MODELING PROGRESS – ANNUAL TECHNICAL REPORT

Oyster Metapopulation Modeling for Louisiana's Estuaries

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Project Summary and Modeling Progress

This Oyster Metapopulation Modeling project is designed to help meet the Trustee Restoration Goal outlined in the PDARP/PEIS to replenish and protect living coastal and marine resources for the Oysters Restoration Type (Section 5.5.9 of the PDARP/PEIS, DWH 2016). The project will provide an oyster metapopulation model at the basin-scale in Louisiana that generates outputs to address the restoration objectives developed by the Louisiana Trustee Implementation Group (LA TIG), including oyster larval transport and recruitment patterns among reefs, size-based density and biomass estimates on oyster reefs, and provide data for determining reef sustainability as well as basin-scale oyster metapopulation sustainability. Outputs from this project will enable the Louisiana Department of Wildlife and Fisheries (LDWF) to assess the impacts of enhanced or restored reef location on larval oyster survival and recruitment to other existing (or proposed) reefs, growth of oysters on existing and proposed reefs, and reef connectivity. This model will specifically support LDWF with evaluating locations for oyster cultch plants and protected spawning or broodstock reefs.

This annual technical report documents the modeling progress and deliverables to date, from March 2023 through March 2024. As of March 2024, all hydrodynamics, larval transport, and oyster reef individual-based models (IBM) have been set up in at least one of the three priority coastal basins. We use the Model Implementation Plan submitted as a deliverable to LDWF in July 2023 to outline our modeling progress for Barataria Basin. Barataria Basin is our first basin-scale application and used as our test case for all model set up, testing and coupling. The ROMS hydrodynamics for Barataria Basin is already calibrated and validated for 2014-2018, and the ROMS outputs have been coupled with the larval transport model (LTRANS-DEK) and the oyster reef IBM. The basin-scale design of the oyster metapopulation model for Barataria Basin has been finalized by the team; the spatial design for the reef IBM point models the key component of the overall design. Full-scale coupling and testing of the oyster metapopulation model for Barataria Basin is underway, with the individual ROMS, LTRANS-DEK, and three oyster reef IBM point models set up and verified to be working correctly. The hydrodynamics model set up, calibration and validation for the North Pontchartrain model domain is ongoing. We will follow the same steps for independent model verification, determining the spatial design and full-scale model coupling for North Pontchartrain. The hydrodynamics for Calcasieu Lake has just been initiated. Again, the model steps and testing for determining the spatial design and coupling for the full-scale oyster metapopulation for Calcasieu Lake will follow those presented in this report for Barataria Basin.

Oyster Metapopulation Modeling for Louisiana's Estuaries

This Oyster Metapopulation Modeling project is designed to help meet the Trustee Restoration Goal outlined in the PDARP/PEIS to replenish and protect living coastal and marine resources for the Oysters Restoration Type (Section 5.5.9 of the PDARP/PEIS, DWH 2016). The project will provide an oyster metapopulation model (see Figure 1), which will provide outputs of Specific, Measurable, Achievable, Relevant, Appropriate Timeline (SMART) objective measures (DWH 2021) including larval transport and recruitment patterns (SMART Objective 3b), size-based density and biomass estimates (SMART Objective 3c), and provide data to develop a SMART Objective related to reef sustainability (Fundamental Objective 2), developed by the Louisiana Trustee Implementation Group (LA TIG). The coupled oyster metapopulation model platform that we are developing is comprised of three model approaches (Figure 1). The basin-scale hydrodynamics (HYDRO) model(s) generate hourly 3D flows, salinity and temperature fields (x,y,z) that drive individual larval growth, vertical behavior, lateral transport and ultimately settlement to suitable reef substrate in the oyster larval transport model. The HYDRO model(s) also produce depth-averaged daily salinity and temperature conditions to drive individual oyster survival, growth, and reproduction on the modeled oyster reef(s). The oyster larval transport model outputs the settlement success in numbers of oyster larvae among the model oyster reefs, and thus can be used to either initiate or potentially drive newly settled spat for the model reef population (Figure 1). Additionally, spawning or production of oyster larvae from the modeled oyster reef(s) could be used to determine when and where oyster larvae are sourced or started in the larval oyster model simulations (dashed line in Figure 1). Outputs from this project will enable the Louisiana Department of Wildlife and Fisheries (LDWF) to assess the impacts of enhanced or restored reef location on recruitment to other existing (or proposed) reefs, larval survival, growth of oysters on existing and proposed reefs, and reef connectivity. Specifically, this model is to support LDWF with evaluating locations for oyster cultch plants and protected spawning or broodstock reefs. The metapopulation model will enable management of oysters to move from individual reef level to assessment of a network of reefs within each of Louisiana's coastal basins under current and future foreseeable conditions, a shared objective by the Regionwide Trustee Implementation Group (RWTIG).

Project Activities:

The Activities were outlined within the "Monitoring and Adaptive Management Activity Implementation Plan: Modeling to Inform Sustainable Oyster Populations in Louisiana Estuaries" and approved by the Deepwater Horizon Louisiana Trustee Implementation Group (LA TIG) in May 2022. The May 2022 document is included in the references section and referred to as the MAIP from hereon. The MAIP Activities originally approved by the LA TIG have updated summary descriptions for this technical progress report, and Activity 6 has been added for Reporting and Project Management.

Activity 1: Set up and update the basin-scale hydrodynamic models and incorporate the updated version of the oyster larval transport model which includes the Dekshenieks (DEK) larval submodels (LTRANS-DEK) to simulate larval oyster dispersal, size-based vertical movement, and settlement criteria with larval recruitment measured across the oyster reef networks for the three priority coastal basins.

Activity 2: Set up the existing oyster reef IBM to simulate individual oyster growth and survival, reproduction, and shell maintenance and surface area of the reef for larval recruitment (i.e., spat settlement) and in relation to daily depth-averaged salinity and temperature.

Activity 3: Couple the LTRANS-DEK and the existing oyster reef IBM point models (single reef model for each defined reef/oyster area in the basin connected by larval transport model, Activity 2) to quantify and provide larval oyster settlement and recruitment among the reefs/oyster grounds, and on-reef filtration, growth, reproduction, and mortality of oyster size classes, as well as reef growth, degradation, and shell budget of the reefs within the estuarine network.

Activity 4: Provide spatial and temporal dynamics of larval settlement distribution and recruitment among the reef networks, and post-settlement oyster size structure, density, biomass and spawning of the oyster reefs under existing or current years simulated by spatially-resolved basin-scale hydrodynamic/water quality models providing fine-scale current velocities (x,y,z), salinity, and temperature conditions that drive the oyster processes in the coupled oyster metapopulation model (Activity 3, comprised of Activity 1 and Activity 2). Use the existing oyster field monitoring data within the coastal basin to help validate the modeled outputs.

Activity 5: Provide forecasted spatial and temporal dynamics of larval settlement distribution and recruitment among the reef networks, and post-settlement oyster size structure, density, biomass, and spawning of the oyster reefs using for foreseeable future conditions that are consistent with the Louisiana Coastal Master Plan and include proposed oyster restoration scenarios.

Activity 6: Technical Reporting, Communications with LATIG, Project Meetings and Management

Project Purpose and Objectives:

The objective of the oyster modeling project stated in the MAIP is to provide an oyster metapopulation model that will provide outputs to measure larval transport and recruitment patterns (i.e., reef connectivity), size-based density and biomass estimates for oyster reefs, and provide data to develop a SMART Objective related to reef sustainability (Fundamental Objective 2). This will be done through:

1) A coupled modeling platform that simulates spatial and temporal dynamics of estuarine flows and circulation, salinity and temperature, oyster larval transport and recruitment, and individual oyster growth, reproduction and mortality, as well as oyster reef growth and reef maintenance (Figure 1) for planning and implementation of oyster restoration. This platform can be used to understand linkages between reefs of different densities and size classes, including larval provision and recruitment across space and time.
2) Reports, maps, and journal papers on predicted larval transport and settlement patterns, recruitment success among reefs, oyster reef growth, survival and reproduction estimates, and oyster reef size structure, density, and/or biomass outputs under foreseeable future conditions that are consistent with the Louisiana Coastal Master Plan, oyster restoration strategies, and coastal habitat restoration scenarios.

