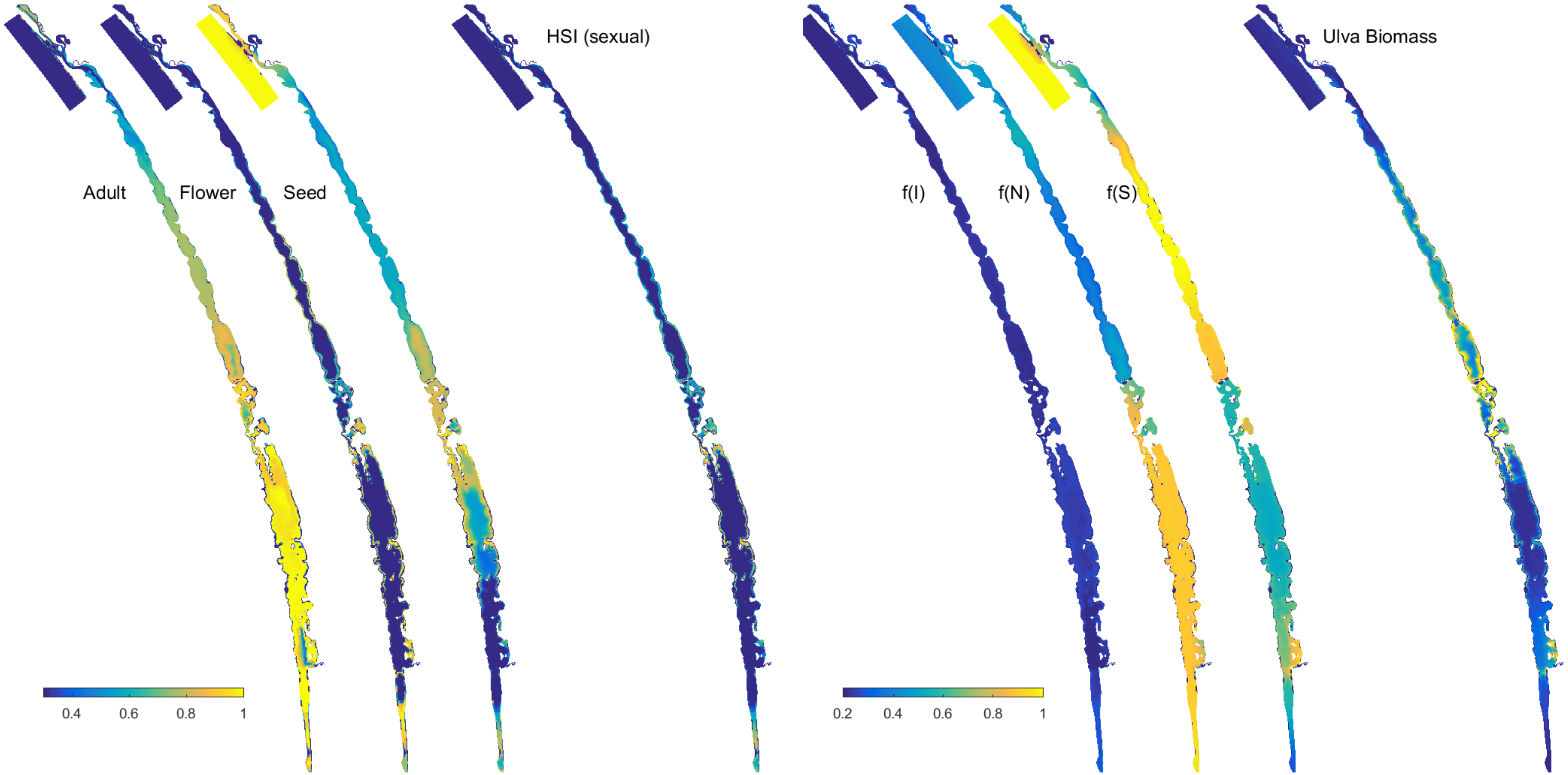

Figure A10: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 10: (10_013_Weir_10_SC70_Needles_Sill04)

