# Historical-Economic Optimization of Climate Adaptation Planning for Historical Resources: A Multi-objective Optimization Approach

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## Introduction

Climate change is increasingly posing great challenges to tangible coastal cultural heritage. Storms events, hurricanes, flooding, rising sea-level, and erosions damage the conditions and historical integrity of the cultural resources in the coastal areas. The National Park Service (NPS) has recognized the impacts of climate change and climate extremes as the greatest threat to the integrity of cultural resources in national parks and highlight the need for historical preservation as its working priority.

In this study, we aim to advance the Optimal Preservation Model (OptiPres) model developed by Xiao et al. (2019) to integrate multiple management objectives: 1) identify the optimal adaptation plans for historic buildings to maximize their historical significance and use potential under climate change; 2) the optimal adaptation plans to achieve the maximum cost-efficiency among different budget scenarios, and 3) the optimal adaptation plans to maximize the number of historical buildings receiving climate-focused adaptation actions; 4) to compare the trade-offs of adaptation actions between the multiple management objectives among different budget scenarios.

## Study Site: Cape Lookout National Seashore (CALO)

In this study, we selected 17 historical buildings located in two historical districts situated on barrier islands along the North Carolina coast and listed on the National Register of Historic Places: Portsmouth Village (PV) and Cape Lookout Village (CLV) in Cape Lookout National Seashore (CALO). These villages provide representations of various periods of coastal occupation during and following US colonization, hold strong place attachments for local communities, and having varying degrees of visitation, with most visitation being to the Cape Lookout Lighthouse and Keeper's Quarters in CLV

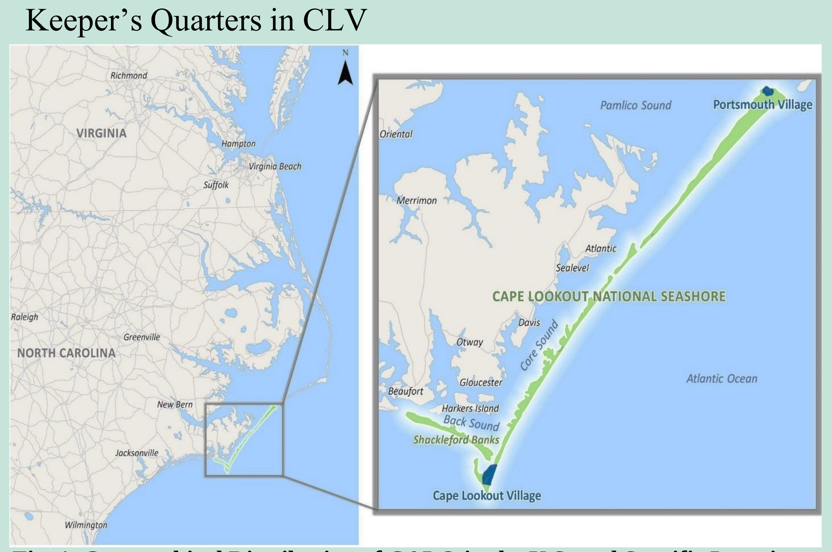

Fig. 1. Geographical Distribution of CALO in the U.S. and Specific Locations of PV and CLV within CALO.

