Final Report for SECASC Project "Integrating Sea Level Rise Scenarios into Everglades Restoration Planning"

SECTION 1. ADMINISTRATIVE

Project title: Integrating Sea Level Rise Scenarios into Everglades Restoration Planning

Principal Investigator: Laura E. D'Acunto, U.S. Geological Survey, Wetland and Aquatic Research Center, Gainesville, FL; ldacunto@usgs.gov

Co-Principal Investigator: Stephanie S. Romañach, U.S. Geological Survey, Wetland and Aquatic Research Center, Gainesville, FL; sromanach@usgs.gov

Agreement Number: SECASC063

Cooperators and Partners:

Stephanie Castellano, University of Florida

Mysha Clarke, University of Florida

Restoration, Coordination, and Verification (RECOVER) – a multiagency team of scientists, modelers, and restoration planners that conduct system-wide scientific evaluations to improve Everglades restoration outcomes.

Date: January 28, 2025

Period of performance: October 2021 – September 2023 (no cost extension to September 2024)

Actual total cost: $191,237.04

SECTION 2: PUBLIC SUMMARY

One of the largest and most expensive restoration efforts in the world is occurring in the Everglades, a sub-tropical freshwater wetland system located in southern Florida. This unique ecosystem supports several endangered species, provides flood control for Florida's large urban population, and provides water for both agriculture and drinking supply within the state. The Comprehensive Everglades Restoration Plan (CERP), authorized by Congress in 2000, guides federal, state, and local efforts to build the infrastructure necessary to bring more water into the Everglades and restore its ecological integrity, while balancing other water-related needs such as water supply and flood protection in the human environment. The Everglades encompasses the southern coast of Florida and restoration efforts are likely to be impacted by climate-induced sea level rise. However, currently, many project planning studies do not formally incorporate the potential impacts of sea level rise when evaluating restoration plan outcomes. Resource managers and project planners require methods and tools to confidently

incorporate scenarios of sea level rise into their evaluations. The U.S. Geological Survey (USGS) and partners from the University of Florida worked with project planners from multiple agencies to identify restoration questions for consideration when addressing sea level rise. In addition, our project team sought to understand the types of sea level rise decision-support tools that would be of interest, and then worked with Everglades restoration managers and project planners to develop those tools. The tools developed by this project can be used by project planners to inform their decision-making abilities when considering multiple restoration plans across the Everglades landscape. Specifically, the novel ways to visualize output information from ecological models that came of this project can help project planners compare alternative restoration plans that include potential sea level rise impacts. This effort demonstrates how incorporating sea level rise scenarios into Everglades restoration project planning can help managers decide whether projects will maintain or improve ecological integrity and evaluate water availability for wildlife and humans.

SECTION 3: TECHNICAL SUMMARY

The Everglades is a vast sub-tropical freshwater wetland located in southern Florida that supports several endemic and endangered species, provides flood risk management for Florida's large urban population, and provides water for both agriculture and drinking supply within the state (Lodge 2016). Attempts to drain the Everglades in the early 20th century led to a degraded ecosystem where the flow of water is heavily managed through a series of canals, levees, and pumps across the landscape (Lodge 2016). The restoration of the Everglades involves changing the current infrastructure and utilizing the system to return the flow of water south to better reflect its historic, natural flow. This effort is one of the largest and most expensive restoration efforts in the world (Sklar et al. 2005; Lodge 2016). The CERP, authorized by Congress in 2000 (Water Resources Development Act, Public Law 106–541) is a significant part of Everglades restoration. Implementing the CERP involves coordination among scientists, managers, decision makers, and community stakeholders to meet both ecological and human water needs. The Everglades science community has long recognized the need to consider the impact of sea level rise on restoration project success, and the multi-agency restoration evaluation and assessment group RECOVER (Restoration, Coordination, and Verification) discussed implications of this in their 2019 and 2024 System Status Report (RECOVER 2019; RECOVER 2024). The current guidance from the U.S. Army Corps of Engineers (USACE) asks planners is to consider how sea level rise may impact projects across the life cycle, with the expectation that sea levels will be between 13 and 66 inches higher in 2050 than in 1995 (RECOVER 2019). Other agencies within RECOVER may have other guidance from their

leadership on how much sea level rise to expect in the future. RECOVER requested help incorporating potential sea level rise scenarios into their current project evaluation process.