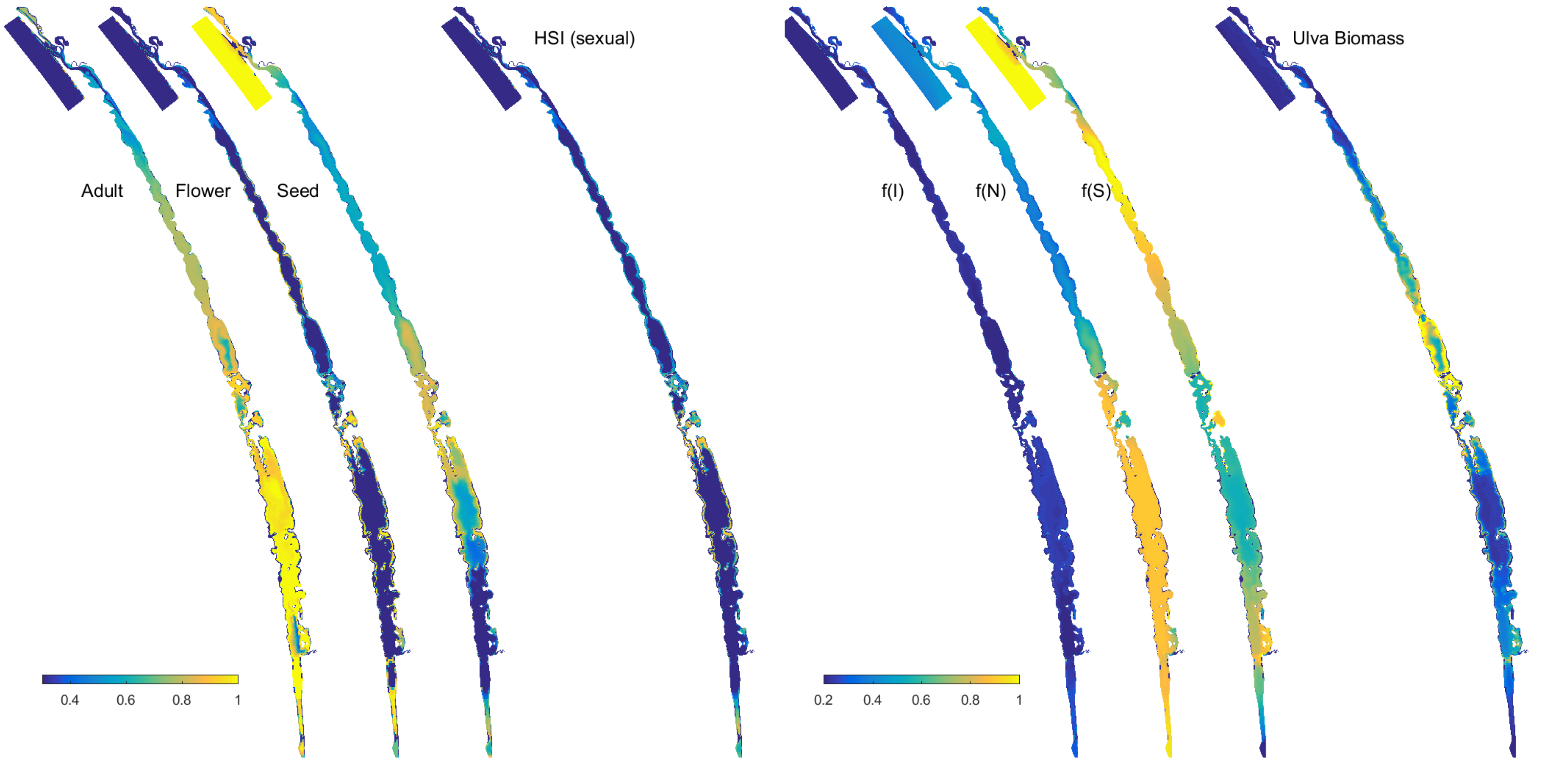

Figure A12: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 11: (11_013_Weir_11_Parnka_SC40_SAL)