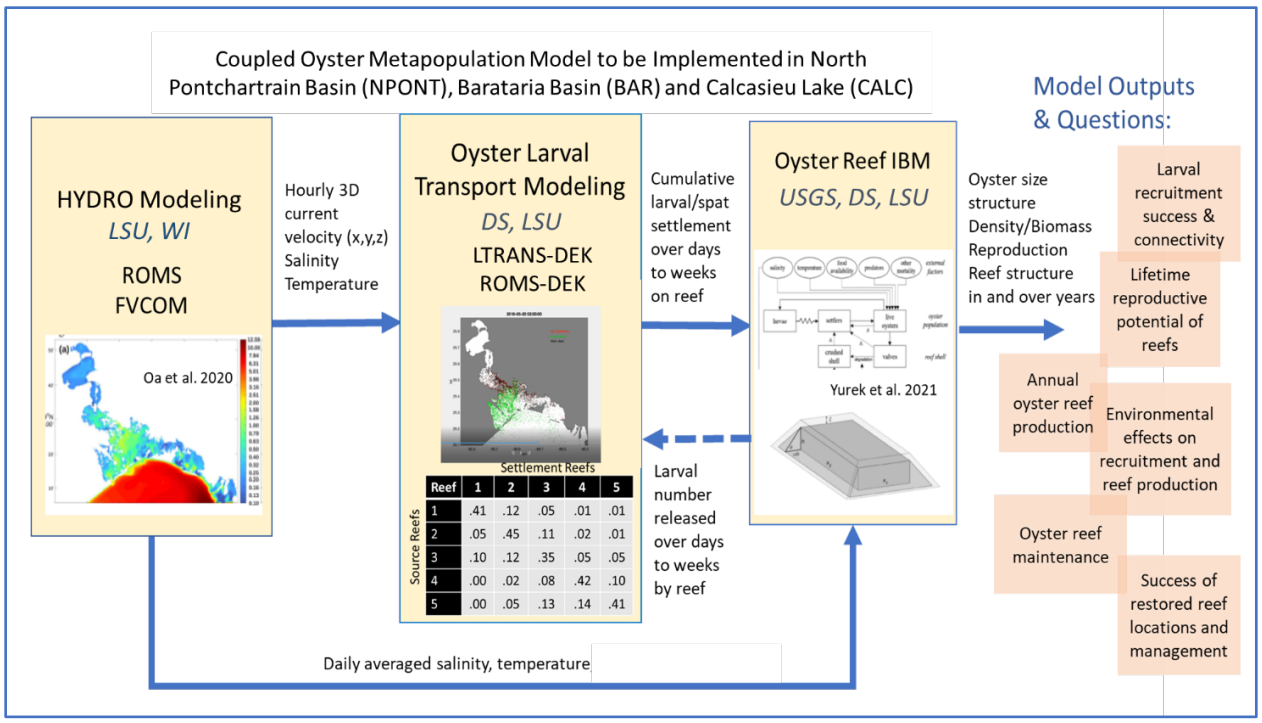


Figure 1. The coupled oyster metapopulation model to be applied in Louisiana coastal basins for evaluating LDWF oyster restoration management questions.

Oyster Metapopulation Model Implementation Plan:

In the first few months of the project, the oyster modeling team prepared a Model Implementation Plan (Sable and Rose, 2023) to provide the model teams with a checklist of steps and deliverables to complete each year and for the project duration (March 2023 through December 2025). Model steps and deliverables were included in 22 "Packets" divided among the three primary model approaches (HYDRO for flow, salinity, temperature; LTRANS for oyster larval transport and settlement; Reef IBM for oyster reef population dynamics, see Figure 1). The three model approaches are coupled for simulating the hourly and daily dynamics of the oyster metapopulation over the network of oyster reefs in each of three coastal basins for existing conditions (2014-2018) and then future foreseeable conditions. The three coastal basins are: North Pontchartrain (NPONT), Barataria (BAR), and Calcasieu Lake (CALC). The teams responsible for completing each packet for the three model approaches are LSU (Oceanography & Coastal Sciences Department), the WI (Water Institute), DS (Dynamic Solutions), and USGS (includes USGS WARC and LSU Agriculture Center, in Figure 1), and All (everyone). The implementation plan was presented to the full modeling team at the workshop held in New Orleans in late May 2023, vetted and revised by the full team, and then finalized and delivered to LDWF as a project deliverable in July 2023.

We briefly describe the 22 packets from the Model Implementation Plan (Sable and Rose, 2023) here because the modeling teams use this plan as a guide to step through and track all modeling progress to assure that we keep on schedule. The flow diagram in Figure 2 is from the Model Implementation Plan (Sable and Rose, 2023) and shows the 22 packets of work to be completed by each model approach with arrows demonstrating the flow and connections among the packets. The packets are numbered going

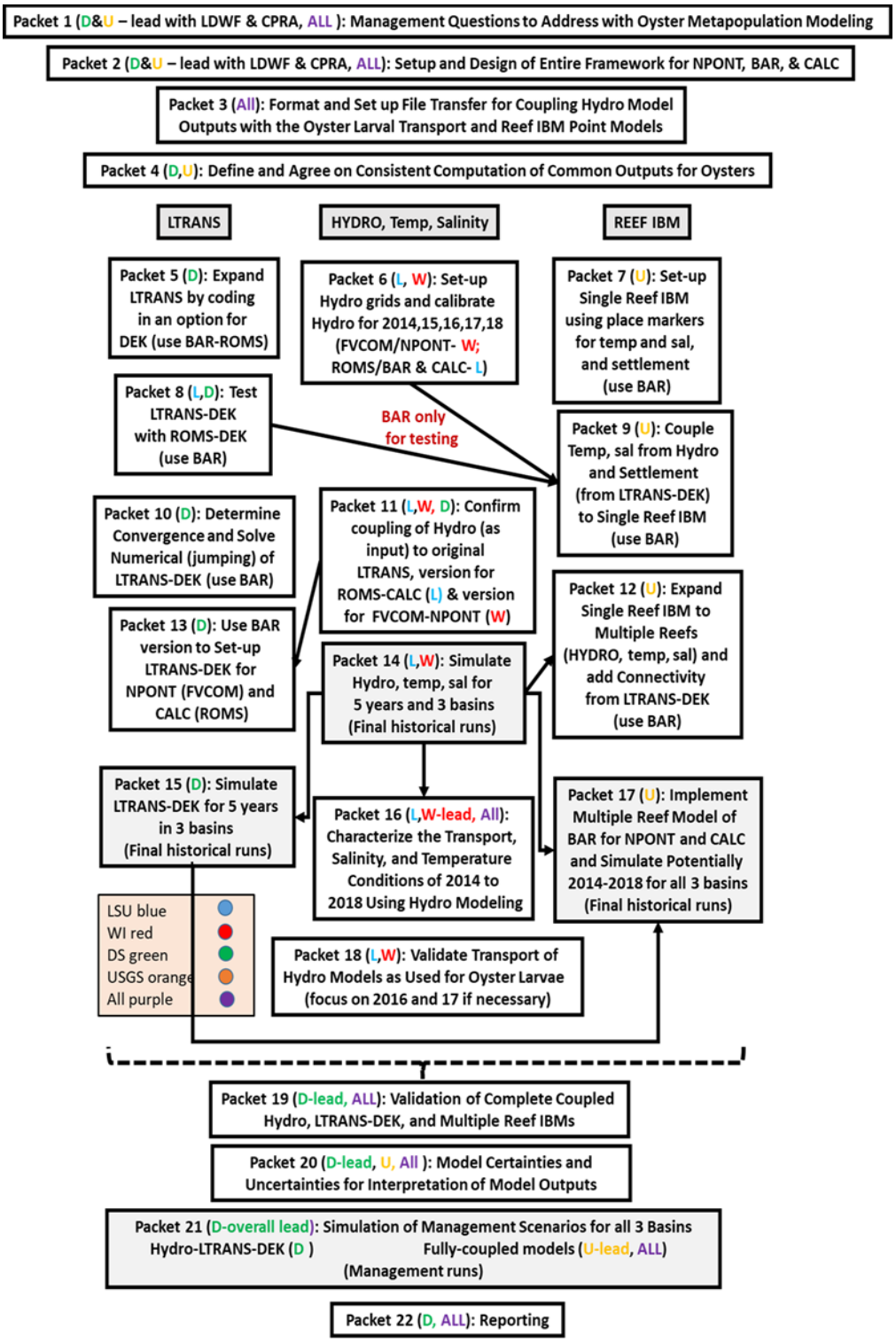


Figure 2. Flow diagram from the Model Implementation Plan describes 22 work packets to be completed for the LTRANS, HYDRO, REEF IBM and the responsible model teams. LSU (L: blue) and WI (W: red) are in charge of the Hydro model packets; DS (D: green (includes K. Rose)) is in charge of the LTRANS model packets and leads model simulations and reporting; USGS (U: orange) is in charge of the reef IBM model packets and scenarios; All (purple) are involved in model simulations and reporting.

