EMI R&D PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026
Project Title:	Adriatic Sea and Coast (AdriSC) climate model v2.0
Computer Project Account:	SPCRDEN2
Principal Investigator(s):	Clea Lumina Denamiel
Affiliation:	Ruđer Bošković Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	/
Start date of the project:	2026
Expected end date:	2028

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	/	/	230,000,000	9,195,025
Data storage capacity	(Gbytes)	/	/	200 TB	5,000

Summary of project objectives

The objective of this Special Project is to develop and deploy AdriSC climate model v2.0, a next-generation high-resolution coupled atmosphere–ocean regional climate modelling framework for the Adriatic–Ionian region. The project upgrades the existing AdriSC system through (i) enlarged and co-located atmospheric and oceanic domains, (ii) full two-way atmosphere–ocean coupling, (iii) integration of wave and land-surface models, and (iv) updated forcing from ERA5, Med-MFC, EFAS, and CMIP6 datasets. It also introduces a storyline-based pseudo-global warming (PGW) framework using carefully selected CMIP6 models and Global Warming Levels (GWLs), enabling physically consistent climate projections under multiple warming pathways, including high-impact storylines. The aim is to provide kilometre-scale climate projections to improve the understanding of air–sea interactions and coastal extremes while supporting robust climate adaptation strategies across the Adriatic.

Summary of problems encountered

No technical problems were encountered in these first 6 months. However, due to unexpected circumstances, the upgrade and testing of the AdriSC climate model v2.0 has been slightly delayed this year and reschedule in the summer. However, an interesting experiment on the climate adaptation of a small lagoon in Croatia has been performed. This explains why nearly no resources have been used yet.

Summary of plans for the continuation of the project

The upgrade of the AdriSC climate model to version 2.0 is now scheduled for completion during the summer, after which the allocated ECMWF resources will be used intensively to perform the planned simulations. The project will focus on testing and validating the upgraded coupled atmosphere–ocean modelling system, followed by the production of the first pseudo-global warming (PGW) experiments based on CMIP6 climate projections and Global Warming Levels. These simulations will support the assessment of future changes in air–sea interactions, marine heatwaves, dense water formation, and coastal climate extremes in the Adriatic and eastern Mediterranean. The project remains on track to achieve its scientific objectives, and a substantial increase in computational resource usage is expected over the coming months.

List of publications/reports from the project with complete references

Denamiel, C. Simulation of the climate adaptation strategies for the Palud-Swamp-Sea system, [report], 2026.

Summary of results

Introduction

We include here an illustrative application based on the Palud swamp system. This very shallow coastal wetland was used as a representative test environment for complex air–sea–land interaction processes relevant to climate adaptation in coastal zones. The Palud case is not part of the model development itself but provides a useful example of the type of highly sensitive coastal environments targeted by AdriSC v2.0 applications. It highlights the challenges associated with representing surface fluxes, shallow-water thermal dynamics, and coupled feedback under evolving climatic conditions. This example is therefore presented as a supporting illustration of the broader class of adaptation problems that AdriSC v2.0 is designed to address in future coastal climate impact studies.

1. Modelling strategy

The Palud swamp is a shallow, semi-enclosed coastal wetland whose ecological functioning is strongly controlled by water exchange with the sea, freshwater inputs, and meteorological forcing. Its sensitivity to temperature, salinity, and dissolved oxygen makes it particularly vulnerable to climate change, especially sea-level rise (SLR), heatwaves, and prolonged summer droughts. The coupled SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model) – ICM (Integrated Compartment Model) modelling system used in the domain presented in Figure 1 provides a physically and biogeochemically consistent framework to quantify these sensitivities and to test potential adaptation strategies before any intervention is implemented in the field.