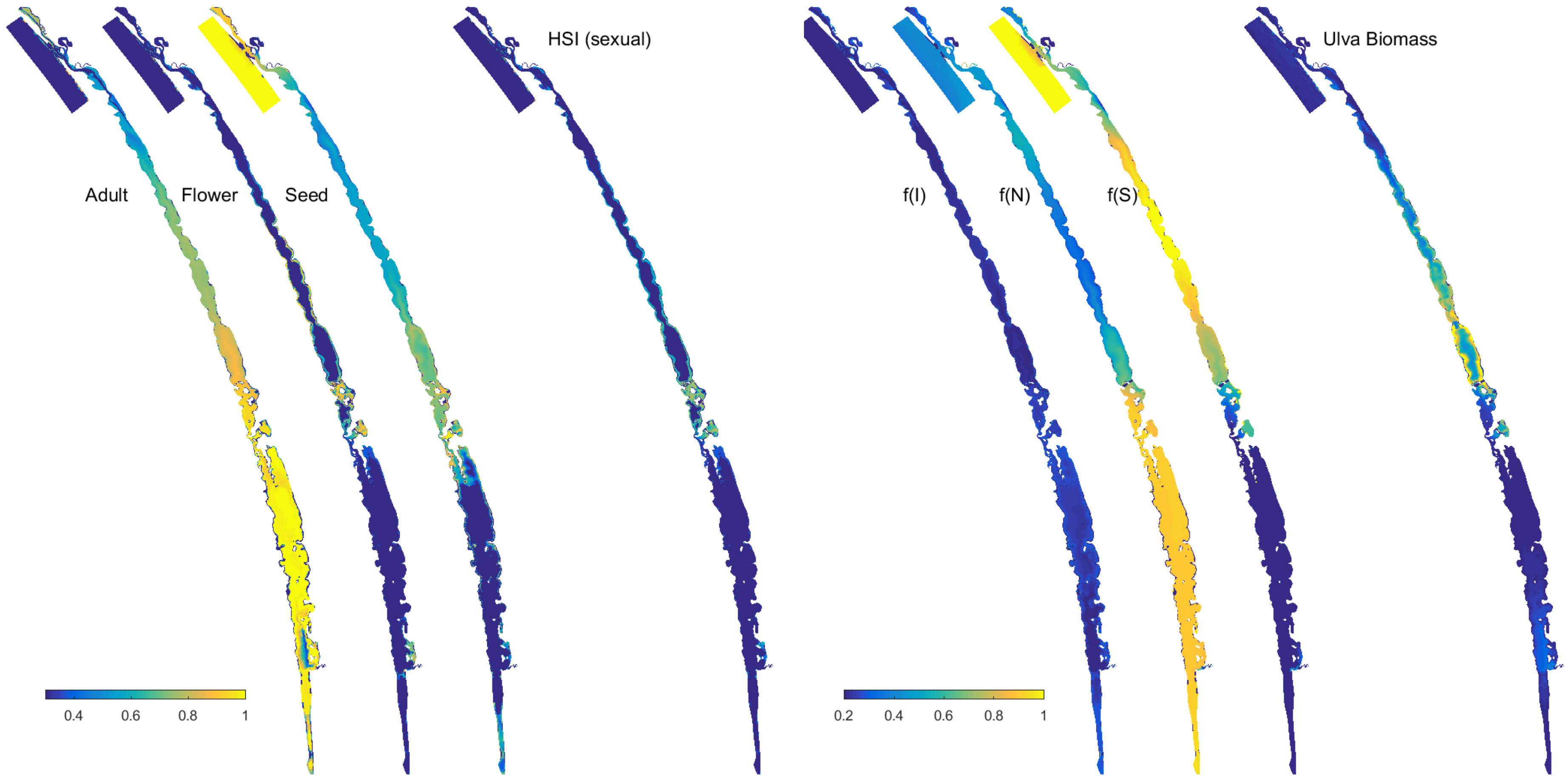

Figure A12: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 12: (12_013_Weir_12_noWeir_SC40_SAL_PGrid)

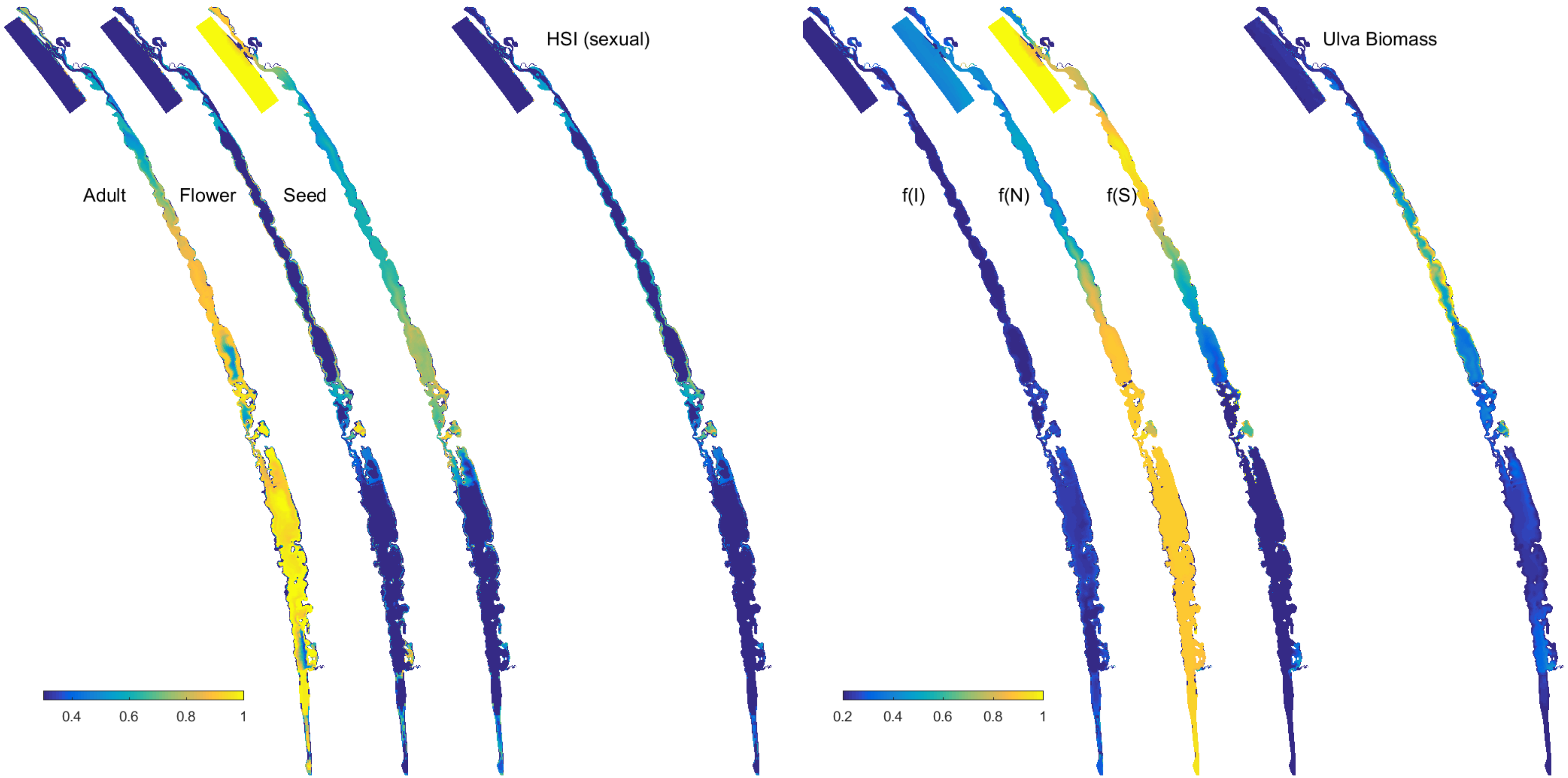

Figure A13: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 13: (13_013_Weir_2_SC40_Parnka)