Fig. 2. Historical Buildings in CALO

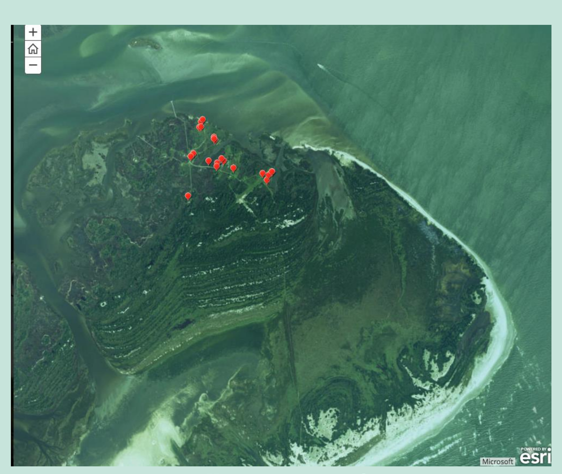

Fig. 3. Satellite Imagery of PV

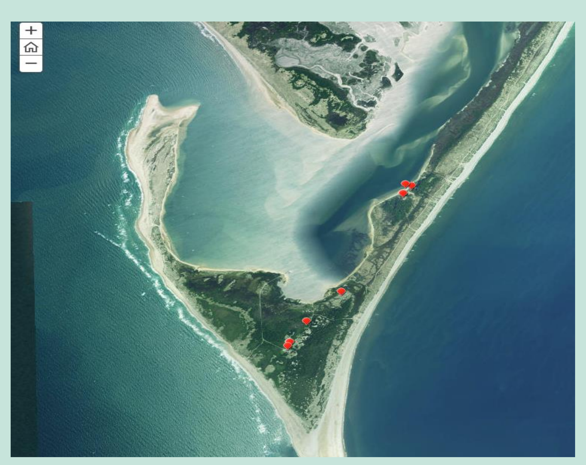

Fig. 4. Satellite Imagery of CLV

## Methodology

**Optimized Preservation Model (OptiPres Model)**

The OptiPres Model expanded the decision support tool developed by Xiao et al. (2019) that includes all sub-attributes of historical significance, use potential and vulnerability to three objective functions, which maximize the total resource value of historical buildings (objective 1), the average cost-efficiency of adaption actions applied to historical buildings (objective 2), and the number of historical buildings received climate-focused preservation actions across the 30-year planning horizon (objective 3).

The optimization uses a machine-learning algorithm (simulated annealing) to calculate the maximum values of total resource values, cost efficiency, and the number of historical buildings receiving climate-focused preservation actions.

**Budget Scenarios**

❑ **Constant Funding Allocation Budget Scenarios**

a) A low budget scenario of historic preservation where the annual budget allocation is $50,000;
b) An industry standard budget scenario of historic preservation where the annual allocation is $222,000;
c) A high budget scenario of historic preservation where the annual allocation is $500,000;

❑ **Periodical Funding Increase Allocation Budget Scenarios**

d) A low periodical funding increase budget scenario, where the annual allocation is $70,000 with an additional $225,000 every five years;
e) A high periodical funding increase budget scenario, where the annual allocation is $222,000 with an additional $225,000 every five years.