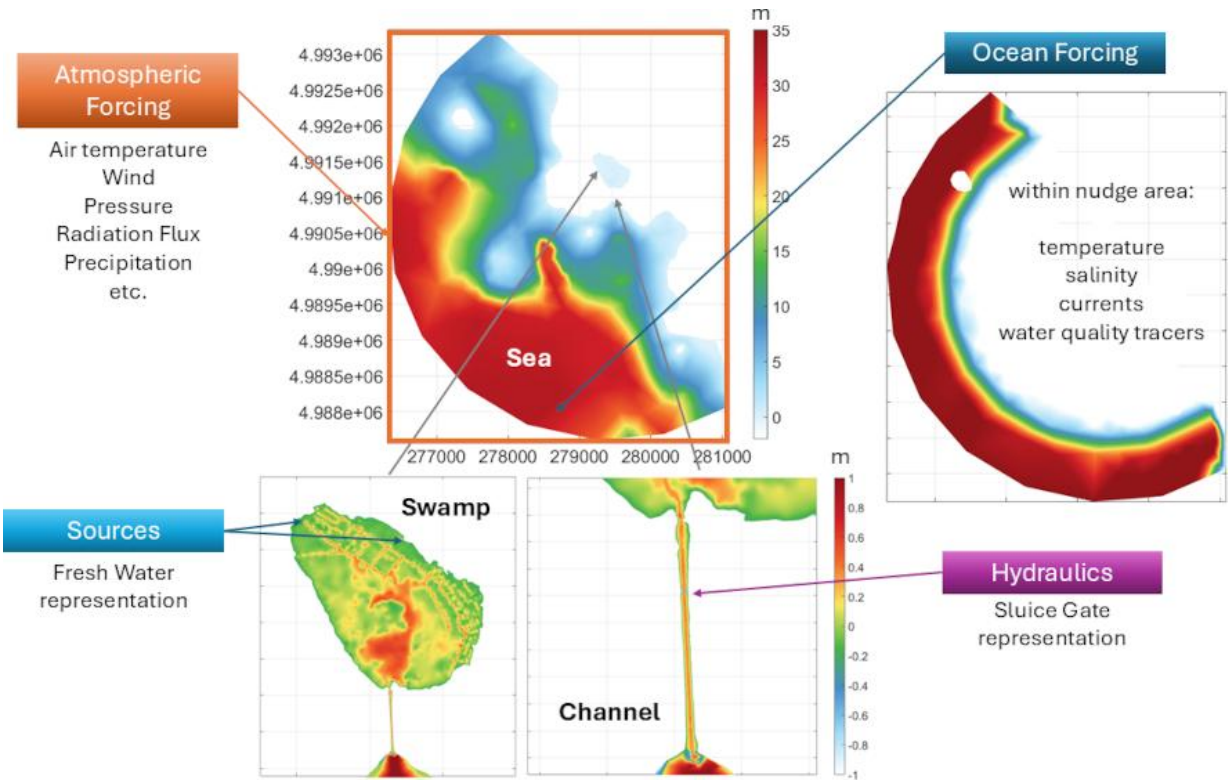

Figure 1. *Model setup including the domain and the different modules used: atmospheric and ocean forcing, sources and hydraulics.*

Atmospheric forcing is applied over the entire computational domain and includes air temperature, wind, atmospheric pressure, radiation fluxes, precipitation, and associated meteorological variables. Oceanic boundary conditions are imposed along the open-sea boundary through a nudging zone in which water temperature, salinity, currents, and selected water-quality tracers are prescribed to ensure realistic large-scale marine conditions. Freshwater inputs into the swamp system are represented through dedicated source terms. The hydraulic exchange between the sea and the swamp is controlled through an explicit representation of the sluice gate within the narrow channel connecting both environments.

As a test case, the present study is limited to a one-year simulation period spanning from 2020-01-01 to 2020-12-31. A total of 14 simulations is implemented with the aim of providing a preliminary assessment of the potential influence of different adaptation strategies on the hydrodynamic and ecological conditions of the Palud Swamp Reserve under ongoing climate warming.