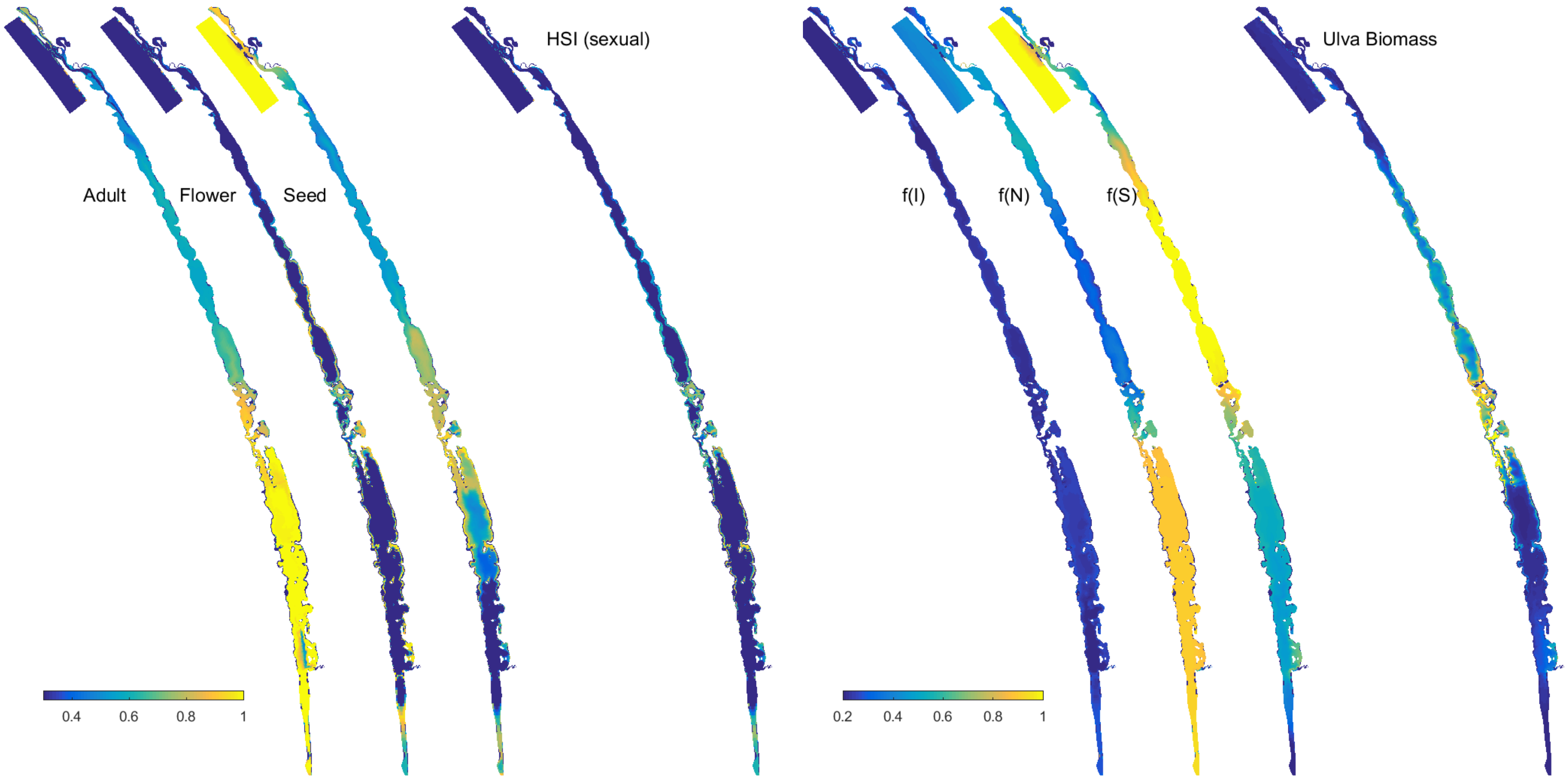

Figure A14: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 14: (14_013_ORH_2014_2016_Needles_Sill)