Ecological models are used extensively to evaluate how various restoration projects can impact indicator species and habitats and Everglades ecosystem health (LoSchiavo et al. 2013). Often, this involves a partnership between the South Florida Water Management District (SFWMD), which models potential hydrology of the system, and the USGS Joint Ecosystem Modeling (JEM) team, which uses these hydrologic scenarios as inputs to a suite of ecological models. These models predict the response of key parts of the Everglades ecological system to the changes in hydrology due to CERP project completion. Everglades restoration projects can vary from local- to landscape-level in geographic scope, and need to balance the water needs of the natural system and the public (Sklar et al. 2005). RECOVER evaluates potential project impacts on the ecological system at a broader landscape level, using ecological models that predict suitable habitat for a suite of indicators of ecosystem health (USACE 2020a, USACE 2020b). Historically, the hydrologic scenarios provided by the SFWMD have not included sea level rise impacts. There was a need to explore how sea level rise scenarios may impact the output of the JEM ecological models and to develop new visualizations that would aid RECOVER in teasing out the impacts to a restoration scenario from sea level rise.

We worked closely with RECOVER using focus groups, semi-structured interviews, and workshops to understand their project evaluation needs and preferences for visualizations. We used insights from the focus groups and interviews to develop example visualizations that were then shared with REOVER at an in-person meeting. Feedback obtained during the meeting was used to adjust the visualizations. We produced final visualizations using scenarios from a recent evaluation project, the Biscayne Bay and Southern Everglades Restoration (BBSEER) project (USACE and SFWMD 2020), the first Everglades restoration evaluation project to incorporate sea level rise scenarios. We also generated our own sea level rise scenarios using the Biscayne and Southern Everglades Coastal Transport (BISECT) hydrologic model (Swain et al. 2019) and produced ecological model output and visualizations under these scenarios. The output and visualizations can be used by RECOVER and JEM to understand how ecological models may perform under sea level rise scenarios and provide project planners and managers with information to aid them in distinguishing between sea level rise impacts from restoration impacts in project evaluations.

SECTION 4: PURPOSE AND OBJECTIVES

RECOVER is tasked with evaluating how CERP projects will impact system-wide Everglades ecological dynamics. RECOVER extensively uses hydrologic and ecological models, which predict the system's response after completion of restoration projects. Focus on the central Everglades and limited resources may impact the ability to incorporate sea level rise into evaluations. With the start of coastal projects such as the BBSEER project have begun, sea level rise scenarios can be part of the project evaluation process.. Given this, RECOVER asked that the JEM team at USGS assist with providing the methods and tools to accomplish this task.

Our project had four broad objectives:

1) Identify the suite of restoration evaluations that could benefit from the incorporation of an evaluation of sea level rise impacts.
2) Identify types of sea level rise scenarios that could be used for project planning within the Everglades.
3) Develop methods for project evaluators that outlines the assumptions, uncertainties, and risks associated with different sea level rise scenarios.
4) Develop and test spatially and temporally explicit visualizations of ecological model and decision tool output that use sea level rise scenarios.

Using interviews, focus groups, and workshops (see Organization and Approach section), we accomplished each of these objectives, however, the methodology to achieve the objectives changed from the original proposal due to project staff changes, funds spending deadlines, and conversations with our primary cooperator, RECOVER.

SECTION 5: ORGANIZATION AND APPROACH

At the beginning of the project, we initiated a collaboration with Dr. Mysha Clarke and graduate student Stephanie Castellano, social scientists in the School of Forest, Fisheries, and Geomatics Sciences at the University of Florida. Using their social science expertise, we developed a two-phased approach to understand RECOVER's needs, which allowed us to receive input on our deliverables before and during the development process. This included initial focus groups, individual interviews, the development of data visualizations, and a final opportunity to provide feedback on the data visualization tools.

Focus Groups

We initiated focus groups with members of RECOVER at a monthly hybrid (in-person and online) meeting on January 19, 2023 in West Palm Beach, FL at the SFWMD headquarters. The focus groups were approved and governed by the University of Florida's Institutional Review Board (IRB Study No.