## Dynamics of Different Management Objectives under Varying Budget Allocation

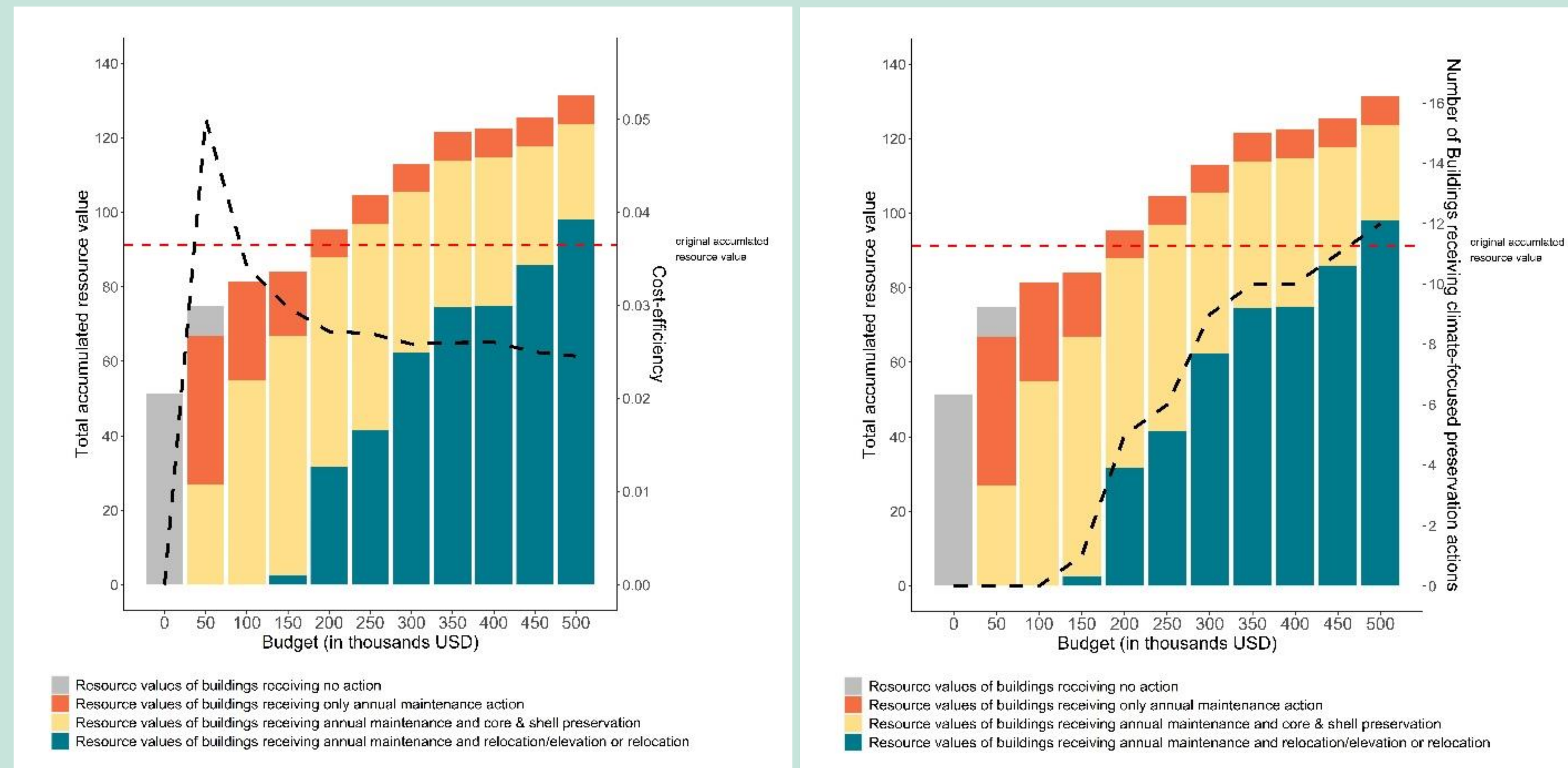



**Fig. 5. The Expected Accumulated Resource Value, Cost-efficiency, and the Number of Buildings Receiving Climate-focused Preservation Actions under $0 to $500,000 Annual Budget Allocation with $50,000 Intervals.**

- The red dash line indicates the original accumulated resource value of CALO's historic buildings without the disruptive interference from climate impacts and ideally presume the resource value unchanged in the scope of the 30-year planning horizon.
- The increase of the annual allocated budget on CALO's historical buildings comes with cumulative growth in accumulated resource value accordingly.
- These results highlight the fact that an increase in the annual allocated budget can lead to an increase in resource value of historical buildings but does not necessarily yield an increase in cost-efficiency in most tested budget scenarios.

