Prepared in cooperation with the National Park Service

Optimizing Historical Preservation Under Climate Change—An Overview of the Optimal Preservation Model and Pilot Testing at Cape Lookout National Seashore

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U.S. Department of the Interior
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Front Cover. Portsmouth Life-Saving Station (circa 1894) in Portsmouth Village (photograph credit: Erin Seekamp, 2015)

Back Cover. 1873 Keeper's Quarters (circa 1873) and Cape Lookout Lighthouse (circa 1812; 1859) within the Light Station Complex of Cape Lookout Village, taken from the Atlantic Ocean dunes (photograph credit: Erin Seekamp, 2015)

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Optimizing Historical Preservation Under Climate Change—An Overview of the Optimal Preservation Model and Pilot Testing at Cape Lookout National Seashore

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Abstract

Adapting cultural resources to climate-change effects challenges traditional cultural resource decision making because some adaptation strategies can negatively affect the integrity of cultural resources. Yet, the inevitability of climate-change effects—even given the uncertain timing of those effects—necessitates that managers begin prioritizing resources for climate-change adaptation. Prioritization imposes an additional management challenge: managers must make difficult tradeoffs to achieve desired management outcomes related to maximizing the resource values. This report provides an overview of a pilot effort to integrate vulnerability (exposure and sensitivity), significance, and use potential metrics in a decision framework—the Optimal Preservation (OptiPres) Model—to inform climate adaptation planning of a subset of buildings in historic districts (listed on the National Register of Historic Places) at Cape Lookout National Seashore. The OptiPres Model uses a numerical optimization algorithm to assess the timing and application of a portfolio of adaptation actions that could most effectively preserve an assortment of buildings associated with different histories, intended uses, and construction design and materials over a 30-year planning horizon. The outputs from the different budget scenarios, though not prescriptive, provide visualizations of and insights to the sequence and type of optimal actions and the changes to individual building resource values and accumulated resource values. Study findings suggest the OptiPres Model has planning utility related to fiscal efficiency by identifying a budget threshold necessary to maintain the historical significance and use potential of historical buildings while reducing vulnerability (collectively, the accumulated resource value). Specifically, findings identify that a minimum of the industry standard ($222,000 annually for the 17 buildings) is needed to maintain the current accumulated resource value. Additionally, results suggest that additional appropriations provided on regular intervals when annual appropriations are at the industry standard are nearly as efficient as annual appropriations at twice the rate of industry standards and increase the amount of accumulated resource values to nearly the same level. However, periodic increases in funding may increase the risks posed to buildings from the probability of a natural hazard (that is, damage or loss from a hurricane). Suggestions for model refinements include developing standardized cost estimations for adaptation actions based on square footage and building materials, developing metrics to quantify the historical integrity of buildings, integrating social values data, including additional objectives (such as public safety) in the model, refining vulnerability data and transforming the data to include risk assessment, and incorporating stochastic events (that is, hurricane and wind effects) into the model.

Introduction

Cultural resources include physical and intangible aspects of what is significant about our heritage, having important historical, cultural, scientific, or technological associations that provide societal meanings (National Park Service [NPS], 1995). The U.S. Department of the Interior NPS is mandated "to identify, protect, and share the cultural resources under its jurisdiction" (NPS, 1998, p. 5), and decision making is predicated on recognizing variations in meaning, integrity (that is, "retains material attributes associated with its social values"), and threats (NPS, 1995, p. 11). One threat that is of concern to the NPS is climate change because changing temperatures, changing precipitation patterns, and rising seas increase the exposure of cultural resources to typical decay patterns and rates, and deferred maintenance and repair make them more sensitive to climate change (Rockman and others, 2016). Natural hazards, such as hurricanes and nor'easter storms, also increase the exposure of cultural resources in the near term. Moreover, the uncertainties of the timing and severity of climate change-related effects complicate managers'

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ability to enhance the resilience of physical cultural resources, particularly when managers must simultaneously consider an assortment of vulnerable resources. The purpose of this study was to develop and test a decision model framework, the Optimal Preservation (OptiPres) Model, to integrate multiple considerations (including budget constraints, cultural resource vulnerabilities to climate-change effects, cultural resource conditions, heritage values, and the use potential of cultural resources) to inform planning decisions for adapting cultural resources to climate change.