UFIRB202300008). We split the participants into six groups, with half of the groups participating virtually, using Zoom's breakout feature to randomly divide the participants into three groups, while in-person attendees were randomly divided into an additional three groups. Each group discussion was led by a dedicated facilitator who posed pre-planned questions to the participants, took notes, and for in-person discussions, recorded them using audio recording devices. Due to technical and facilitator error, we were not able to record the virtual discussions. Only recorded sessions were used for formal analysis. Each group was asked the following questions:

1) How will sea level rise impact Everglades restoration?
    a) Prompt: Can you identify one assessment, evaluation, or decision that you (meaning the office, agency, organization, or unit you represent) will need to consider when making decisions about sea level rise?
2) What types of outputs or information do you need to address sea level rise and Everglades restoration?
    a) Prompt: What information do you need about sea level rise to do your job well?
    b) Prompt: How would you like this information presented to you?

Semi-structured Interviews

The semi-structured interviews were an opportunity for RECOVER members to individually discuss how they believed sea level rise would broadly impact Everglades restoration and what types of tools they needed to plan for those impacts. We invited 62 individuals who were active members of RECOVER or who work closely with RECOVER on CERP projects to participate in the interviews. We emailed interview requests to these 62 members and sent two follow-up emails within six weeks of the initial request if no response was received. The interview questions were approved in advance by the University of Florida's Institutional Review Board (IRB Study No. IRB202300008). All the interviews (29 total) were held virtually via Zoom or Microsoft Teams and were recorded with the interviewees' consent. All interviews lasted approximately one hour.

The interviews were structured into four parts:

1. Participants' background information and roles in RECOVER.
2. How they interpreted sea level rise would impact Everglades restoration outcomes.
3. Challenges and opportunities for integrating sea level rise into restoration planning.
4. Participants' perceptions of the modeling tools and guidance provided by JEM.

To conduct the fourth part of the interview, we showed participants three examples of decision-support tools designed by JEM and asked a series of questions based on those examples. Interview

transcripts, which were generated automatically by video conferencing software, were analyzed with the software NVivo. We initially created codes that matched our interview questions to organize responses and identify any emergent themes; then we created additional codes for those emergent themes.
The goal of our project is sea level rise decision-support tools that are highly usable and useful to RECOVER members. Therefore, to explore RECOVER members' perceptions of the decision-support tools developed by JEM, we applied Stern's innovation-decision process, which is based on Rogers' Diffusion of Innovations Theory (Rogers 2003; Stern 2018). Diffusion Theory examines how ideas or "innovations" are spread through social networks and adopted by target audiences. It can be applied in natural resource management contexts, when, for example, people are asked to adopt new forms of collective decision making (Stern 2018). In this case, we considered the sea level rise decision-support tools as the "innovation." Diffusion Theory and the innovation-decision process have not been applied to research specifically on the adoption of decision-support tools in natural resource management, making this project a novel contribution to the theory.

Development of Visualizations

We generated a series of potential visualization options using the BBSEER restoration project data, which included sea level rise scenarios. These options used elements from visualizations JEM currently provides for evaluations (Hackett et al. 2023) and incorporated new elements using the insights from the focus groups and semi-structured interviews. The visualizations included maps and graphs summarizing JEM ecological model output from sea level rise scenarios (an intermediate scenario of 53 cm and a high scenario of 152 cm rise) compared to a baseline scenario of simulated current conditions. The sea level rise scenarios correspond to USACE's current recommended scenarios.

These visualizations were presented to RECOVER at an in-person monthly meeting on May 16, 2024. We set up five stations, one each for the four main elements of the visualizations, Interpretation, Aesthetics, Measurement, and Layout, as well as a "Miscellaneous" board for items that did not fit into any category. Participants were split into five groups, and individual participants were asked to write down what they liked or did not like within each design element on sticky notes for three minutes, and then moved onto the next element. The feedback was collated and used to finalize the new visualizations.

Exploring How Sea Level Rise Impacts JEM Ecological Models

To illustrate how JEM ecological models respond to sea level rise using the new visualizations, we developed two sea level rise scenarios using the BISECT model (Swain et al. 2019) which reflected the intermediate (53 cm) and high (152 cm) projections from the U.S. Army Corps of Engineers (USACE), as

these are the scenarios required to be used in USACE projects (Regulation ER 1100-2-8162). USACE and SFWMD are the main partners responsible for the implementation of the CERP, therefore these scenarios are required in Everglades restoration project evaluations (RECOVER 2019, 2024). We then ran the vegetation sub-model of the Everglades Vulnerability Analysis (EVA, D'Acunto et al. 2023a; D'Acunto et al. 2023b) and post-processed the output to produce the new visualizations. Using the visualizations, we explored how sea level rise scenarios impact the model outcomes and uncertainty associated with those outcomes to better understand how the ecological models respond to sea level rise scenarios.