Attention is given to the management of the newly installed sluice gate system, which plays a key role in regulating water exchange and maintaining suitable habitat conditions for the bird populations inhabiting the reserve. Several simplified management scenarios were therefore investigated, including maintaining the sluice gate at mean sea level (MSL) conditions, as well as progressively raising the regulation threshold by +5 cm, +10 cm, and +15 cm. In addition, exploratory scenarios involving freshwater injections at 5 L/s and 10 L/s during the summer season are considered to evaluate their potential for mitigating salinity increases and thermal stress during periods of elevated temperatures and reduced freshwater availability. Summary of the simulations is presented in Table 1.

Table 1. Number of simulations and modules used.

	Simulations	Hydrodynamics	Hydraulics	ICM	Source
1	Baseline	X			
2	Baseline + ICM	X		X	
3	Sluice gate +0cm	X	X		
4	Sluice gate +5cm	X	X		
5	Sluice gate +10cm	X	X		
6	Sluice gate +15cm	X	X		
7	Sluice gate +0cm + sources 5L/s	X	X		X
8	Sluice gate +5cm + sources 5L/s	X	X		X
9	Sluice gate +10cm + sources 5L/s	X	X		X
10	Sluice gate +15cm + sources 5L/s	X	X		X
11	Sluice gate +0cm + sources 10L/s	X	X		X
12	Sluice gate +5cm + sources 10L/s	X	X		X
13	Sluice gate +10cm + sources 10L/s	X	X		X
14	Sluice gate +15cm + sources 10L/s	X	X		X

To capture localized coastal dynamics and the rapid thermal response of the shallow environment of the Palud swamp-sea system, the 3 km spatial resolution AdriSC WRF hourly results are used as atmospheric input. Similarly, the open boundary of the model is located at the open sea and is forced with the 1 km spatial resolution AdriSC ROMS hourly results that are used as ocean input. However, for ICM, the open boundary of the model is forced with the 4 km spatial resolution CMEMS MEDSEA daily results (re-interpolated hourly).

Additionally, the hydraulic exchange between the Palud swamp and the channel via the sluice gate is represented in SCHISM using the integrated hydraulics module. In the present setup, the sluice gate located within the narrow connecting channel is parameterized as a hydraulic structure controlling water fluxes between the sea and the wetland according to prescribed elevation thresholds and flow conditions.

Finally, freshwater inputs within the Palud swamp system are implemented in SCHISM using the standard source–sink framework. The imposed freshwater sources are designed to reproduce localized freshwater inflows into the wetland and to investigate potential mitigation strategies during summer periods (between June 1 and September 1) characterized by elevated temperatures and enhanced salinity.

2. Model results

- **Baseline Environmental Conditions (Summer 2020)**

The spatial distributions of salinity and temperature across the wetland basin during the summer 2020 baseline period are illustrated in Figure 2. This baseline establishes the highly sensitive environmental dynamics of the swamp prior to any structural modifications.
The system is characterized by ambient hyper-saline conditions, with baseline salinity levels consistently ranging between 39 and 39.5 throughout the main water body. The spatial footprint of water temperature reveals a distinct thermal gradient across the basin, oscillating between 20°C and 28°C. A pronounced plume of warmer water (exceeding 26°C) is visible originating near the southern channel entrance and expanding into the central basin, highlighting that the exchange with the sea tends to bring warm waters. To monitor localized impacts, specific points of interest—including the deeper central basin (Deepest point of the swamp), the inlet channels (Before the gate and After the gate), and shallow peripheral zones (Point 1, Point 2, and Point 3)—were extracted for targeted time-series and statistical analysis.