across the three modeling approaches so numbering is done for a row and then moves down to the next row. This is done to show the approximate timeline of packets and how work is performed in parallel by the teams with each approach and the approximate schedule. For example, in Figure 2, our numbering shows how Packet 14 results from the HYDRO, Temp, Salinity modeling are needed for the next numbered Packets 15 (LTRANS), 16 (Characterizing years), and 17 (Reef IBM). The oyster larval transport model selection and testing work previously completed for LDWF in 2022 (Sable et al. 2022) focused on BAR, so BAR is often used to test the models in the packets since the BAR modeling is ahead of the other two basins. Some packets are the responsibility of one team, some packets involve multiple teams, and other packets involve all teams. Team members determine how they will work through multiple packets at once and how to work through the steps within each of their assigned packets, and do not necessarily need to perform the work in order of the packet numbers. A team may work on two or more packets at the same time or early and late numbered packets at the same time. An important part of how each team organizes their effort are the arrows in Figure 2. The arrows show critical connections among the packets, where outputs from one packet are necessary for the receiving packet to be done.

The implementation plan includes a table that lists key LDWF oyster restoration management questions, the common model outputs which are either directly used or post-processed as result to evaluate the different questions, and the modeled indicators (see Table 1 for one example management question). This table (Table 1, Sable and Rose, 2023) was key to develop with LDWF and CPRA for Packet 1 and towards oyster restoration to assure that we design, couple, and apply the models as efficiently as possible to appropriately address the LDWF management questions. The table of management questions is to be revisited and potentially revised throughout the project. The implementation plan is additionally set up to be revisited at the end of each project year for updating, trouble shooting, and adjustments based on how the modeling work is progressing. We often refer to the Packets from the Model Implementation Plan (Figure 2) as we report the technical details and progress of our modeling efforts.

Modeling Progress:

As of March 2024, all hydrodynamics, larval transport, and oyster reef individual-based models (IBM) have been set up in at least one of the three priority coastal basins. The BAR oyster metapopulation model, which is the first of our fully coupled basin-scale oyster metapopulation model applications, is in process of full-scale model coupling and testing to verify that the oyster larval transport and series of oyster reef IBM point models are realistically and reasonably predicting: (a) oyster larval growth, transport and settlement among the modeled reefs; and (b) oyster sizes, density, survival, growth and spawning for the modeled reef populations. The BAR oyster metapopulation model is comprised of the ROMS hydrodynamics model, the LTRANS-DEK oyster larval transport, and multiple oyster reef IBM point models. Modeling progress for BAR, with some example model results for demonstration, is the focus of our report because the same model steps and verification of model results will be followed exactly for the set up and simulation of oyster metapopulation dynamics in NPONT and the CALC later this year. The model Packets in Figure 2 are referenced while describing the model progress to help LDWF and the LA TIG SWG generally track our modeling progress and schedule.

For each basin-scale oyster metapopulation model domain, defining the oyster reef IBM model locations and spatial area grid resolution or grain requires several steps (Figure 2, Packet 2). First, we use the calibrated hydrodynamic models to output bottom layer and depth-averaged daily salinity and

Table 1. Oyster restoration management questions with oyster model outputs and indicators. Question (1) example is copied from Table 1 in the Model Implementation Plan. See Sable and Rose, 2023 for the full table for the complete list of oyster management questions, model output and indicators.

Oyster Restoration Management Questions	Model Outputs	Indicators
(1) Where should LDWF construct oyster spawning reefs?	(a.1) Evaluate which modeled source reefs have the highest annual recruitment success (i.e., larval settlement) over at least five years under existing (2014 through 2018) conditions, and future foreseeable conditions (wet, dry, average sequences) with no restoration and two restoration management scenarios (a.2) Use table to show recruitment by source reefs for Spring and Fall by year, to rank reefs from highest to lowest overall recruitment success, and how recruitment success varies among source reefs by seasons and years, for existing and future scenarios	(a) Percent recruitment success of source reefs
	(b.1) Evaluate which modeled settlement reefs have the highest annual recruitment success over at least five years, under existing and future foreseeable conditions without and with restoration (b.2) Use table to show recruitment success by settlement reefs for Spring and Fall by year to rank them and show the variation among reefs by seasons and years, for existing and future scenarios	(b) Percent recruitment success of settlement reefs
	(c) Estimate annual oyster adult (≥ 50 mm length) density, biomass per reef IBM point model and plot all reefs over at least five years to identify trends in adult oyster biomass supported by each reef and relative to the other modeled reefs	(c) Oyster adult density and biomass on reef
	(d) Estimate annual oyster egg production per reef IBM point model and plot all reefs over at least five years to identify trends in reef egg production and relative to the other modeled reefs	(d) Oyster reef total annual egg production
	(e) Estimate lifetime reproductive potential of recruited (settled) larvae in year 1 to reef IBM point model over next 5 years after settlement – compare among reefs and over at least 5 years for the simulated scenarios	(e) Track and sum annual egg production from all settled larvae in year 1 over the 5-year simulation for lifetime reproductive potential of recruited larvae to each reef model

temperature across the model domains for 2016 and 2017. We count the number of total days for each year when salinity was below 10 ppt, and count the number of consecutive days when: a) salinity is < 5 ppt and temperature was ≥ 32 °C, and b) salinity is < 1ppt and temperature was ≥ 20 °C. These environmental thresholds relate to experimentally defined survival and feeding rates and from oyster occurrence data in the field (Swam et al., 2022; Lavaud et al., 2017, 2024). The same salinity threshold conditions have been used to map oyster habitat suitability based on survival and growth responses (Swam et al., 2022), as well as to simulate oyster growth and spawning potential using the oyster DEB model (Lavaud et al., 2024). The 2D salinity threshold maps from the HYDRO models are overlaid with grids composed of regular 1-km to 5-km cells created with the ESRI ArcGIS gridding tool, fishnet. The oyster modelers carefully evaluate the threshold maps by eye to choose the grid scale resolution necessary to differentiate between salinity threshold gradients across cells.

After the appropriate spatial grain for the oyster reef IBM point models is determined for the basin, the grid is overlaid on the hydrodynamic output, so that all open water habitat capable of supporting subtidal oyster reef substrate and production over time can be delineated for initializing the oyster reef IBMs. The centroid of open water (i.e., wetted) area in each grid cell is located. That is, if a grid cell contains some dry land (< 50% of the grid cell area), the centroid is defined by the nearest open water area in that cell. In this way, all open water area in each of the grid cells can potentially be a model oyster reef and/or serve as settlement substrate for modeled oyster larvae recruitment. The centroids represent the specific locations of the oyster reefs, and the 2-km grids represent the scale at which conditions are averaged. This model assumption that all open water habitat can potentially support oysters has been carried over from the previous modeling with LDWF (Sable et al. 2022), and is meant to provide a more robust estimate of oyster bottom habitat in the basins given much of the area are private oyster leases with no available data.