SECTION 6: PROJECT RESULTS

Focus Group Results

We had a total of 33 participants across six focus groups, all of whom were active RECOVER members or worked closely with the group. When asked "How will sea level rise impact Everglades restoration?", participants discussed the anticipated impacts of sea level rise on the Everglades ecosystem such as saltwater intrusion, increased flooding, and loss of coastline. Participants also discussed wanting to incorporate climate change impacts beyond sea level rise, such as temperature and rainfall changes, into decision-support tools. When asked "What types of outputs or information do you need to address sea level rise and Everglades restoration?", many participants focused on the desire to project vegetation succession as sea level increases and that step-change simulations of hydrology are less suitable than incremental simulations. Participants expressed a desire to see visualizations on a more local scale and to view outputs across different temporal scales. Most focus group participants preferred to receive ecological model output as interactive data visualization via a website. In terms of project deliverables, participants expressed that they did not want a guidance document and instead preferred concise and flexible documentation and visualizations.

Semi-structured interviews

We conducted 29 interviews with RECOVER members belonging to federal, state, and tribal organizations. The first part of the interviews identified barriers to incorporating sea level rise into restoration planning. Seven main barriers emerged from the interviews:

1) There is a lack of appropriate modeling tools for projecting sea level rise impacts on restoration outcomes, especially when simulating new hydrologic conditions.
2) There are many uncertainties associated with climate change generally such as how much sea level rise to expect, and how certain the JEM models are at predicting responses.
3) There is a lack of appropriate data to construct reliable models, especially at smaller scales.

4) RECOVER struggles to fully fund the monitoring and modeling efforts expressed the need to feel more confident in their project evaluations.
5) Current hydrologic models are based on weather patterns from the historical record and respondents expressed this is inadequate to fully understand how sea level rise and climate change may impact the Everglades.
6) There is no consensus within RECOVER on how sea level rise should be incorporated into the planning process.
7) Different entities within RECOVER have mandates or preferences for the specific sea level rise scenarios they would like to use in project planning.

The second part of the interview discussed whether there are aspects or attributes of the JEM modeling tools that prevent them from understanding the impacts of sea level rise on the Everglades. Three major limitations emerged from these discussions:

1) Respondents expressed a desire for succession models instead of step-change models of sea level rise.
2) Many models used are limited in their geographic scope and scale.
3) Respondents expressed a desire for additional modeling of changes in elevation and salinity.

The third part of the interviews focused on what information respondents are seeking from the ecological models without consideration of known limitations. Four main themes emerged:

1) Understanding how habitats and species will change over time with incremental sea level rise.
2) Understanding ecological resiliency across the landscape.
3) Understanding thresholds for collapse related to salinity intrusion, water depths, and soil accretion-subsidence dynamics.
4) Understanding to what extent will sea level rise counteract the benefits of increased freshwater flows from CERP projects.

The fourth and final part of the interviews focused on providing feedback on mock-ups of data visualization tools developed after receiving feedback from the focus groups. Participants were shown three examples of data visualizations that the JEM group at USGS could provide to RECOVER. Participants were asked to provide feedback on each of the three examples and were also asked a series of questions relating to the following components of the innovation-decision process: relative advantage, compatibility, complexity, trialability, and observability (Rogers 2003, Stern 2018).

Example 1: Animated maps

The first example was an animated map that depicted species or vegetation responses (such as probability of presence) to hydrologic conditions over time. Most participants expressed that the animated map was good for communicating trends to a non-scientific audience, including policymakers, but did not serve as well for scientific analysis.

Example 2: Static maps and bar charts

The second example depicted a series of successional outputs of species or vegetation responses (such as probability of presence) to hydrologic conditions over time, through both maps and bar graphs of the outputs at fixed time points (5- and 10-year increments were shown). Several respondents said the second example seemed more usable for the scientific community because it can be more readily quantifiable than an animation.