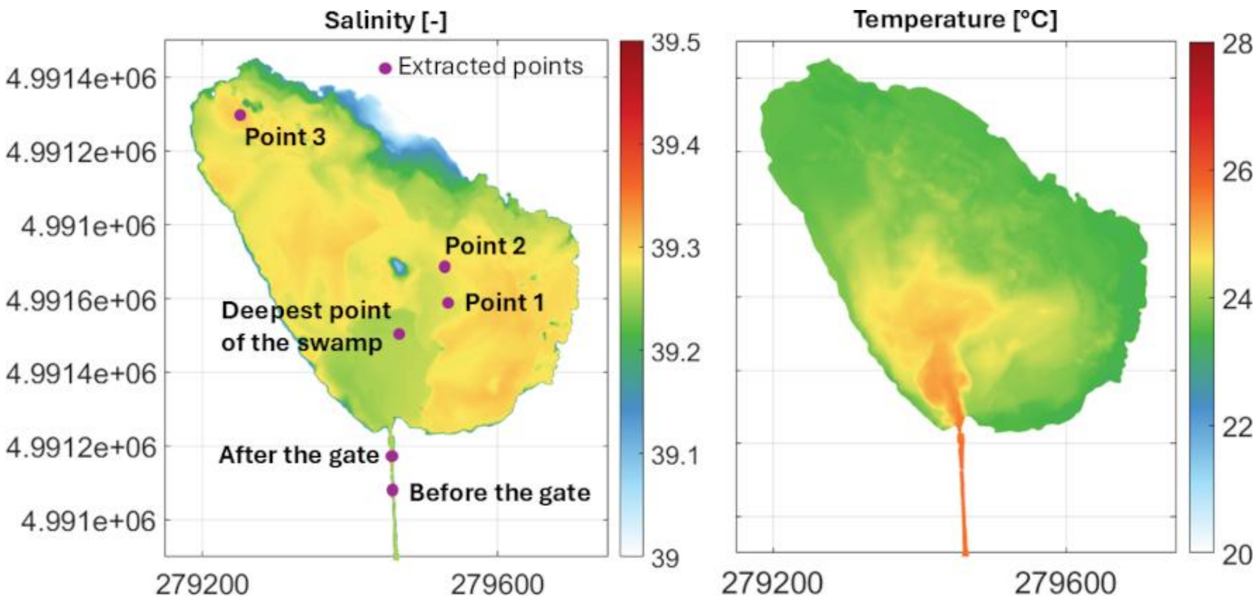

Figure 2. *Spatial distributions of temperature and salinity during summer 2020 and location of the extracted point of interest.*

- **Tidal Suppression and Drawdown**

In all scenarios lacking freshwater injections, the presence of the sluice gate alters water levels inside the system relative to the baseline. As the structural height of the gate is progressively raised from 0 cm to 15 cm, it acts as a physical barrier that systematically suppresses tidal peaks and dampens the overall tidal prism. This restriction prevents the full volume of high-tide marine waters from entering the swamp, resulting in a net structural drawdown of the average water column inside the basin.

- **Influence of Fresh Water Source Discharge**

When a 5 L/s freshwater discharge is introduced, the localized volume input provides minor hydrodynamic buffering, slightly elevating minimum water level thresholds during low-tide periods. Increasing the freshwater discharge to 10 L/s further supplements the basin's water volume, partially offsetting the drawdown induced by the 10 cm and 15 cm gate configurations. However, the macro-tidal attenuation and reduction in peak water levels remain strictly dominated by the height of the gate structure rather than the volume of the fresh water sources.

- **Median Salinity Reductions**

The configurations where the sluice gate is implemented without a freshwater source result in a remarkably minimal impact on the swamp's median salinity (Fig. 3). Across most of the central basin, the median salinity values deviate from the baseline by nearly zero, showing almost no perceptible change on average.

On average, the implementation of the source scenarios yields a net reduction in median salinity across the broader central basin of the swamp. The integration of the fresh water sources effectively dilutes the baseline hyper-salinity (Fig. 3): the median lines for Point 1, Point 2, and Point 3 shift downward with increasing discharge rates, with the 10 L/s source executing the most substantial reduction.

- **Median Temperature Anomalies**

The interventions reduce average water temperatures across large portions of the deeper interior basin. The fresh water sources act as a direct thermal sink, introducing cooler water that lowers the overall median baseline temperatures within the immediate vicinity of the discharge points and along the deep central trough (Fig. 4).

- **Exacerbation of Boundary Salinity Extremes**

Despite lowering average salinity, the adaptation solutions introduce a severe unintended consequence regarding extreme values. Figure 3 demonstrates that the maximum salinity differences spike sharply ($\Delta S > +2.5$ to $+5$) relative to the baseline along the shallowest peripheral boundaries of the swamp.