Barataria Basin:

The ROMS hydrodynamics model (Oa et al. 2020) is calibrated and validated to salinity data from 2014 through 2018 (see Figure 2, Packet 6). We previously used the BAR ROMS to simulate spring and fall flows, salinity and temperature fields for 2016 and 2017 (see Figure 3 for a demonstration of the mean depth-averaged salinity) and drive two independent oyster larval transport models (ROMS-DEK and LTRANS) to compare their predicted larval settlement success patterns for BAR (Sable et al. 2022). For our current project, LSU has used the ROMS to generate daily depth-averaged salinity and temperature netcdf (nc) output files for three test locations upon request by the oyster model teams (DS and USGS). These daily files were used to drive the oyster reef IBM point models for the three locations, and verified that the ROMS and oyster reef IBM model coupling was working correctly (Figure 2, Packet 9). The calibrated ROMS results were also used to support the oyster modelers with the spatial design of the oyster reef point models across BAR (Figure 2, Packet 2). The daily salinity and temperature results were generated by the ROMS across BAR for 2016 and 2017, and carefully evaluated by the oyster model team to determine the oyster model reef locations and spatial resolution or grain to represent each modeled reef. LSU worked with the WI to post-process the ROMS daily salinity and temperature outputs in order to count the total

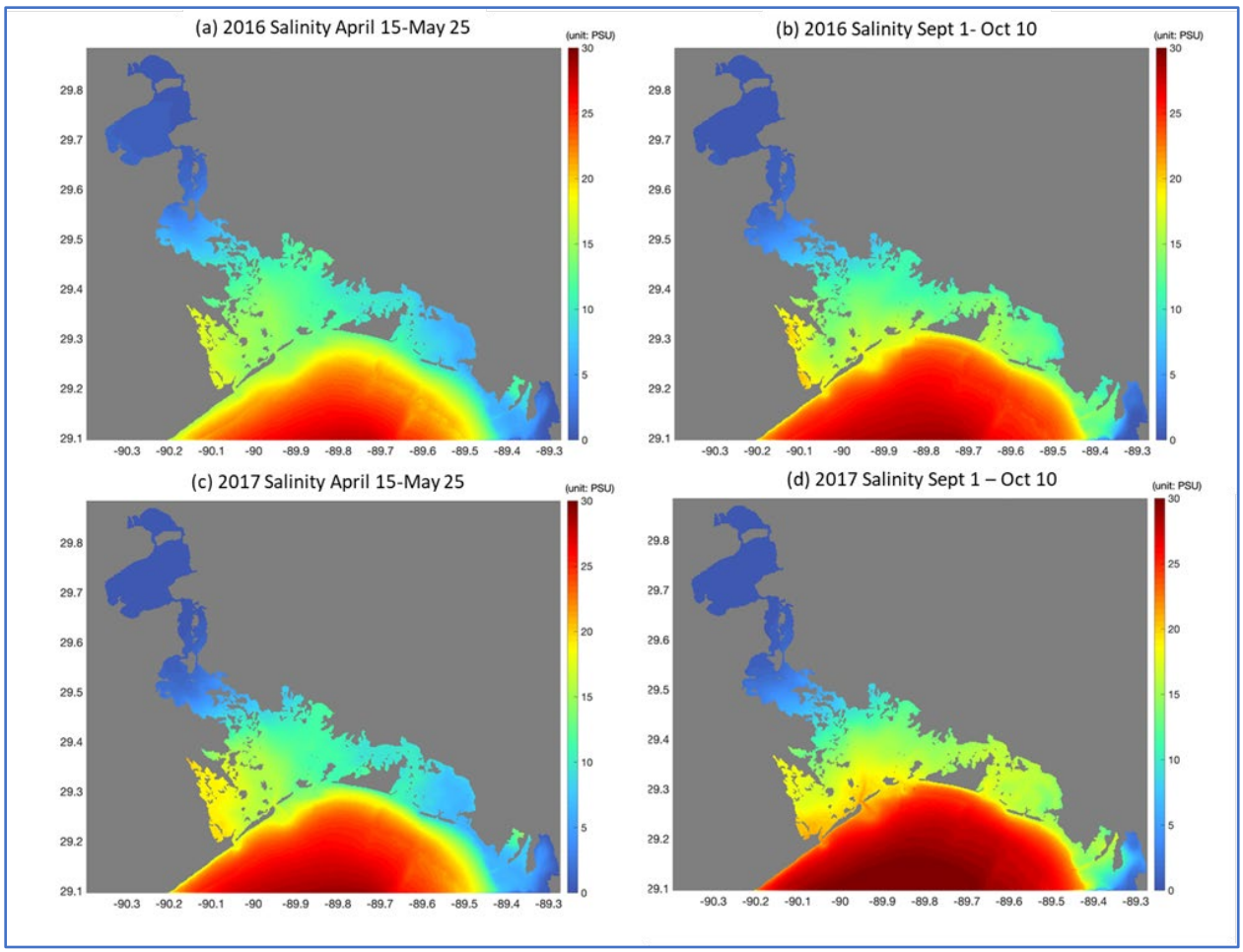


Figure 3. Mean depth-averaged salinity gradients generated by the ROMS for the first 40 days of simulation in (a) Spring 2016, (b) Fall 2016, (c) Spring 2017, (d) Fall 2017.

and consecutive number of days when salinity dropped below 10 ppt, when salinity was below 5 ppt and temperature was ≥32° C, and when salinity was below 1 ppt and temperature was ≥ 20° C (Figure 4). These same salinity thresholds for oyster growth and survival have been used consistently with interpolated field data (CRMS and HYCOM stations) and in recent works by members of the oyster modeling team (Swam et al. 2022, Lavaud et al. 2024). The studies show that reef oyster growth and survival processes are reduced when salinities are low at warmer temperatures after 7 days. Figure 5 shows a 2-km spatial grid scale for the oyster reef IBM point model setup. LSU is post-processing the daily temperature and salinity output files for the defined centroid locations in the oyster reef spatial grid (Figure 5). It is important to note that the final oyster metapopulation modeling results may not be presented at 2-km grid scale resolution; this grid scale resolution is purely for the finest possible oyster model evaluation of where and how the oyster model results vary within the modeled Barataria domain.

Based on the oyster larval transport model testing previously conducted in BAR (Sable et al. 2022), the first step towards implementing oyster larval transport for the metapopulation modeling was to modify the LTRANSv2b source code by incorporating growth and behavior routines from Dekshenieks et al. (1996), referred to as DEK. We refer to this modified version as LTRANS-DEK. The incorporated DEK routines