Adapting cultural resources to climate-change effects challenges traditional cultural resource decision making because some adaptation strategies can negatively affect the integrity of cultural resources, and the timing of many climate-change effects are uncertain. In other words, effects to social values and the uncertainties of climate change increase the complexity of adaptation because managers may need to apply actions that tradeoff potential or uncertain future effects against more near-term maintenance of cultural resources. Such challenges increase the complexity of long-term planning, particularly when cultural resources exist in dynamic landscapes like coastal systems where stochastic storms occur. Additionally, the lack of sufficient financial resources to adequately manage all cultural resources—as evidenced by the backlog of deferred maintenance—necessitates that decision makers must consider prioritizing some resources over others. Prioritization imposes an additional management challenge: managers must make difficult tradeoffs to achieve desired management outcomes related to maximizing the resource values (for example, significance, integrity, and use potential) within cultural landscapes. Yet, when approached with a systematic process for addressing such complex decisions, a management agency can enhance the transparency of values embedded within planning and decision making and increase its ability to preserve cultural resource values for present and future generations.

Current policy guidance (NPS, 2014) for the stewardship of cultural resources in relation to climate change states that management decisions should be directed toward resources that are “both significant and most at risk.” The NPS has since implemented a process for assessing climate change vulnerability of coastal park assets, which includes facilities, infrastructure, and cultural resources (NPS, 2016; Peek and others, 2017). Additionally, Fatorić and Seekamp (2017a, 2018) developed a framework for measuring the significance and use potential of one specific type of cultural resource: historic buildings. This report provides an overview of a pilot effort to integrate vulnerability (exposure and sensitivity), significance, and use potential metrics in a decision framework to inform climate adaptation planning of a subset of buildings in historic districts (listed on the National Register of Historic Places) at Cape Lookout National Seashore, North Carolina.

The decision framework, the OptiPres Model, developed and piloted at Cape Lookout National Seashore is an innovative approach for climate adaptation planning of an assortment of resources, advancing single-resource planning approaches described in the NPS’s Cultural Resources Climate Change Strategy (Rockman and others, 2016) and the Interagency Climate-Smart Conservation (Stein and others, 2014) guidance document. More specifically, the OptiPres Model uses numerical optimization methods (that is, an algorithm) to assess the timing and application of a portfolio of adaptation actions that could most effectively preserve an assortment of buildings associated with different histories, intended uses, and construction design and materials over a 30-year planning horizon. Such optimization approaches are widely used in landscape planning. For example, Westphal and others (2007) used an optimization model to identify sites for landscape reconstruction to maximize the number of bird species in the Mount Lofty Ranges, South Australia.

The modeling effort described in this report is the culmination of the structured decision-making (SDM) process implemented at Cape Lookout National Seashore that began with Fatorić and Seekamp’s (2017b, 2018) measurement framework, a project funded by the U.S. Department of the Interior Southeast Climate Science Center. It is our intention that the OptiPres Model outputs can enhance NPS managers’ ability to make more informed and transparent climate adaptation decisions given various uncertainties and management constraints. Yet, it is important to note that the OptiPres Model is not intended to be prescriptive. Rather, it should be used as one of several information sources (for example, stakeholder studies) for guiding climate adaptation planning and management. Additional model outputs, with slight modifications to the algorithm, can be found in Xiao and others (2019).

It also is important to note that the cultural resources addressed in the decision framework are physical historic assets (buildings). Although intangible cultural resources (for example, community practices and knowledge) are important considerations for adaptation planning, they are not addressed in this study. Additional research is needed that specifically addresses how to integrate intangible resources into climate adaptation planning. For example, see Henderson and Seekamp (2018) for a community engagement study that provides a first step towards developing an approach for climate adaptation planning of intangible cultural resources.