## The Effectiveness of Budget Allocation on Different Management Objectives of Historical Preservation

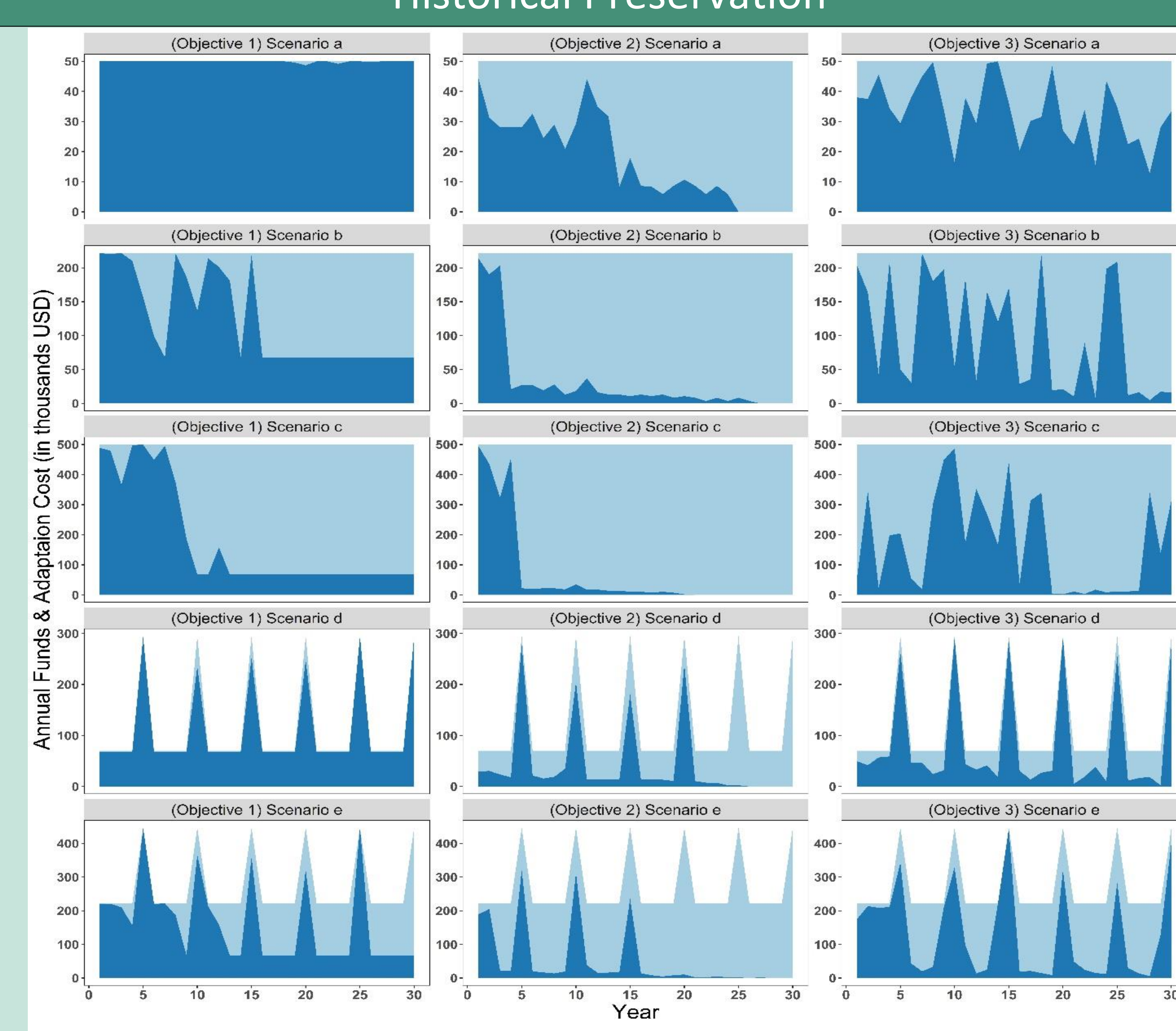



**Fig. 6. Total Adaptation Cost and Allocated Budget by Three Management Objectives under scenarios a, b, c, d, and e**

- Objective 1 intends to accumulate as much total resource value of CALO's buildings as possible; thereby, allocating funds is proportionally delegated to recurring annual maintenance and adaptation actions optimally to maximize the resource value.
- Objective 2 prioritizes cost-efficiency as its primary consideration. Therefore, the optimized algorithm intentionally saves unnecessary expenses to improve the performance of cost-efficiency.
- Objective 3 intends to relocate buildings in CALO that are vulnerable to the impacts of climate change. With the threat of extreme climatic circumstances, actions are based on the consensus to mitigate devastating risks activated by the deterioration of climate change. Hence, relocate action is set to be the prioritized action when balancing trade-offs under limited budget scenarios. The keen-edged peaks of used funding under five tested budget scenarios display the preferred adaptation of relocate or elevate and relocation actions since they are comparatively costly.
- Although the accumulative effectiveness of budget allocations by objective 3 and objective 1 are somewhat identical, the temporal patterns of funding usage for preservation actions were different between these two objectives, especially under scenarios b & c.