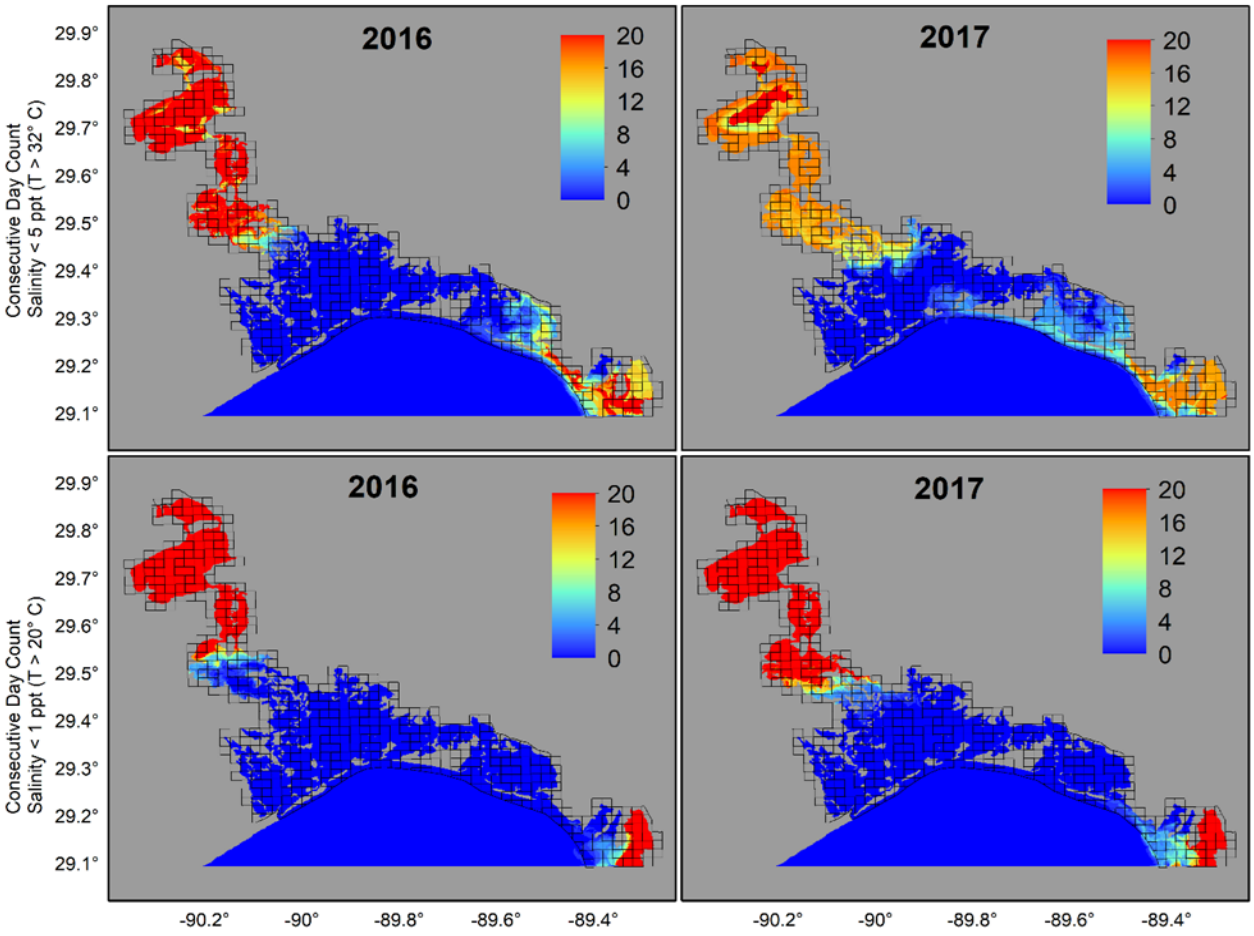


Figure 4. The maximum consecutive number of days in 2016 and 2017 with ROMS-generated salinity below 5 ppt and temperature ≥ 32 °C (top panels) and below 1 ppt and temperature ≥ 20 °C (bottom panels). The 2D maps are overlaid with the 2-km spatial grid of the oyster reef point models.

simulate larval growth and vertical movement based on encountered temperature, salinity, turbidity, and food availability. Whereas, the LTRANSv2b routine assumes growth as a function of time and simulates vertical movement based on different salinity thresholds and movement algorithms. Further, the DEK routines evaluate settlement based on simulated oyster size (due to growth), and LTRANSv2b evaluates settlement based on age (because size is not computed). Thus, DEK provides a more mechanistic simulation of oyster growth, settlement, and mortality; but LTRANSv2b provides a convenient and efficient off-line model that does not require conducting a hydrodynamic simulation for each oyster larval transport simulation.

The DEK routines from the ROMS source code were adapted and added to the LTRANSv2b model to: 1) Compute larval growth rate based on encountered salinity and temperature (turbidity, and food availability also options), then compute oyster size based on growth rate. 2) Incorporate DEK vertical movement behavior as a function of oyster size and salinity. 3) Apply DEK vertical movement to update larval positioning (langrangian movement). 4) Include the algorithm to evaluate larval settlement based on size rather than age. 4) Expand the LTRANS user input file to include options for initial larval size, food availability, turbidity, size at which larvae settle, and an option to select behavior routines (e.g., added DEK

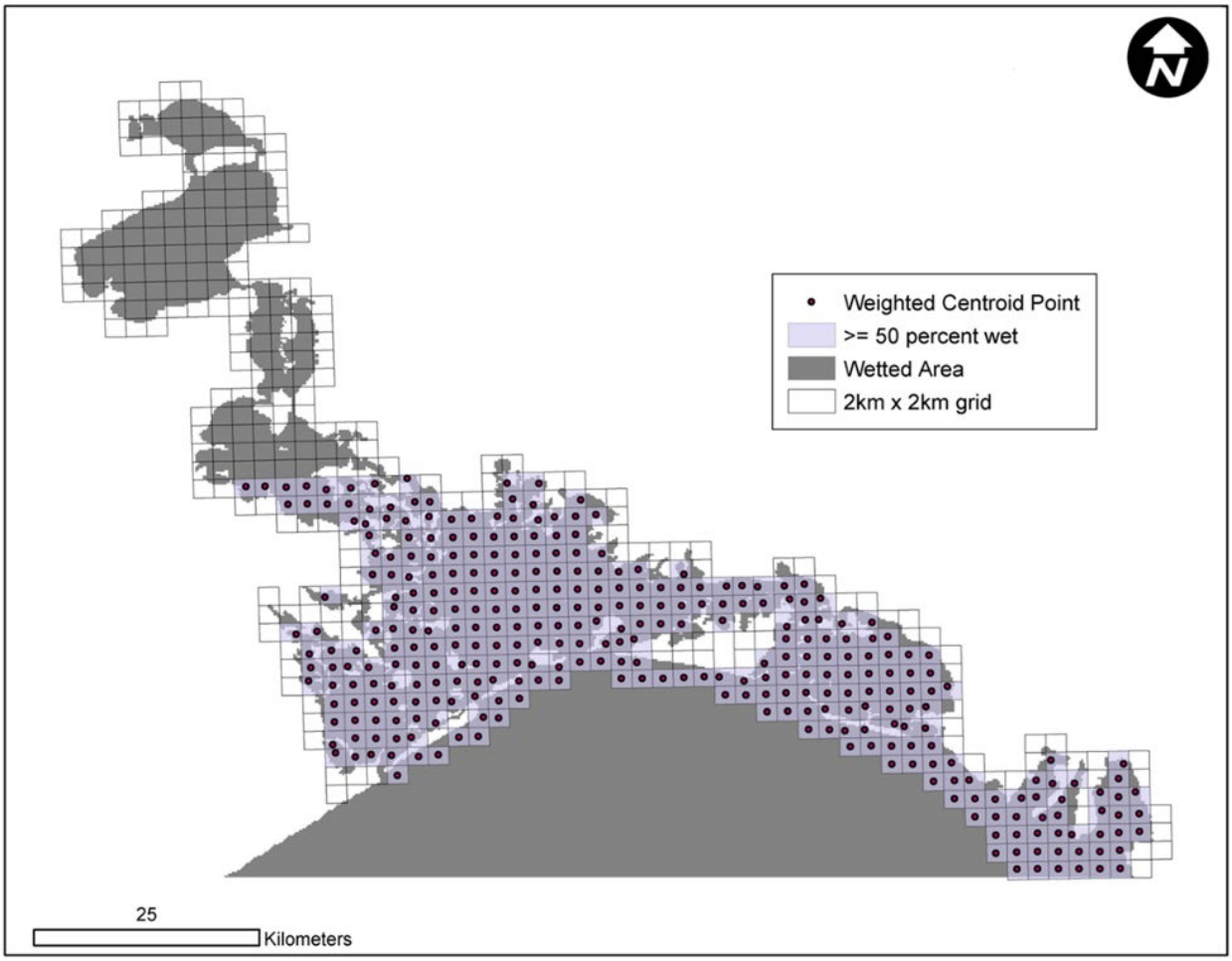


Figure 5. The spatial grid representing the oyster reef IBM point models in 332 of the 2-km^2 grid cells for BAR with the weighted centroid point marking the open water area delineated for each potential oyster reef grid cell. In this spatial design, each 2-km^2 grid cell could represent an oyster reef IBM population capable of growth and spawning. Each grid cell could also potentially source oyster larvae and/or serve as settlement reef area for larval recruitment.

behavior or existing LTRANS options). Therefore, LTRANS-DEK provides all the features available in LTRANSv2b, but it adds the capability to simulate larval growth, vertical behavior, and settlement according the DEK model.