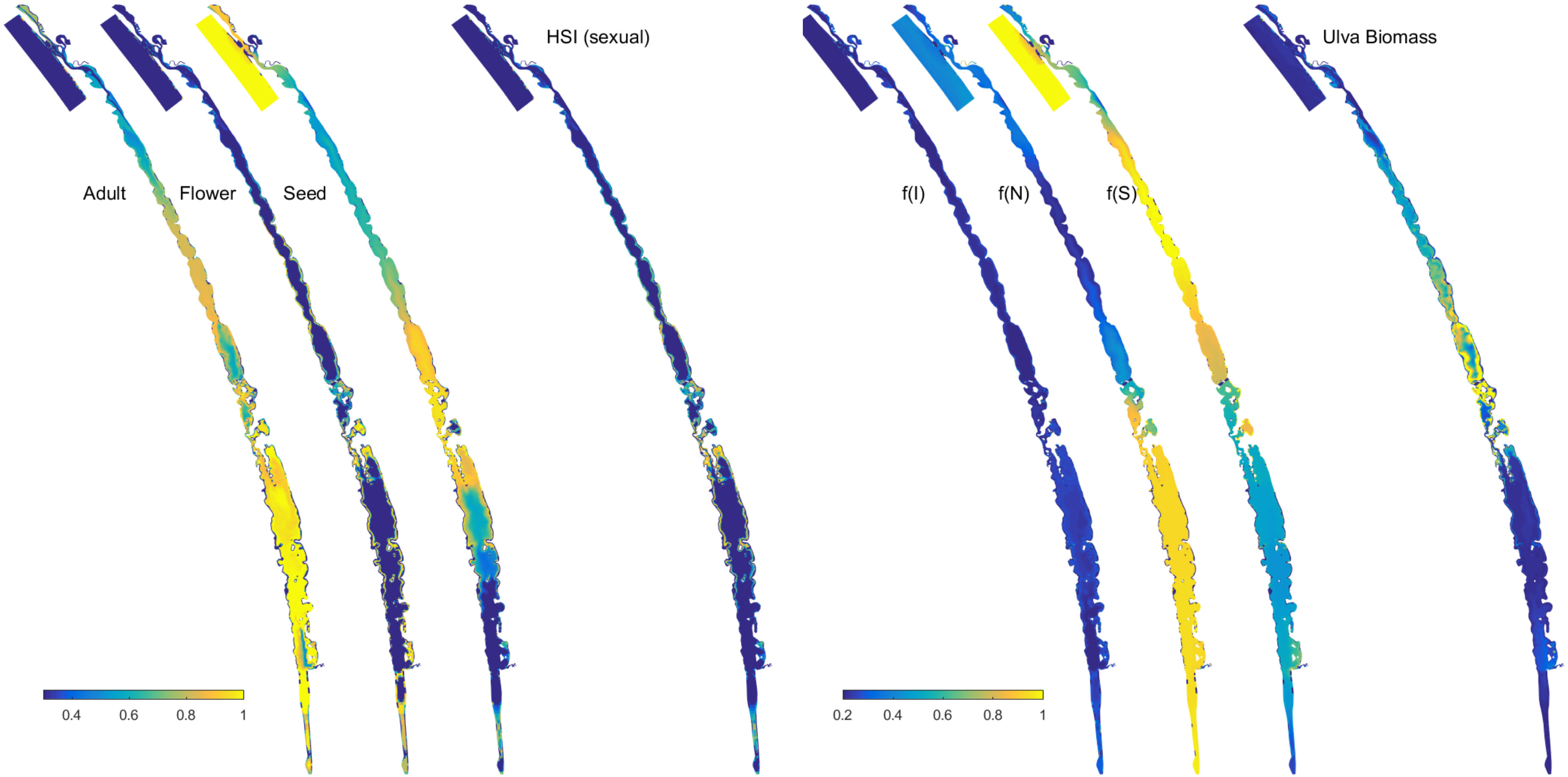

Figure A15: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Simulation 15: (15_013_Weir_13_Parnka_SC55_J)