## Trade-offs of Historical Preservation by Different Optimization Objectives

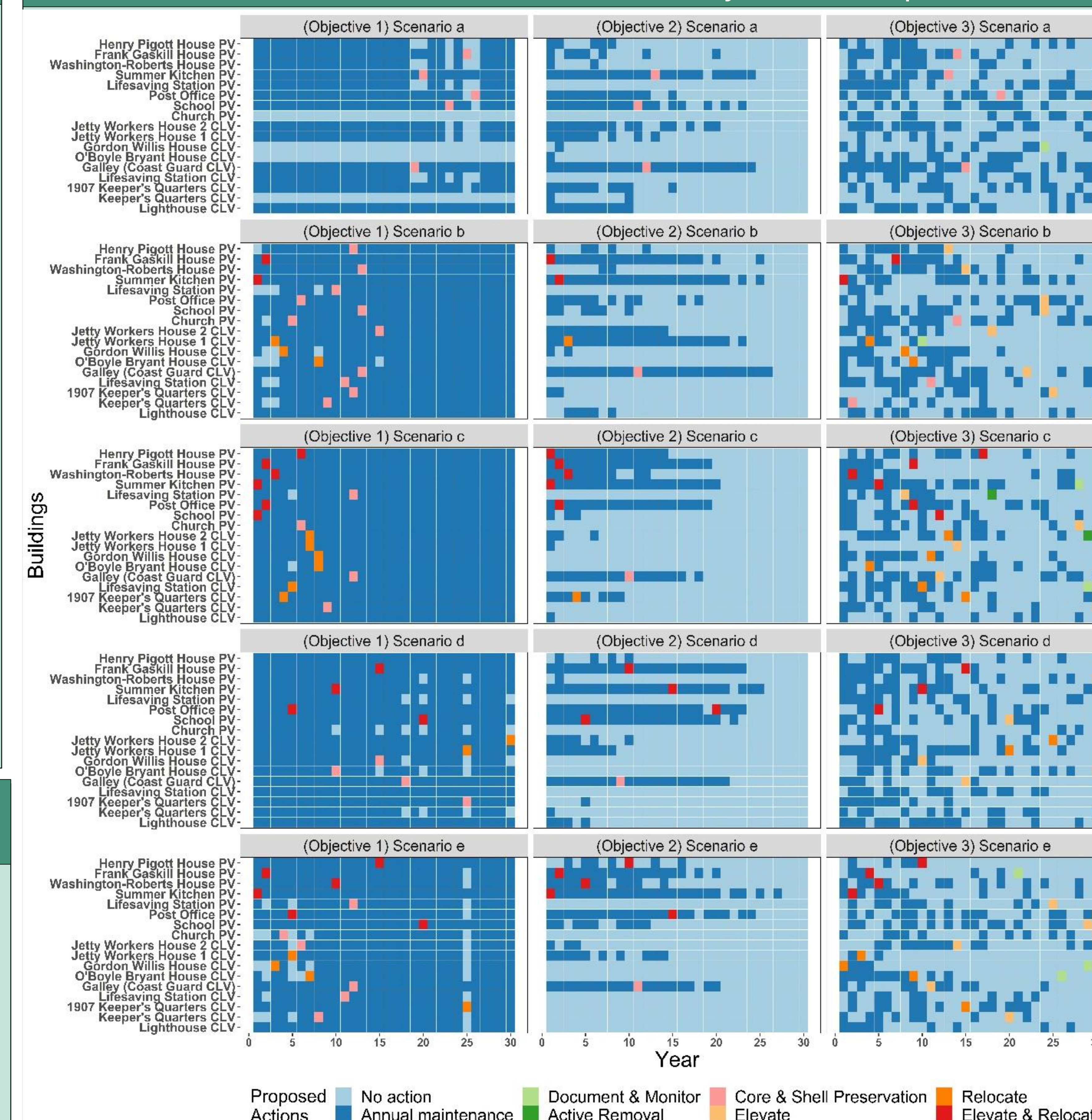



**Fig. 7. Proposal Adaptation Plans for three management objectives under budget scenarios a, b, c, d, and e**

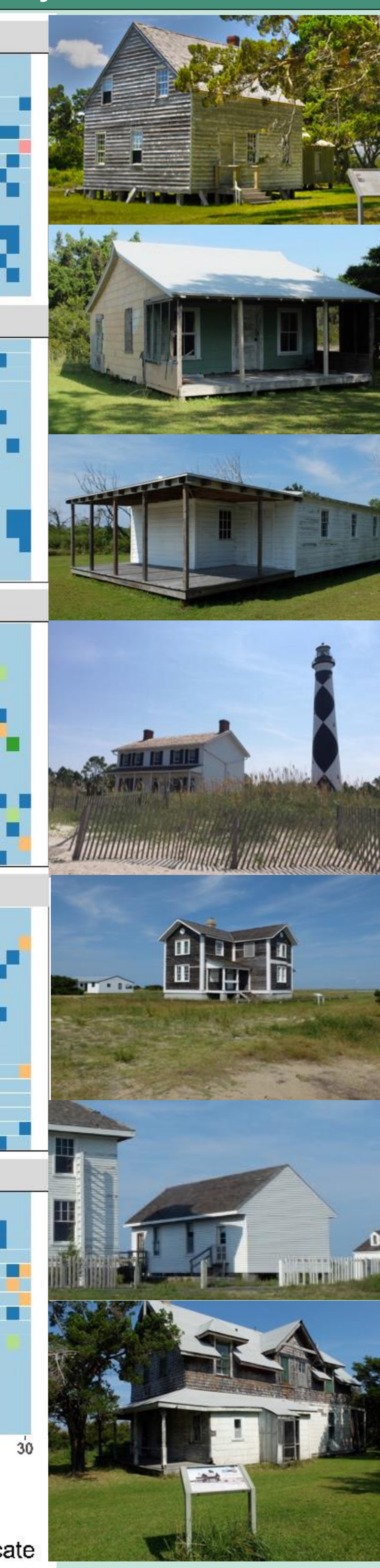

**Fig. 8. Historical Buildings in CALO**

- Maximizing resource value (Objective 1): Annual maintenance is expected to be applied across the planning horizon (except the year when a one-time large preservation action is applied to the building) to decelerate the decay rates of historical buildings when allocated funding is sufficient. Core and shell preservation action is often expected to be applied during the medium or late periods of the 30-year planning horizon under the constant budget allocation scenarios (scenarios a, b, and c)
- Maximizing the cost-efficiency of historical preservation (Objective 2): Aims to maximize the improvement of resource value per unit of cost spent on historical preservation. Annual maintenance enjoys the least costs with substantial improvement of historical significance from no action; naturally manifests the higher cost-efficiency.
- Maximizing the number of buildings receiving climate-focused adaptation actions (Objective 3): Prioritizes the efforts that relocate or elevate more buildings with high-risks of unanticipated climatic calamities to less vulnerable locations with recurring maintenances permanently. objective 3 prefers to relocate buildings in the early phase and elevate buildings in the middle or late planning phases under the constant budget allocation scenarios because relocation can reduce the vulnerability to the lowest value and yielding a greater one-time improvement of resource value than elevation.

## Conclusion

- The historical-economic optimization model of historical preservation integrates multiple management objectives, evaluates the trade-offs of adaptation actions by historical, economic, and climate-related factors systematically, and defines desirable preservation objectives that satisfy the practical and realistic preservation needs of coastal parks by quantitative metrics.
- The OptiPres model in this study provides insight to prioritize adaptation plans that enhancing the historical significance and use potential; investing the limited funds to achieve the highest efficiency of cost-benefit for resource value by appropriate adaptation actions and minimizing the risks to climate extremes and uncertainties for all historical buildings at CALO.
- The historical-economic optimization approach of climate adaption planning developed in this study demonstrates the OptiPres model can be transferred to other coastal parks by modifying optimization objectives, and the transparency of climate adaptation planning for cultural resources can be enhanced by the OptiPres model through the quantitative assessment of trade-offs.