Extensive testing of LTRANS-DEK was completed for verification that user inputs and options were functioning correctly and simulating user specifications (Figure 2, Packet 5, see Figure 6 for example larval tracks and growth for LTRANS-DEK). QA/QC and model testing was performed by DS conducting simulations from a strategically designed run matrix that encompassed various combinations of simulation options (e.g., behavior routine, settlement, mortality). Model outputs were evaluated to verify simulation options were applied correctly, the additions in LTRANS-DEK functioned correctly, and that they did not interfere with existing option in LTRANSv2b. In addition, model testing was performed to ensure that the additions made available in LTRANS-DEK did not modify the default oyster simulation options in LTRANSv2b. Testing was performed using Fall and Spring 2017 simulations for BAR and confirmed that the LTRANSv2b behavior routines are identically available in LTRANS-DEK. Additionally, DS has nearly solved

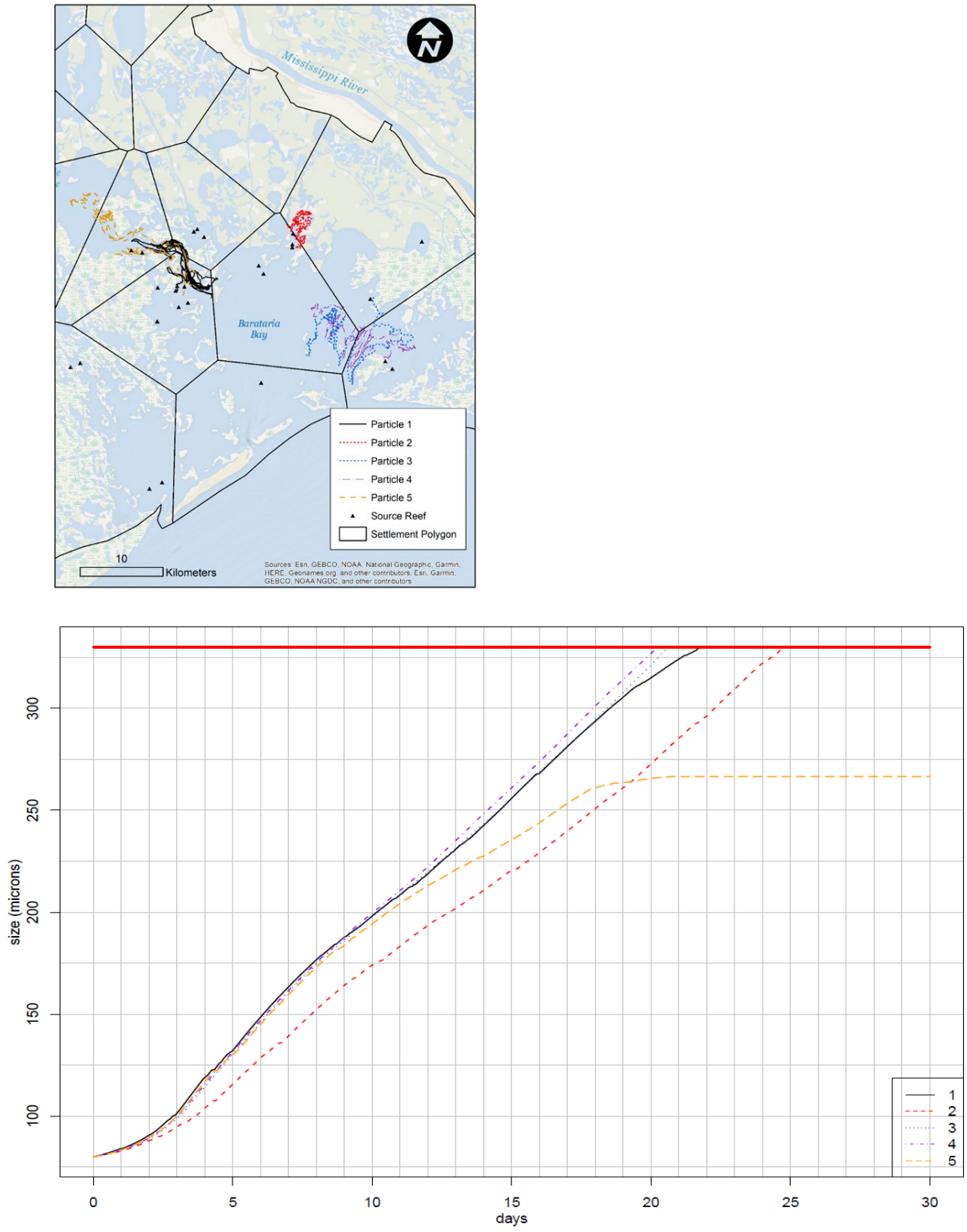


Figure 6. Larval tracks (top) and growth (bottom) over 30 days simulated by LTRANS-DEK for five particles. The solid red line indicates settlement size (330 microns). Differences among the particle growth lines reflect differences in encountered temperature and salinity among the particles, noting that larval particle 5 never reaches settlement size and dies with mortality set to 30 days.

the numeric issues and larval particle skipping that was identified to occur in the LTRANS (Figure 2, Packet 10).

New model testing scenarios to evaluate the performance of ROMS with LTRANS-DEK and ROMS-DEK are underway with LSU (Figure 2, Packet 8), with the model comparison similar to that performed in Sable et al. 2022 (see Figure 7 for example larval results from the previous comparison between ROMS-DEK and the default LTRANS). LTRANS-DEK and ROMS-DEK larval transport and recruitment results will be compared by evaluating larval distributions after 20 to 30 days (Figure 7 - top), larval connectivity matrices, and settlement success among spatial reef polygons (Figure 7 – bottom). Any differences among the LTRANS-DEK and the ROMS-DEK are expected to occur as a result of hydrodynamic transport and spatiotemporal interpolation in LTRANS-DEK rather than due to the behavior routines. The experimental set up requires strategic model configuration of ROMS-DEK to match that of LTRANS-DEK including the exact same hydrodynamic simulation period, the number of simulated particles, and larval particle release location and timing. If LTRANS-DEK produces similar oyster larval transport and recruitment results to ROMS-DEK, then LTRANS-DEK can serves as a versatile, mechanistic offline larval transport model (LTRANS-DEK) which can be coupled to potentially any available hydrodynamics model for any coastal basin to evaluate larval transport (oyster, or any larval species with larval behavior algorithms and rules).

The LTRANS-DEK was used to output daily larval settlement numbers for three example locations in BAR, and the daily output files generated from LTRANS-DEK were coupled with the three oyster reef IBMs to drive daily oyster larval numbers available to settle as spat (i.e., recruitment) to the reef IBMs (Figure 2, Packet 9). The simplified coupling scheme between the oyster larval transport model and the reef IBM point models was verified to be working correctly. Upon recent agreement of the final oyster model reef spatial design for Barataria Basin (Figure 5), we have initiated the work towards full-scale coupling and testing scenarios between LTRANS-DEK and the oyster reef IBM point models using the ROMS generated conditions from 2014-2018 (Figure 2, Packets 12, 14, 15, 17).

The oyster reef IBM source code and all input files necessary to run the reef model (Yurek et al. 2020) in MATLAB were supplied by S. Yurek at USGS. The reef IBM set up and parameterization, and testing for BAR to verify that the reef model was projecting reasonably realistic oyster growth, survival, and spawning over time was completed in Fall 2023. Oyster sizes, densities, and spawning events were plotted using salinity and temperature conditions from interpolated field data from 2016-2020, and a small set of parameters (i.e., natural mortality rate, predation mortality rate, and filtration or grazing rate) were adjusted to calibrate the IBM to predict generally similar oyster reef size structure, density, and spawning events for the reef compared to observed oyster reefs in Louisiana and Texas and described in the oyster life history literature (e.g., La Peyre et al. 2013, Lavaud et al. 2017). USGS made several simplifications and adjustments to the IBM source code and ran numerous simulation tests to verify all model changes worked as intended without changing the model functioning or input/output structure. USGS also added an option to use a larval pool from an independent model by importing a daily input file (to be provided by LTRANS-DEK in our case) instead of estimating the pediveliger larval pool from oyster spawning (total daily eggs) on the modeled reef. The default IBM option simulates the full life cycle of the oyster reef population by storing the eggs released from reef spawning then reducing the egg numbers to larvae and to pediveliger larvae by the egg and larval stage survival. The resulting pediveliger larval pool is ready to settle as spat on the reef if there is available space. Therefore, the two options for supplying oyster

pediveliger larval pools capable of settling as spat on the oyster reef are included in the modified IBM we use for oyster metapopulation modeling in coastal Louisiana.