Study Area

Cape Lookout National Seashore is located on a 56-mile long chain of barrier islands (about 29,000 acres) on the coast of North Carolina. The barrier islands are subject to coastal dynamics that change the location of sands, tidal marshes and flats, and inlets; historical records document the effects of storm-related flooding and erosion on the islands’ evolution and migration over the past two centuries (Riggs and Ames, 2007). The park unit has two settlements that have been designated on the National Register of Historic Places (NRHP) as historic districts: (1) Portsmouth Village (designated in 1976) and (2) Cape Lookout Village (designated in 2000). Most buildings in these villages experience periodic but recurring flooding after storms. Portsmouth Village has a traditional village feeling, with community buildings (church, post office and general store, and school) and private residences, as well as a former Life-Saving Service station. Although Cape Lookout Village also has ties to Federal maritime history (that is, the Cape Lookout Light Station Complex was listed on the NRHP in 1972, and the Cape Lookout Coast Guard Station Complex was listed on the NRHP in 1988), and some former residences are linked to this history, the 14 residential buildings (one of which is a former Life-Saving Service station) are not arranged as a traditional village but rather as separate vacation and secondary homes or seasonal fishing camps.

Although Cape Lookout National Seashore has archeological sites, cemeteries, and cultural artifacts associated with World War II military installments, we restricted our pilot study to a subset of historic buildings (*n*=17), predominately pre-World War II, to test the OptiPres Model before investing further into its development. With the guidance of park managers, we selected the buildings to represent a range of historic periods and occupational uses. During the selection discussions with the park superintendent and the park chief of resources, we sought variability in the current physical condition of buildings and vulnerability (that is, exposure and sensitivity) to climate-change effects (table 1). This initial assessment of exposure and sensitivity (that is, vulnerability) was based on park managers' knowledge of prior flooding and storm-related damage. It is important to note that few buildings at Cape Lookout National Seashore were of low or moderate vulnerability, which was confirmed by the vulnerability assessment by Peek and others (2017).

Model Development

The development of the OptiPres Model represents a continuation of a SDM process described by Fatorić and Seekamp (2017b). SDM is rooted in decision analysis and behavioral decision theory (Gregory and others, 2011; Runge and others, 2013) and is considered a transparent and collaborative approach for supporting informed and defensible decisions (Irwin and others, 2011). The SDM process breaks complex decisions into six primary components that can be addressed individually and then reintegrated to identify a solution: (1) problem—defining a clear problem statement; (2) objectives—identifying participants' values and translating these into measurable objectives; (3) alternatives—specifying a set of available actions that are viewed as possible alternatives for achieving defined objectives; (4) consequences—predicting and quantifying the outcomes of alternative actions in terms of stated objectives; (5) tradeoffs—when objectives are in competition, a value-based evaluation of tradeoffs among objectives for any given action is required; and (6) decision—integrating the previous components allows the decision maker to select the action that provides the highest likelihood of achieving the specified objectives (Runge and others, 2013).

This structured process can facilitate transparency and, hence, legitimacy and buy-in for climate adaptation decisions, particularly in situations with high uncertainty (for example, financial and climate). The advantage of using such a decision process is the explicit valuation of decision makers' and stakeholders' preferences and distinguishing these from predictions of the outcomes of implementing a decision (that is, objective science; Gregory and others, 2011; Runge and others, 2013). To the best of our knowledge, this project represents the first application of an SDM process in the context of climate change adaptation for cultural resource preservation.

Because the purpose of this report is to present the OptiPres Model and describe how its outputs may inform climate adaptation planning efforts, we provide an overview of the structured process used that resulted in the OptiPres Model in figure 1. This process included an initial workshop at Cape Lookout National Seashore, followed by iterative meetings with Cape Lookout National Seashore managers and North Carolina State Historic Preservation Office managers and staff, online expert elicitations, and two workshops to expand the expert elicitation to broader audiences at (1) the 2016 George Wright Society annual conference and (2) the National Conference of State Historic Preservation Officers. Additional details on the earlier stages of the process that resulted in the historical significance and use potential attributes and metrics were provided in Fatorić and Seekamp (2017a, 2017b, 2018).