This phenomenon is driven by a localized feedback loop in the shallow margins:

1. The sluice gate restricts tidal exchange, cutting off the regular flushing volume of marine water that normally circulates through the system.
2. In these shallow zones, intense summer atmospheric evaporation plays a dominant role, rapidly evaporating the stagnant water column.
3. Because the gate has diminished the overall exchange and dilution capacity with the open sea, highly concentrated brines become trapped along the shallowest banks, generating severe hyper-saline spikes.

Furthermore, while the 5 L/s and 10 L/s fresh water sources successfully lower the median salinity profiles, they do not significantly reduce these boundary extremes. Because the freshwater inputs are point sources, their localized flushing momentum cannot fully penetrate or offset the intense evaporative concentrations occurring along the isolated, shallowest margins of the swamp.

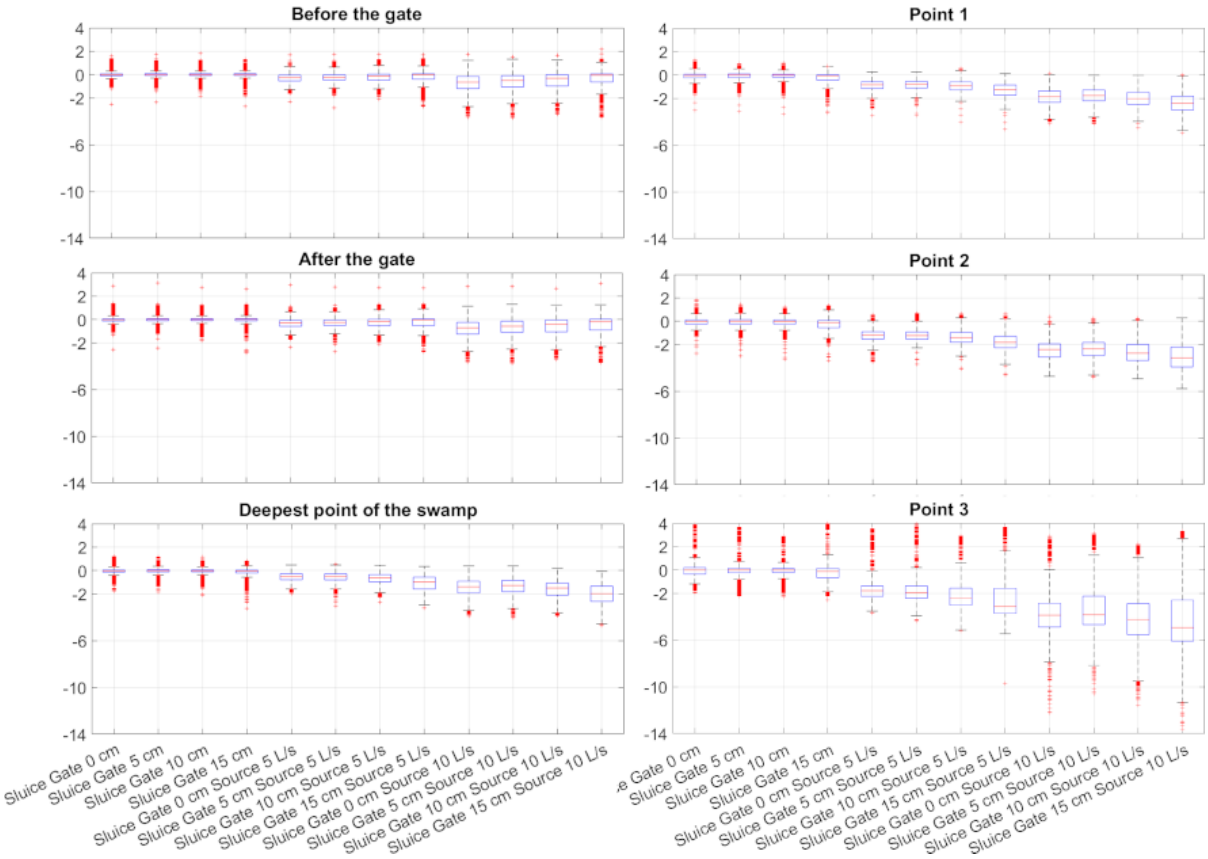

Figure 3. Box plot distributions of the difference in salinity between different sluice gate heights (0, 5, 10, 15 cm) and sources (5 L/s and 10 L/s) and the baseline.