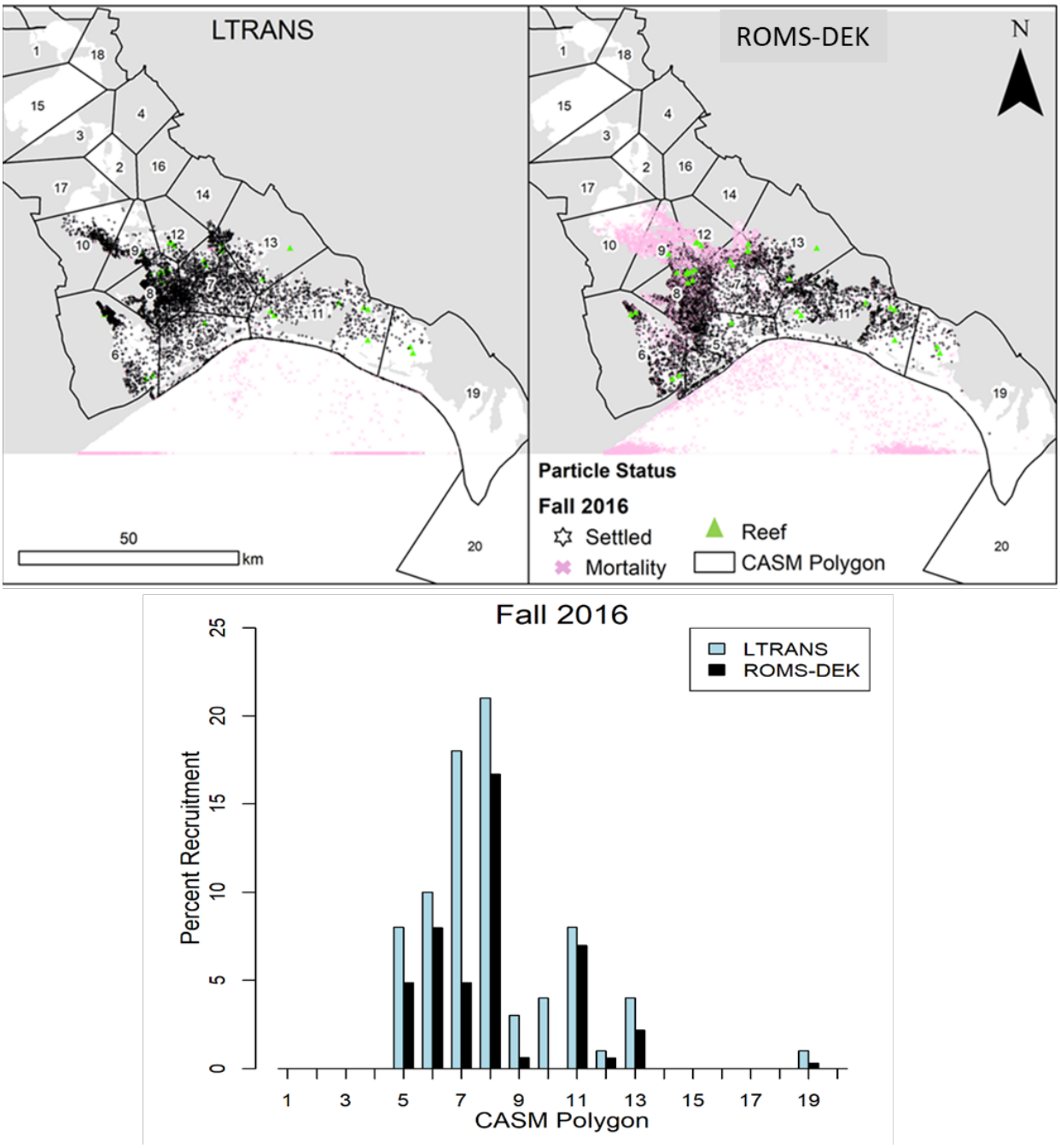


Figure 7. Example results from the previous comparison between LTRANS and ROMS-DEK for the Fall 2016 simulation showing larval particle distribution after 30 days (top) and successful settlement (percent recruitment) by the 19 CASM polygons. Results like these will be used again to compare the new LTRANS-DEK with the ROMS-DEK for simulating oyster larval transport and recruitment in BAR.

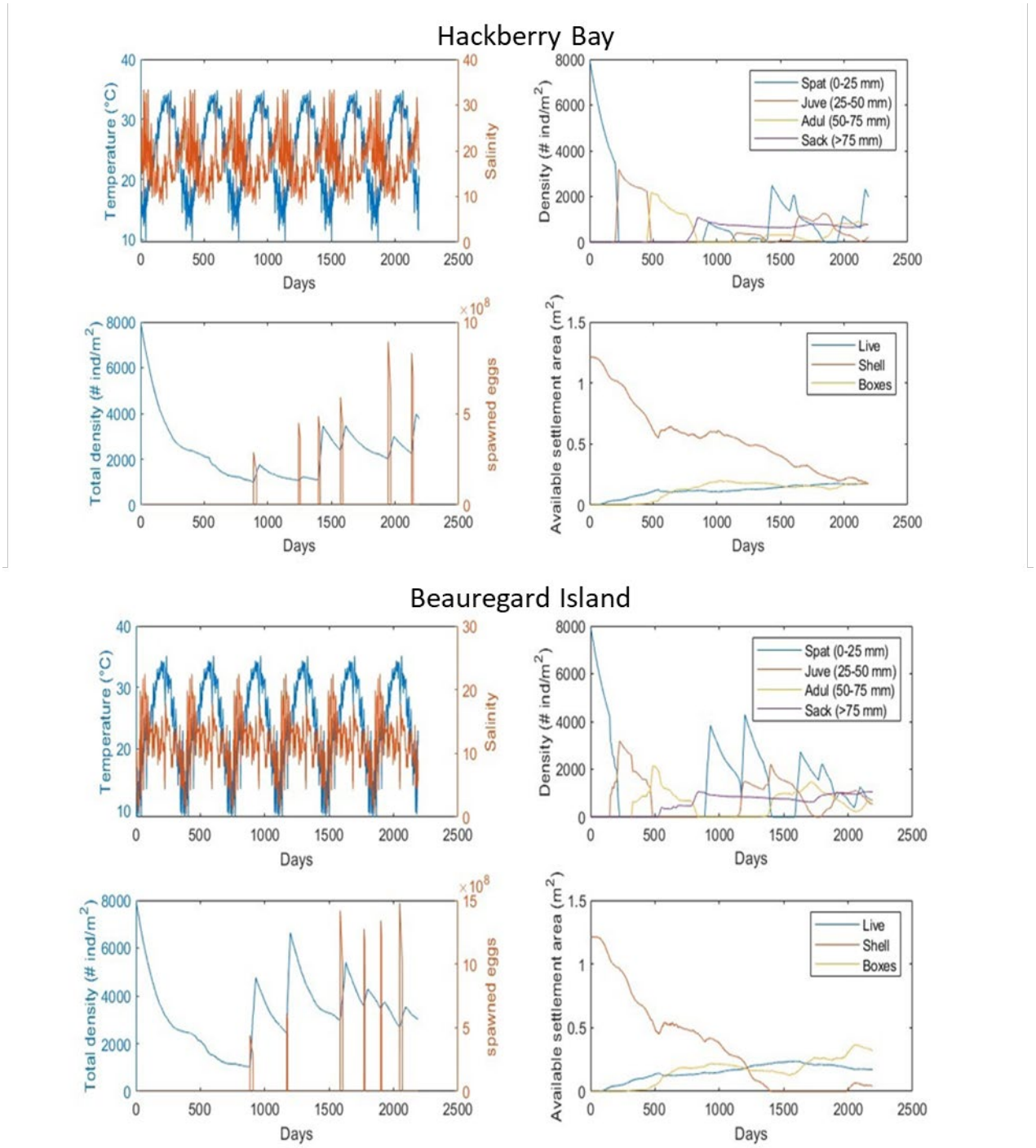


Figure 8. Example results from the oyster reef IBM run over six years and using the ROMS daily depth-averaged temperature and salinity in 2016 for a location in Hackberry Bay (top panels), and a location near Beauregard Island just above Grand Isle (bottom panels). The third location to test the ROMS BAR coupling with the oyster reef IBM was located southeast of Little Lake. The 2016 salinities generated by ROMS were below 5 ppt and the oyster reef population crashed, as expected.