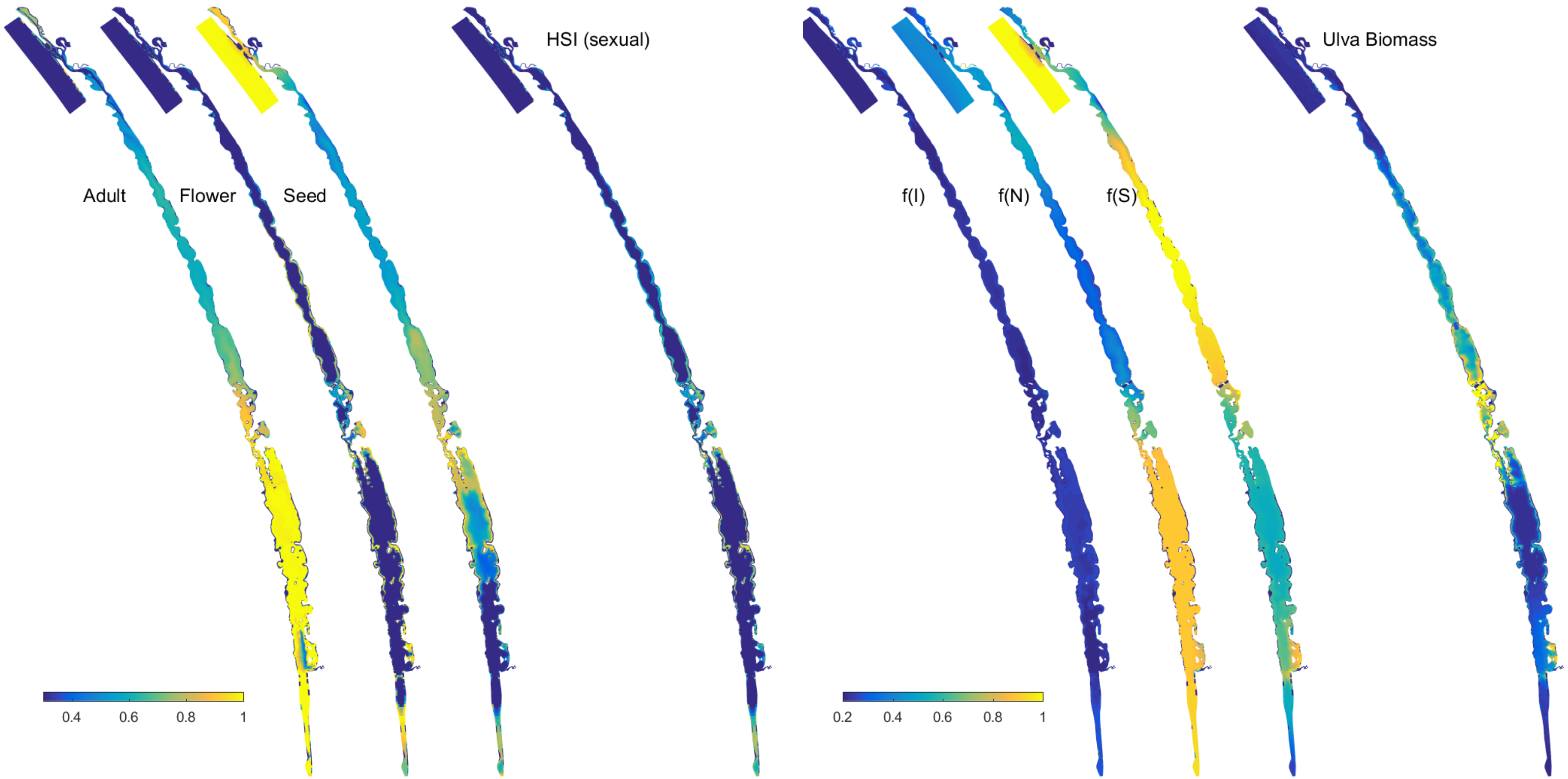

Figure A16: 2014 *HSI* (sexual) distribution, based on the adult, flower and seed life-stages (left), and controls on *Ulva* distribution, and biomass (right).

Table A1: The area of suitable habitat, A^{HSI} (x10^3 Ha), for the completion of the **full sexual life-cycle**, presented for CNL, PR and CSL. In addition, the relative difference (%) between the predictions of a scenario is presented relative to both the ORH base-case simulation, and the NoWeirSC40 simulation.

	Area (x10^3 Ha)								2015 % difference relative to ORH			2015 % difference relative to No Weir SC40			2-yr total % difference relative to No Weir SC40
	CNL		PR		CSL		Total		CNL	PR	CSL	CNL	PR	CSL	CNL+PR+CSL
Scenario:	2014	2015	2014	2015	2014	2015	2014	2015	2015	2015	2015	2015	2015	2015	2014+2015
ORH: 0	1.13	0.57	1.38	1.36	1.17	0.69	3.69	2.61				-25.3	5.5	-3.7	-4%
NoWeir SC40: 1	1.08	0.76	1.45	1.29	1.25	0.71	3.79	2.76	33.9	-5.2	3.8				-
Parnka SC40: 2	0.94	0.56	1.23	0.93	1.18	0.65	3.34	2.13	-2.0	-31.4	-5.9	-26.8	-27.6	-9.3	-16%
Needles SC40: 3	0.98	0.56	1.14	1.21	1.17	0.71	3.29	2.49	-1.4	-10.5	3.8	-26.4	-5.5	0.0	-12%
NoWeir SC70: 4	1.07	0.91	1.49	1.14	1.31	1.28	3.86	3.33	60.7	-15.9	86.6	20.0	-11.3	79.7	10%
Parnka SC70: 5	0.98	0.56	1.17	0.80	1.21	0.97	3.36	2.32	-1.1	-41.3	40.8	-26.2	-38.0	35.6	-13%
Needles SC70: 6	1.04	0.76	1.04	0.89	1.20	1.08	3.28	2.73	33.6	-34.5	57.4	-0.2	-30.9	51.6	-8%
NoWeir SC55: 7	1.08	0.87	1.49	1.25	1.30	0.89	3.86	3.01	53.5	-8.0	29.5	14.6	-2.9	24.8	5%
Parnka SC55: 8	0.96	0.54	1.20	0.85	1.22	0.70	3.38	2.09	-4.8	-37.5	1.8	-28.9	-34.0	-2.0	-16%
Needles SC55: 9	1.01	0.55	1.09	1.07	1.21	0.81	3.31	2.43	-2.4	-20.9	17.5	-27.1	-16.5	13.2	-12%
Needles SC70 Sill@0.4: 10	1.06	0.74	1.31	0.87	1.31	1.12	3.68	2.74	29.9	-35.6	63.9	-3.0	-32.0	57.9	-2%
Parnka SC40 HighSalinity: 11	1.00	0.81	1.00	0.37	0.15	0.11	2.14	1.29	43.0	-72.4	-84.2	6.8	-70.9	-84.8	-47%
NoWeir SC40 HighSalinity: 12	1.21	1.00	1.13	0.57	0.34	0.07	2.67	1.64	76.9	-57.9	-90.4	32.1	-55.6	-90.8	-34%
Parnka SC40 AugCulverts: 13	0.89	0.51	1.18	0.90	1.22	0.62	3.28	2.03	-9.3	-33.9	-9.8	-32.3	-30.3	-13.1	-19%
Needles ORH Sill@0.4: 14	1.17	0.52	1.36	1.49	1.23	0.68	3.75	2.69	-8.1	9.8	-1.3	-31.3	15.9	-4.9	-2%
Parnka SC40 Jul flow start: 15	0.94	0.85	1.16	0.87	1.29	0.65	3.39	2.37	49.4	-35.9	-4.9	11.6	-32.4	-8.4	-12%

Table A2: The area of suitable habitat, A^{HSI} ($x10^3$ Ha), for the completion of the **seed**, presented for CNL, PR and CSL. In addition, the relative difference (%) between the predictions of a scenario is presented relative to both the ORH base-case simulation, and the NoWeirSC40 simulation.