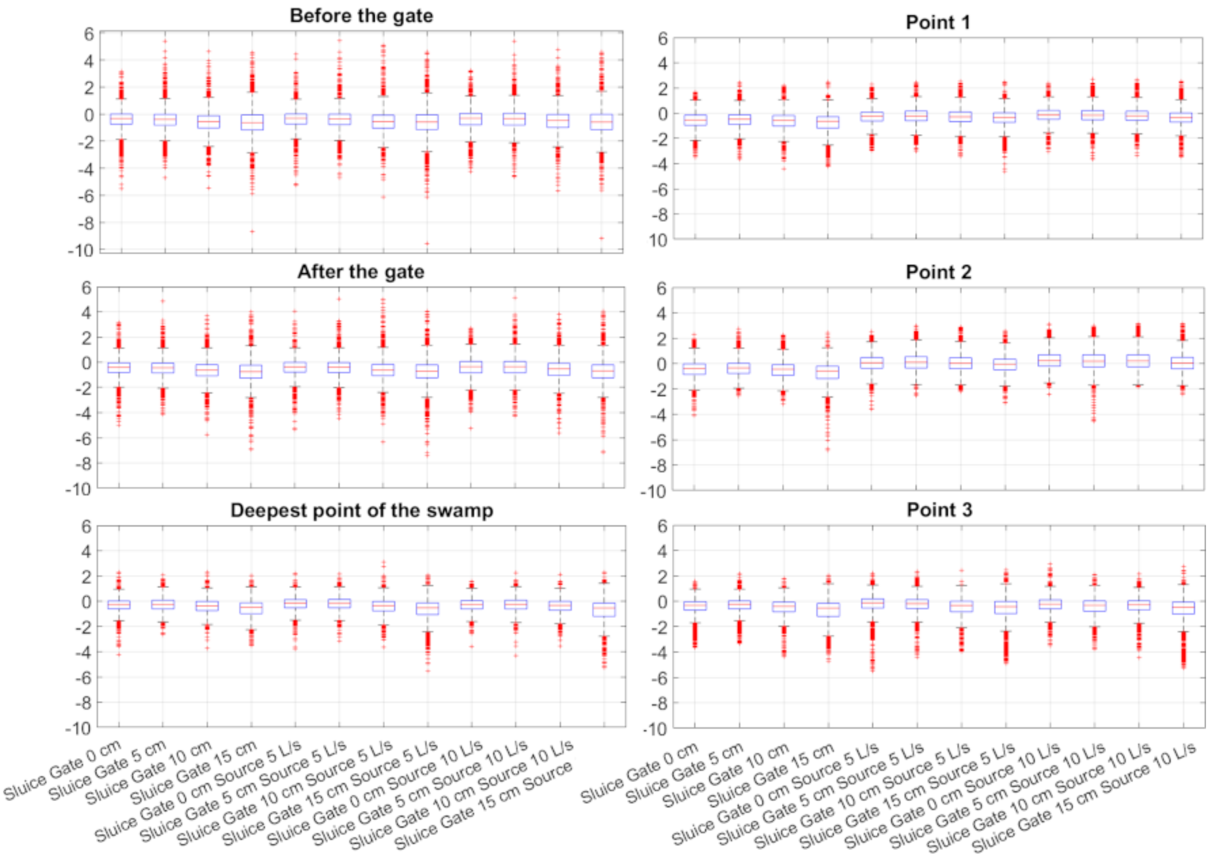

Figure 4. Box plot distributions of the difference in temperature between different sluice gate heights (0, 5, 10, 15 cm) and sources (5 L/s and 10 L/s) and the baseline.