After the single reef IBM was successfully set up and calibrated for BAR conditions, the oyster reef IBM was coupled with the ROMS and LTRANS-DEK outputs for three locations. LTRANS-DEK provided daily larval

supply to the reef (i.e., number of pediveliger larvae capable of settling). The ROMS provided daily depth-averaged salinity and temperature to drive oyster growth, survival, and reproduction or spawning in the IBM (Figure 2, Packet 9, see Figure 8). USGS is in the process of constructing the N array of reef IBM point models for Barataria Basin (see Figure 5 for spatial grid with 332 potential oyster reef models). These N reef IBM point models will each use daily depth-averaged salinity and temperature conditions from the ROMS at the defined centroid locations (Figure 5) from 2014-2018 to drive oyster survival, growth, spawning, and reef maintenance processes. Design of the full-scale coupling and testing scenarios have been initiated between the model teams responsible for the LTRANS-DEK and the oyster reef IBM point models in BAR (Figure 2, Packet 12). Oyster team meetings will outline exactly how the oyster models will be coupled for multiple year simulations in order to best evaluate oyster metapopulation dynamics at the basin-scale, and address the oyster restoration management questions (Table 1 example, see Table 1 in Sable and Rose, 2023).

North Pontchartrain Basin and Calcasieu Lake:

The FVCOM hydrodynamics model for the NPONT was set up by the WI with a refined Delft-FM grid. Model testing, calibration and validation for 2014-2018 are ongoing (Figure 2, Packet 6). The coupling of the FVCOM for NPONT with the original LTRANSv2b was successfully completed and tested for passive particles and the default oyster larval behavior by the WI (Diaz et al. 2023). This coupling was an important step (Figure 2, Packet 11) to make sure that we could do the FVCOM-LTRANS coupling. Next, the updated and fully tested LTRANS-DEK will be coupled to the NPONT hydrodynamics model calibrated and validated for 2014-2018, following the coupling procedures and lessons learned from the FVCOM-LTRANS coupling verification exercise.

Next Steps and Recommendations:

We are working on the spatial design of the oyster reef IBM point models (locations, spatial grain or area of each modeled reef) for each coastal basin. The spatial design of the oyster reef models is the crux of the project because we want the oyster metapopulation model set up (larval transport and oyster reef IBM point models) at the basin-scale to provide realistic results based on sufficiently resolved spatiotemporal gradients and changes generated by the hydrodynamic models.

After we have our full-scale oyster metapopulation modeling set up and tested for BAR, including our coupling scheme between the LTRANS-DEK and oyster reef IBMs determined, we will validate that the oyster model projections from 2014-2018 are realistic for the system (Figure 2, Packet 19). Validation of the fully coupled oyster metapopulation model will be completed by early 2025 for existing conditions from 2014-2018. All modeling will be completed for BAR first, with modeling for NPONT and CALC completed soon after using the same model steps, coupling methods, and lessons learned from the BAR application.

The ROMS set up for simulating 3D hydrodynamics for CALC was just initiated by LSU (Figure 2, Packet 6). After the ROMS is calibrated and validated for CALC, using at least 2016 and 2017 conditions, the ROMS will be used to simulate conditions from 2014-2018. The ROMS output files (nc) will be used to drive oyster larval transport and recruitment among defined oyster reef models using the LTRANS-DEK. The ROMS outputs will be used to create the daily depth-averaged conditions to drive the oyster reef IBM point models for CALC.

The spatial design for the reef IBM point models in NPONT and CALC will be determined by the full modeling team in Summer 2024 (Figure 2, Packet 2). Running the fully coupled oyster reef models for NPONT and CALC from 2014-2018, will be initiated by early fall 2024 (Figure 2, Packets 12, 13, 14, 15, 17).

2023 Products:

Project-related meetings, workshops, documents, technical memorandums and conference presentations made by the oyster modeling team members in 2023.

Project Kickoff Meeting held in-person and virtually on March 22, 2023. Kickoff presentation available upon request.

Two-day modeling workshop was held at Evans-Graves Engineers, New Orleans, LA before the State of the Coast Conference on May 30-31, 2023

Oyster Metapopulation Modeling Session with four oral presentations at State of the Coast on June 1, 2023.

- La Peyre, M., S. Sable, H. Wang, C. Perez, L. Swam, B. Carter D. Lindquist. 2023. Modeling to inform sustainable oyster metapopulations in Louisiana estuaries: Where are we and what do we need to know? State of the Coast 2023, New Orleans, LA. Oral presentation.
- Stephens, T., Z. Zang, S. Sable, K. Rose, and Z. Xue. 2023. Oyster Larval Transport Model Comparison in Barataria Basin. State of the Coast 2023, May 31 – June 2, New Orleans, LA. Oral presentation.
- Lavaud, R., S. Yurek, M. La Peyre, H. Wang, S. Sable. 2023. Modeling oyster reef population dynamics from individual bioenergetics to structural mechanics. State of the Coast 2023, May 31 – June 2, New Orleans, LA. Oral presentation.
- Sable, S., K. Rose, M. La Peyre, T. Stephens, Z. Zang, Z. Xue, O. Diaz, I. Georgiou, R. Lavaud, H. Wang, S. Yurek, C. Perez, L. Carnes, B. Carter, D. Lindquist. Oyster Metapopulation Modeling for Louisiana's Estuaries. State of the Coast 2023, May 31 - June 2, New Orleans, LA. Oral presentation.

DS with K. Rose led team in preparation and review of the model implementation plan. The final 2023 Model Implementation Plan is available upon request.

- Sable, S.E., and K.A. Rose. Model Implementation Plan. 2023. Prepared for Project: Oyster Metapopulation Modeling for Louisiana's Estuaries. July 11th, 2023.

Diaz Garcia, O., I. Georgiou, F. Messina. OYSTER METAPOPULATION MODELING: LTRANS-FVCOM Tests. September 15th, 2023. Input and coordination during testing: Tim Stephens (Dynamic Solutions), Kenny Rose (UMCES). Submitted to: Kenny Rose (UMCES), Shaye Sable (Dynamic Solutions).

Zang, Z., Z. Xue, S. Sable, M. La Peyre, D. Lindquist, K. A. Rose, Y. Oa. A numerical study of eastern oyster (Crassostrea Virginia) larvae growth and dispersal in Barataria Bay, Louisiana. 2023 Coastal and Estuarine Research Federation Conference, Portland, OR. Oral presentation.

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Louisiana's Coastal Basins. Industry Summit on Nature-based Solutions, Athens, GA, November 2023. Poster Presentation.

Lavaud, R., S. Sable, T. Stephens, M. La Peyre, K. Rose, Z. Zang, Z. Xue, O. Diaz, I. Georgiou, S. Yurek, H. Wang, B. Carter, D. Lindquist. 2023. Oyster metapopulation modeling to support restoration in Louisiana's coastal basins. Abstract: Poster Presentation, 116th National Shellfisheries Association meeting. https://www.shellfish.org/annual-meeting

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