Example 3: Interactive maps

The third example featured a dynamic map that participants could interact with via a web-based platform. In the example, users had the ability to add and remove layers of both hydrologic metric inputs and species or vegetation responses (such as probability of presence). Respondents generally expressed enthusiasm about the interactive capabilities of the third example. They reported liking the functionality of adding and removing layers on a map and being able to zoom in and out to desired resolutions. A few respondents commented that Example 3 would be more useful for someone in a more technical role, or who is producing technical reports, but less so for someone in a management or executive role, who would merely want to be shown the outputs.

Development of Visualizations

After analyzing the interview results, we initially focused efforts on developing visualizations according to Example 3 as this was the preferred method across participants. Originally this was planned to be developed within an ArcGIS Online website hosted by USGS. During the development, the contract between USGS and ESRI changed, making this approach financially infeasible for the project. We pivoted instead to providing visualizations according to Example 2. We developed 10 types of example visualizations using the vegetation sub-model from EVA and scenarios developed for the BBSEER restoration project scenario. The feedback gathered at the RECOVER workshop in May 2024 provided us with information on what the participants liked about the visualizations and areas for improvement. We used this feedback to adjust the visualizations.

SECTION 7: ANALYSIS AND FINDINGS

Our first objective was to identify restoration evaluations that may incorporate an evaluation of sea level rise impacts. In general, RECOVER interview respondents indicated they were eager to have additional decision-support tools that help them consider sea level rise in project evaluations. Our project revealed that RECOVER members acknowledge the need to incorporate sea level rise in both hydrologic and ecological models, but significant barriers to this process still exist. The largest barrier identified is the lack of successional hydrologic modeling (versus step-change modeling) that would allow RECOVER to identify potential thresholds or tipping points of sea level rise for ecological resilience. Related to our second objective to identify the types of sea level rise scenarios that could be used for project planning in the Everglades, we discovered that the multiple agencies that comprise RECOVER have mandates for specific sea level rise scenarios. Therefore, flexible decision-support tools could accommodate different agency priorities. Through formal and informal engagement with RECOVER, we were able to better understand partner preferences in terms of science information delivery for project evaluations. This allowed us to generate visualizations from model output that can be more informative and understandable to our partners, accomplishing objective 3 of the project to develop methods to communicate the uncertainty, assumptions, and risks associated with considering sea level rise in project evaluations. These new visualizations are novel in that it is the first time uncertainty is incorporated into the visualizations RECOVER uses to evaluate restoration projects. Finally, in accordance with our final objective, we identified that incorporating sea level rise scenarios into Everglades ecological restoration modeling will likely increase the uncertainty associated with the outputs through the testing of spatially and temporally explicit visualizations.

SECTION 8: CONCLUSIONS AND RECOMMENDATIONS

RECOVER is actively interested in understanding how sea level rise will impact restoration success in the Everglades. Our project discovered several barriers to accomplishing this understanding—the largest of which our project team is unable to fully address. Many RECOVER members, even when prompted to discuss ecological modeling outputs, were focused on the hydrologic scenarios produced by the Interagency Modeling Center (IMC; CERP Guidance Memorandum 030.00) and the ways they incorporate climate change (or fail to do so). Addressing this issue was outside the scope of our project, but our findings support the conclusions of the National Academies of Sciences, Engineering, and Mathematics Committee on Independent Scientific Review of Everglades Restoration (CISRERP), which identified this as a major modeling gap that could inhibit restoration progress (NASEM 2024). Through the iterative process of engagement with RECOVER, we were able to identify strategies for visualizing our

modeling output that can benefit future projects. JEM is regularly called on by USACE to provide ecological modeling output for restoration project planning and the new visualizations can be incorporated into the information provided. Finally, we were able to generate ecological modeling output from scenarios including sea level rise from both the IMC and using the BISECT hydrodynamic model. These outputs can be used to explore how sea level rise scenarios may impact the ecological model conclusions and certainty around those conclusions.

We encountered some issues during our project lifespan. Some project personnel had knowledge gaps about how Everglades restoration operates and RECOVER's formal role in that process. If we were to conduct this project again, more time would be spent on this education so that the focus groups and interviews could remain more focused to the objectives of the project. Additionally, our original vision of an interactive tool could not be materialized due to unanticipated changes in the funding needed to host and maintain such a tool. However, partly due to the results of this project, the USACE has initiated a new project with the JEM team to begin to build a decision-support tool that allows interactive visualization of both current and modeled conditions across the Everglades. The results from this project can provide insights into how to design and implement this tool for use by RECOVER and the broader Everglades community.