The problem statement that was finalized at the first workshop at Cape Lookout National Seashore (together with its relevant elements shown in parentheses) stated the following: climate change is threating cultural resource preservation at coastal national park units. The NPS (decision maker) wants to develop a transparent and objective decision framework that will help guide their funding allocations (action) toward cultural resource adaptation efforts within Cape Lookout National Seashore that includes two historic districts, Portsmouth and Cape Lookout Villages, and their associated buildings (scope). Although the funding allocation decisions (within budget constraints) for cultural resource maintenance or additional preservation treatments are made annually, the NPS' vision for managing cultural resources looks forward over the next 30 years (timing) and aims to incorporate fiscal, climate, and environmental uncertainties (uncertainty). Given legal requirements (constraint) and NPS' mission (trigger), the decision framework would consider the nature and intent of the National Historic Preservation Act and the NPS' stewardship responsibilities.

The objectives that were refined throughout the process included maintaining historical significance, maximizing the use of historic buildings (hereafter "maximizing use potential"), maximizing financial efficiency, and minimizing climate vulnerability (exposure and sensitivity to sea level rise and storm-related flooding effects) in adapting historic buildings. The first three objectives (maintaining historical significance, maximizing use potential, and maximizing financial

Table 1. Details of 17 buildings selected for pilot study.

			Selection criteria		
Historic district	**Building (circa)**	**Building abbreviation**	**Condition[1]**	**Vulnerability[2]**	**Use[3]**
Iconic buildings					
Cape Lookout Village	Cape Lookout Lighthouse (1812; 1859)	Lighthouse	Fair	Moderate	Open to public visitation
Portsmouth Village	Methodist Church (1840; 1915)	Church	Fair	High	Open to public visitation
Early Federal maritime history					
Cape Lookout Village	Cape Lookout Life-Saving Station (1887; 1958)	Lifesaving Station CLV	Poor	Moderate	No use
Portsmouth Village	Portsmouth Life-Saving Station (1894)	Lifesaving Station PLV	Fair	High	Open to public visitation
Mid-Federal maritime history					
Cape Lookout Village	1873 Keeper's Quarters (1873)	Keeper's Quarters	Fair	High	Open to public visitation and operational use
Cape Lookout Village	1907 Keeper's Quarters (1907; 1958)	1907 Keeper's Quarters	Fair	Moderate	No use
Late maritime history					
Cape Lookout Village	Jetty Workers House I (1915)	Jetty Workers House 1	Fair	High	No use
Cape Lookout Village	Jetty Workers House II (1920)	Jetty Workers House 2	Poor	High	No use
Secondary buildings within a complex of buildings					
Cape Lookout Village	Coast Guard Station Galley (1917)	Galley	Fair	Low	No use
Portsmouth Village	Portsmouth Life-Saving Station Summer Kitchen (1894)	Summer Kitchen	Good	High	Operational use
Community buildings					
Portsmouth Village	Portsmouth Island Schoolhouse (1910)	School	Fair	High	Open to public visitation
Portsmouth Village	Portsmouth Island Post Office and General Store (1900)	Post Office	Fair	High	Open to public visitation
Residential buildings					
Cape Lookout Village	Gordon Willis House (1950)	Gordon Willis House	Fair	High	No use
Cape Lookout Village	O'Boyle Bryant House (1938)	O'Boyle Bryant House	Poor	Moderate	No use
Portsmouth Village	Washington–Roberts House (1840)	Washington–Roberts House	Good	High	Open to public visitation
Portsmouth Village	Frank Gaskill House (1930)	Frank Gaskill House	Poor	High	No use
Portsmouth Village	Henry Pigott House (1902)	Henry Pigott House	Good	High	Open to public visitation

[1]Condition was determined by using the List of Classified Structures (LCS) condition scores and reviewed by the park superintendent and chief of resources to confirm or modify current condition status.

[2]Vulnerability was determined by the park superintendent and park chief of resources and confirmed by the vulnerability assessment conducted by Peek and others (2017).

[3]Visitation and operational use were determined by the park superintendent and chief of resources.