	Area ($x10^3$ Ha)								2015 % difference relative to ORH			2015 % difference relative to No Weir SC40			2-yr total % difference relative to No Weir SC40
	CNL		PR		CSL		Total		CNL	PR	CSL	CNL	PR	CSL	CNL+PR+CSL
Scenario:	2014	2015	2014	2015	2014	2015	2014	2015	2015	2015	2015	2015	2015	2015	2014+2015
ORH: 0	5.13	4.03	2.85	2.65	3.66	2.43	11.64	9.11				-3.9	1.8	-12.8	1%
NoWeir SC40: 1	4.55	4.19	2.71	2.61	3.69	2.79	10.95	9.59	4.1	-1.7	14.7				-
Parnka SC40: 2	4.21	3.71	2.64	2.31	3.55	2.07	10.40	8.10	-7.8	-13.0	-14.7	-11.4	-11.5	-25.7	-10%
Needles SC40: 3	4.39	4.16	2.69	2.53	3.67	2.51	10.75	9.19	3.2	-4.8	3.2	-0.8	-3.1	-10.0	-3%
NoWeir SC70: 4	4.55	4.26	2.71	2.63	3.69	4.88	10.95	11.77	5.7	-1.0	100.8	1.6	0.7	75.0	11%
Parnka SC70: 5	4.21	4.14	2.64	2.25	3.55	3.76	10.40	10.14	2.8	-15.3	54.5	-1.3	-13.8	34.7	0%
Needles SC70: 6	4.39	4.43	2.69	2.45	3.67	4.38	10.75	11.25	10.0	-7.8	79.9	5.7	-6.2	56.8	7%
NoWeir SC55: 7	4.55	4.21	2.71	2.63	3.69	3.18	10.95	10.01	4.4	-1.0	30.6	0.3	0.8	13.8	2%
Parnka SC55: 8	4.21	3.91	2.64	2.27	3.55	2.25	10.40	8.42	-3.0	-14.5	-7.5	-6.8	-13.0	-19.4	-8%
Needles SC55: 9	4.39	4.28	2.69	2.49	3.67	2.78	10.75	9.56	6.2	-6.1	14.5	2.1	-4.4	-0.2	-1%
Needles SC70 Sill@0.4: 10	4.41	4.28	2.69	2.56	3.67	4.66	10.78	11.49	6.2	-3.6	91.5	2.0	-1.9	66.9	8%
Parnka SC40 HighSalinity: 11	4.27	4.46	2.07	0.90	0.89	0.33	7.23	5.70	10.8	-65.9	-86.3	6.4	-65.3	-88.1	-37%
NoWeir SC40 HighSalinity: 12	4.62	4.73	2.07	1.32	0.80	0.34	7.49	6.39	17.5	-50.2	-86.1	12.9	-49.4	-87.9	-32%
Parnka SC40 AugCulverts: 13	4.21	3.80	2.64	2.26	3.55	1.96	10.40	8.03	-5.6	-14.8	-19.2	-9.3	-13.3	-29.6	-10%
Needles ORH Sill@0.4: 14	5.06	3.86	2.85	2.67	3.63	2.43	11.55	8.95	-4.2	0.6	-0.2	-8.0	2.4	-13.0	0%
Parnka SC40 Jul flow start: 15	4.18	4.03	2.65	2.17	3.60	2.10	10.43	8.30	0.2	-18.2	-13.7	-3.7	-16.7	-24.8	-9%

Table A3: The area of suitable habitat, A^{HSI} ($x10^3$ Ha), for the completion of the **flower**, presented for CNL, PR and CSL. In addition, the relative difference (%) between the predictions of a scenario is presented relative to both the ORH base-case simulation, and the NoWeirSC40 simulation.