- **Stagnation and Extreme Heating Events**

In stark contrast to the median cooling trends, Figure 4 reveals a nearly ubiquitous, severe increase in maximum temperature anomalies across virtually the entire spatial extent of the swamp under managed gate scenarios, with localized spikes exceeding +5 °C above baseline conditions.

This systemic increase in extreme thermal values is directly linked to the altered hydrodynamic buffering of the swamp:

Sluice Gate Installation ──► Suppressed Tidal Exchange ──► Lower Water Volume Inside Basin

Under baseline conditions, flooding tides import large, moving volumes of open ocean water that buffer the system against afternoon solar radiation. When the sluice gate restricts this exchange, a smaller, more stagnant mass of water is impounded inside the shallow basin. This reduced water volume possesses a much lower thermal capacity, causing it to heat up rapidly and severely during peak daylight hours.

The 5 L/s and 10 L/s freshwater streams lack the volumetric capacity to distribute thermal relief to freshwater fringes, leaving the restricted swamp ecosystem highly vulnerable to extreme atmospheric heating events (Fig. 4).

3. Conclusions

Based on the initial summer 2020 simulations, several tentative recommendations can be formulated regarding the potential adaptation pathways for the Palud swamp reserve. Given the preliminary nature of this work, these points should be treated as hypotheses for further testing rather than finalized engineering solutions.

Future management strategies might focus on hybrid configurations where tidal restriction is structurally balanced by active freshwater inputs. The data indicates that passive gating configurations are likely most effective when coupled with a continuous freshwater discharge (such as the simulated 5 L/s or 10 L/s configurations) to stabilize median salinity profiles. If these adaptation concepts are pursued, future engineering designs should explore modifying the freshwater delivery geometry. Rather than relying on localized inputs, it may be beneficial to evaluate a distributed diffuser network or secondary micro-channels that specifically target the isolated, shallow margins to enhance localized flushing. Rather than implementing permanent, season-long gate settings, future operational protocols could evaluate flexible or dynamic gating schedules. For instance, optimizing gate openings during specific low-tide cycles could facilitate the flushing of accumulated brines, while strategic openings during peak daylight hours might maximize the intake of cooler marine waters to serve as a thermal buffer.

The present work should be regarded as a preliminary assessment, and additional investigations are required before drawing definitive conclusions regarding the effectiveness and sustainability of the proposed adaptation measures. Longer-term simulations, including a fully integrated water quality module, are necessary to better evaluate the cumulative hydrodynamic and ecological consequences associated with the different management strategies implemented at the Palud swamp reserve. Future modelling efforts must look beyond median environmental shifts to specifically track and mitigate the localized extreme values identified in this study. While passive structural regulation via the sluice gate alters water levels, its standalone impact on median salinity is minimal—a predictable outcome given the conservation of mass and the lack of a marine chemical dilution source. However, by throttling the tidal prism, the gate induces stagnation and severe evaporative feedback, resulting in localized maximum salinity and thermal spikes along the shallow peripheral boundaries of the basin. Future research should therefore evaluate optimized freshwater delivery

designs, such as distributed diffuser networks or secondary micro-channels, to actively flush these isolated shallow margins.
Future analyses should therefore include extended SCHISM-ICM simulations under both historical climate conditions and future climate projections to assess how these adaptation measures may perform under warmer conditions and increased environmental stress. Such simulations will provide a more robust understanding of the long-term evolution of water temperature, salinity, water exchange, and suitability for bird populations within the reserve. Crucially, these extended runs will help determine whether the dramatic maximum thermal anomalies (exceeding +4 °C) and boundary hyper-saline brines captured in our short-term summer profiles surpass critical ecophysiological thresholds for local flora and fauna, potentially triggering habitat degradation.

Consequently, the results presented here should be interpreted as an initial step toward identifying potentially suitable adaptation pathways, while final recommendations should await the outcomes of comprehensive long-term past and future climate simulations in which the proposed measures are systematically evaluated with the forcing provided by the AdriSC V2.0 model.