2015
- Preparatory meetings with Cape Lookout National Seashore managers
    - Draft problem statement
- Workshop I with National Park Service (NPS) and North Carolina State Historic Preservation Office (NC SHPO) staff, regional and local stakeholders, and knowledge experts
    - Final problem statement
    - Draft objectives
    - Draft adaptation actions

2016
- Iterative meetings with Cape Lookout National Seashore managers
    - Refinement of historical significance and use potential attributes and metrics
    - Refinement of adaptation actions
- Meeting with NC SHPO staff
    - Refinement of historical significance and use potential attributes and metrics
- Iterative meetings with Cape Lookout National Seashore managers
    - Refinement of historical significance and use potential attributes and metrics
    - Adaptation action costs estimated
- Online elicitation with workshop I participants
    - Scores of metrics and weights of attributes
- Beta version of Optimal Preservation (OptiPres) Model
    - Integration of vulnerability, significance and use potential attributes with adaptation action costs and alternative budget allocations
- Workshop II with NPS and NC SHPO staff
    - Review and feedback of OptiPres Model beta version
    - Deliberation of alternatives and optimization tradeoffs
    - Refinement of model attributes, adaptation costs, budget allocations, and scenarios

2017
- Iterative meetings with Cape Lookout National Seashore managers
    - Refinement of model attributes, adaptation costs, budget allocations, and scenarios
- Online elicitation with workshop I participants
    - Weights of attributes
- Workshop III at National SHPO Conference
    - Weights of attributes
- Workshop IV at George Wright Society Forum
    - Weights of attributes
- OptiPres Model refinements

Figure 1. Timeline of the structured process used in the pilot study at Cape Lookout National Seashore.

efficiency) are considered fundamental objectives (the ends to be achieved). The fourth objective (minimizing climate vulnerability) is a means objective (the way in which the fundamental objectives can be achieved).

Other terminology used in this report include “attribute” (that is, an important and measurable characteristic of an objective that helps define its meaning and value; synonymous with “performance metric”), “metric” (the unit of measurement that is applied to each attribute), “score” (the numeric value that represents each level of a metric and the scaled difference between each level of a metric), and “weight” (the importance of each attribute relative to all other attributes).

The Optimal Preservation Model

The purpose of the OptiPres Model is to provide decision makers with guidance on how to best manage multiple historic buildings over time. More specifically, the model uses an optimization algorithm to evaluate tradeoffs among (1) investing in actions that maintain or preserve resources in situ, (2) investing in actions that preserve a structure but remove it from its historical context, or (3) making triage decisions to free up resources for more costly actions. The model selects the combination of investments that provides the most resource value to the decision maker over a specified period and budget constraint.

We have provided visual descriptions of optimal investment portfolios (sequences of actions applied to a set of buildings; hereafter “portfolio” or “portfolios”) to aid with data interpretation. Managers using this model should recognize that the model outputs (that is, visualizations) are not prescriptive (that is, do not provide a specific path for implementing adaptation actions) but rather are descriptive (that is, demonstrate the patterns of, or strategic approaches for, optimal actions given specific budget constraints) and should be used to inform decision making. In this report, we demonstrate the use of this model assuming the objective is to maximize total resource value (historical significance and use potential) over a 30-year planning horizon.

It is important to note specific limitations related to the use of a 30-year planning horizon. For example, climate change scenarios and land-cover change projections change as forecasting science becomes more fine-tuned, and current models highlight that drastic sea level rise effects may not be actualized in 30 years. Managers may find that inundation will occur at increased or decreased rates compared to the forecasting scenario used in this study (Representative Concentration Pathway [RCP] 8.5), which will enhance or limit the effectiveness of some adaptation strategies in a 30-year planning horizon.

We developed an objective function, or a numerical expression of the statement above, which integrates weighted resource value attributes related to historical significance and use potential (for specific details, see Fatorić and Seekamp, 2017a, 2018), and nonweighted vulnerability attributes (that is, exposure and sensitivity data) for flooding-related coastal climate change threats (for specific details, see NPS, 2016; Peek and others, 2017).

The historical significance attributes include the following:

- Association with fundamental purpose of the park unit,
- Condition of the building,
- Historic character (a weighted average of two subattributes: defining character and uniqueness to the park), and
- National Register (a weighted average of two subattributes: spatial significance and eligibility).

The use potential attributes include the following:

- Operational use,
- Visitor use,
- Interpretive use,
- Third-party use, and
- Scientific use.

The exposure attributes include the following:

- Flooding exposure (based on Federal Emergency Management Agency flood maps),
- Storm surge estimates (mean high tide during category 3 hurricanes),
- Sea level rise projections for 2050 (under a high, RCP 8.5 emission scenario),
- Erosion and coastal proximity, and
- Evidence of historical flooding.