	Area ($x10^3$ Ha)								2015 % difference relative to ORH			2015 % difference relative to No Weir SC40			2-yr total % difference relative to No Weir SC40
	CNL		PR		CSL		Total		CNL	PR	CSL	CNL	PR	CSL	CNL+PR+CSL
Scenario:	2014	2015	2014	2015	2014	2015	2014	2015	2015	2015	2015	2015	2015	2015	2014+2015
ORH: 0	1.24	0.66	1.52	1.46	2.00	1.41	4.76	3.54				-33.2	3.3	-11.6	-5%
NoWeir SC40: 1	1.25	0.99	1.51	1.42	1.92	1.59	4.68	4.00	49.6	-3.2	13.1				-
Parnka SC40: 2	1.12	0.74	1.31	1.13	1.64	1.59	4.07	3.47	11.5	-22.7	13.4	-25.5	-20.2	0.2	-13%
Needles SC40: 3	1.14	0.68	1.19	1.34	1.69	1.52	4.03	3.54	1.9	-8.4	8.2	-31.9	-5.3	-4.3	-13%
NoWeir SC70: 4	1.23	1.15	1.56	1.26	1.96	1.65	4.75	4.06	72.8	-13.8	17.0	15.5	-10.9	3.4	1%
Parnka SC70: 5	1.19	0.70	1.27	1.03	1.70	1.56	4.16	3.28	4.6	-29.9	10.6	-30.1	-27.6	-2.2	-14%
Needles SC70: 6	1.21	0.93	1.13	1.07	1.73	1.61	4.08	3.61	40.1	-27.2	14.4	-6.4	-24.8	1.1	-11%
NoWeir SC55: 7	1.24	1.10	1.56	1.38	1.97	1.72	4.77	4.20	65.3	-5.7	22.0	10.5	-2.6	7.9	3%
Parnka SC55: 8	1.16	0.67	1.29	1.06	1.70	1.60	4.15	3.34	1.4	-27.4	14.0	-32.2	-25.0	0.7	-14%
Needles SC55: 9	1.18	0.64	1.16	1.22	1.76	1.59	4.10	3.45	-3.7	-16.6	13.0	-35.6	-13.9	-0.1	-13%
Needles SC70 Sill@0.4: 10	1.24	0.93	1.37	0.95	1.93	1.48	4.54	3.36	40.1	-35.0	5.0	-6.3	-32.8	-7.2	-9%
Parnka SC40 HighSalinity: 11	1.15	0.94	1.07	0.41	0.32	0.42	2.54	1.78	41.1	-71.8	-69.8	-5.7	-70.9	-73.3	-50%
NoWeir SC40 HighSalinity: 12	1.34	1.18	1.16	0.64	0.84	0.55	3.35	2.37	77.0	-56.0	-61.0	18.3	-54.6	-65.6	-34%
Parnka SC40 AugCulverts: 13	1.07	0.67	1.28	1.10	1.68	1.59	4.03	3.36	1.2	-24.9	13.0	-32.3	-22.4	-0.1	-15%
Needles ORH Sill@0.4: 14	1.27	0.65	1.48	1.67	2.02	1.44	4.78	3.76	-2.8	14.3	2.6	-35.1	18.1	-9.3	-2%
Parnka SC40 Jul flow start: 15	1.15	1.02	1.25	1.19	1.78	1.59	4.18	3.80	53.0	-18.6	13.2	2.3	-15.9	0.1	-8%

Table A4: The area of suitable habitat, A^{HSI} ($x10^3$ Ha), for the completion of the **adult**, presented for CNL, PR and CSL. In addition, the relative difference (%) between the predictions of a scenario is presented relative to both the ORH base-case simulation, and the NoWeirSC40 simulation.

	Area ($x10^3$ Ha)								2015 % difference relative to ORH			2015 % difference relative to No Weir SC40			2-yr total % difference relative to No Weir SC40
	CNL		PR		CSL		Total		CNL	PR	CSL	CNL	PR	CSL	CNL+PR+CSL
Scenario:	2014	2015	2014	2015	2014	2015	2014	2015	2015	2015	2015	2015	2015	2015	2014+2015
ORH: 0	5.11	3.83	2.67	2.23	8.16	7.74	15.94	13.80				2.1	-0.7	2.6	1%
NoWeir SC40: 1	5.09	3.76	2.71	2.25	8.16	7.54	15.97	13.54	-2.0	0.7	-2.6				-
Parnka SC40: 2	4.59	3.27	2.84	2.49	8.33	7.49	15.76	13.25	-14.6	11.5	-3.2	-12.9	10.7	-0.7	-2%
Needles SC40: 3	5.05	3.65	2.78	2.47	8.20	7.42	16.03	13.54	-4.7	10.7	-4.1	-2.8	10.0	-1.6	0%
NoWeir SC70: 4	5.18	3.98	2.71	2.22	8.12	7.51	16.01	13.71	3.9	-0.7	-3.0	6.0	-1.4	-0.5	1%
Parnka SC70: 5	4.72	3.74	2.88	2.56	8.35	7.52	15.95	13.82	-2.4	14.7	-2.8	-0.4	14.0	-0.2	1%
Needles SC70: 6	5.15	4.02	2.80	2.39	8.19	7.38	16.14	13.79	5.0	7.2	-4.6	7.1	6.4	-2.1	1%
NoWeir SC55: 7	5.16	3.91	2.71	2.23	8.13	7.55	16.01	13.69	2.1	0.1	-2.5	4.2	-0.6	0.1	1%
Parnka SC55: 8	4.70	3.54	2.87	2.53	8.35	7.40	15.91	13.46	-7.8	13.5	-4.4	-5.9	12.7	-1.9	0%
Needles SC55: 9	5.13	3.81	2.80	2.41	8.19	7.31	16.12	13.54	-0.5	8.0	-5.5	1.5	7.3	-3.0	0%
Needles SC70 Sill@0.4: 10	5.15	4.03	2.76	2.30	8.16	7.37	16.07	13.70	5.1	2.9	-4.7	7.3	2.2	-2.2	1%
Parnka SC40 HighSalinity: 11	5.08	4.13	2.91	2.69	8.11	7.66	16.10	14.48	7.7	20.4	-1.0	9.9	19.6	1.6	4%
NoWeir SC40 HighSalinity: 12	5.41	4.37	2.72	2.47	7.93	7.63	16.07	14.47	14.1	10.7	-1.5	16.5	10.0	1.1	3%
Parnka SC40 AugCulverts: 13	4.17	3.29	2.88	2.48	8.48	7.52	15.52	13.28	-14.2	11.1	-2.9	-12.4	10.3	-0.3	-2%
Needles ORH Sill@0.4: 14	5.14	3.79	2.73	2.29	8.18	7.74	16.05	13.83	-1.0	2.7	0.0	1.0	2.0	2.6	1%
Parnka SC40 Jul flow start: 15	4.33	3.59	2.92	2.58	8.49	7.41	15.75	13.58	-6.3	15.4	-4.3	-4.3	14.6	-1.8	-1%