SECTION 9: MANAGEMENT IMPLICATIONS AND PRODUCTS

"*We never have enough money to do everything and focus on every problem. So I want to know where the problems are going to be the most severe and where I might have the greatest impact [in] solving this problem.*" – RECOVER member.

Our project worked closely with our partner, RECOVER, to ensure the science produced can be used in the future. We did this by formally and informally soliciting feedback from the group before, during, and at the end of the project lifespan. This gave the JEM team insight into what types of visualizations are preferred by the group and can be used in model output delivery to RECOVER, which includes representatives from the following agencies and tribal organizations:

- U.S. Army Corps of Engineers
- South Florida Water Management District
- Florida Department of Agriculture and Consumer Services
- National Oceanic and Atmospheric Administration

- U.S. Environmental Protection Agency
- Florida Department of Environmental Protection
- National Park Service
- U.S. Fish and Wildlife Service
- Florida Fish and Wildlife Conservation Commission
- Seminole Tribe of Florida
- U.S. Geological Survey
- Miccosukee Tribe of Indians of Florida

Study deliverables and findings will likely be used by RECOVER in their CERP programmatic support activities, such as evaluating interim goals and targets, and their assessment reporting, such as the System Status Reports and reports to Congress. Additionally, RECOVER may use the results from this project in their project-specific support capacity, such as regulatory support and selection of restoration management plans.

SECTION 10: OUTREACH AND COMMUNICATION

Final interview results were presented to RECOVER on May 16, 2024, at a monthly RECOVER meeting. We engaged with RECOVER and other partners at RECOVER monthly meetings and the Greater Everglades Ecosystem Restoration conference throughout the life of the project. Outside of the Everglades community, we also presented this project at national conferences and through a public seminar hosted by the SECASC. We are scheduled to deliver a SECASC-hosted science seminar in June 2025. We have drafted one manuscript describing the social science part of the project and plan to draft a journal article describing the new visualizations and the insights they bring when teasing apart sea level rise and restoration impacts during Everglades restoration evaluations. JEM engages in ongoing communication with RECOVER and any additional products generated from this project will be shared widely among the group.

Data Releases

D'Acunto, L.E. and Romañach, S.S. 2025. Hydrologic simulation and ecological model output used to explore potential sea level rise scenario impacts on ecological models used in Everglades restoration planning, U.S. Geological Survey data release, https://doi.org/10.5066/P1DEDKQV.

Conference Abstracts (ordered by date)

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Castellano, S., D'Acunto, L.E., Romañach, S.S., and Clarke, M. 2023. Examining Stakeholder Perceptions of Sea-Level Rise and How It Impacts Everglades Restoration, [abs] at the International Association of Society and Natural Resources (IASNR) Annual Conference, June 11-15, 2023, Portland, Maine. IP-149821. Approved on 07/21/2023.

Castellano, S.L., Clarke, M.K., D'Acunto, L.E., and Romañach, S.S. 2024. Barriers to understanding sea-level rise impacts on Everglades restoration [abs.], 9th University of Florida Water Institute Symposium, February 20-21, 2024, Gainesville, FL, https://conference.ifas.ufl.edu/waterinstitute. IP-158717. Approved on 03/06/2024.

Castellano, S.L., Clarke, M.K., D'Acunto, L.E., and Romañach, S.S. 2024. Barriers to understanding sea-level rise impacts on Everglades restoration, [abs]. National Conference on Ecosystem Restoration (NCER), April 14-19, 2024, Albuquerque, NM, USA. IP-157263. Approved on 04/29/2024.

Conference Presentations / Seminars (ordered by date)

D'Acunto, L.E. 2023. Integrating Sea Level Rise Scenarios into Everglades Restoration Planning [presentation], Southeast Climate Adaptation Science Center Virtual Science Seminar, February 14, 2023, virtual presentation, https://secasc.ncsu.edu/event/se-casc-science-seminar-introduction-to-new-se-casc-projects/. IP-149953. Approved on 03/20/2023.

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Workshops with Partners

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