The sensitivity attributes include the following:

- Flood damage potential,
- Storm resistance,
- Prior storm damage, and
- The presence of protective engineering.

The vulnerability attributes include the following:

- Exposure and
- Sensitivity.

More details for the historical significance, use potential, exposure, sensitivity, and vulnerability attributes, including metrics and scores, are provided in appendix 1 (tables 1.1–1.5).

Under specific budget allocations, the model searches for optimal combinations of adaptation action applied to each building over a 30-year time horizon. Adaptation actions were developed based on those listed in the NPS Cultural Resource Climate Change Strategy (Rockman and others, 2016). The cost of each action is building-specific, and the total annual cost of these actions must stay under the annual budget cap or constraint. The available adaptation actions (fig. 2) include the following:

- Preservation (core and shell) using historic materials,
- Preservation (core and shell) using resilient materials,
- Elevate,
- Relocate,
- Relocate and elevate,
- Document and monitor, and
- Active removal.

It is important to note that “relocate and elevate” was included as one adaptation action for the buildings in Portsmouth Village. The most ideal relocation zones (mapped by project collaborators in the Program for the Study of Developed Shorelines at Western Carolina University who conducted the Vulnerability Assessment for the NPS) were in an area that experiences periodic standing water after storms (verified by Cape Lookout National Seashore staff), which made relocation as a stand-alone adaptation action unfeasible. Additionally, the relocation zone maps illustrated that there is not a suitable location to move the Lighthouse or the Keeper’s Quarters at the Light Station Complex area within Cape Lookout Village; the Galley at the Cape Lookout Coast Guard Complex was the only building with a low vulnerability score and, thus, relocation was not an applicable adaptation strategy.

All the adaptation action cost estimates include costs affiliated with documenting each building in its new condition (and for a historic structures report if one has yet to be written), as well as interpreting (minimally or extensively) the way the park has adapted each building to minimize climate-change effects. Additional actions that can be applied within the model include no action and annual maintenance. We did not include annual inflation rates within the cost estimates or within the annual budget allocations. A full description of the actions is provided in appendix 1, table 1.6, and the costs applied for each action to each building are provided in appendix 1, table 1.7. It is important to note that the costs estimated for each type of action being applied to each building are conservative (understated) given the additional burden of transportation and lodging needed at Cape Lookout National

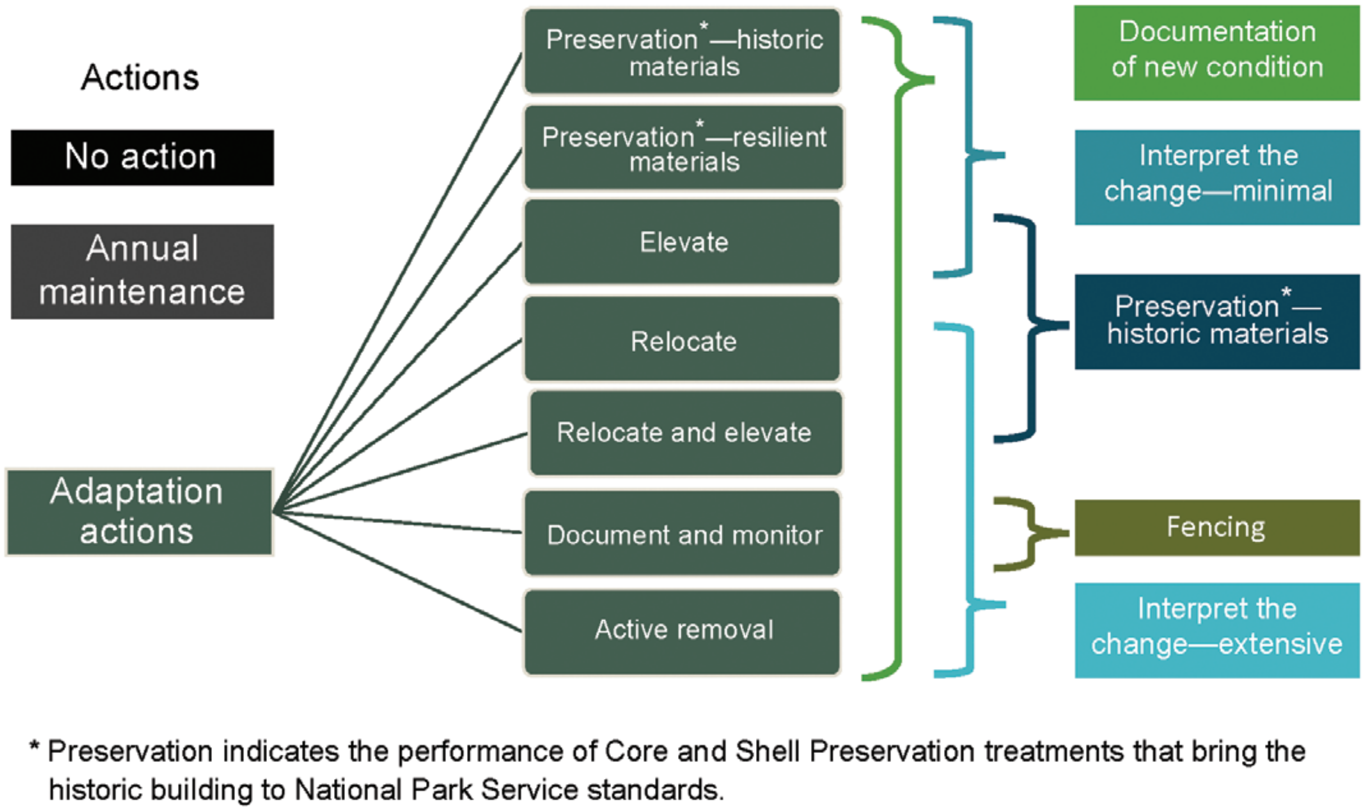

Figure 2. Annual alternative actions considered in the Optimal Preservation Model. Primary categories included deferring action on a structure for a given year (no action), actions that are considered routine maintenance (annual maintenance), and proactive or reactive alternatives designed to adapt buildings to climate impacts (adaptation actions). The latter category includes seven distinct alternatives available to managers (middle column), each of which may share component subactions with other alternatives (right column).

Seashore and that they were developed with the assumption of the NPS performing the work (not contracted work); however, the costs were consistently estimated based on building type and size. More research is needed to enhance the accuracy of these costs when the OptiPres Model is transferred to other park units.

The model uses a stochastic search algorithm (that is, simulated annealing) that randomly picks 1 year and one building and then randomly selects an action. It then projects the effect of that single change on each of the metrics, beginning with the initial conditions, over all 30 years. If the total resource value improves because of the change, then the change is retained until a better one is found. If the resource value does not improve, then the change is rejected and another one is selected. Additional model parameters are used to control how selective the algorithm is about how large an improvement is required for acceptance. If run many millions of times, the algorithm should converge on a near-optimal solution. In order to ensure this was the case, we also applied a local search algorithm in between runs of the simulated annealing algorithm. The dynamics of the projection over time are specific to the actions applied. As such, each action can affect the relative resource value of any given building (positively or negatively), as well as reduce the vulnerability of a specific building (fig. 3). More specific details on the model dynamics are provided in appendix 1, table 1.6.

We performed all our analyses in the R programming environment (R Core Development Team, 2017). Because of the large number of possible combinations of resources and actions, running the optimization algorithm in R would have taken a prohibitively long time. Instead, we wrote both the simulated annealing and local search algorithms in C++ and used the Rcpp (Eddelbuettel and Francois, 2011) and RcppArmadillo (Eddelbuettel and Sanderson, 2014) packages to embed the code in R as a function (see appendix 3 documents available for download at https://doi.org/10.3133/ofr20181180). We then ran each of the different scenarios in R on the YETI High Throughput Computing System maintained by the U.S. Geological Survey.

We based the range of budget allocations included in this pilot study on realistic assumptions, including a no action scenario. We estimated the industry standard for continual preservation of buildings in these districts (inspection, corrective maintenance, preventative maintenance, cyclic maintenance, and recurring maintenance) to be $222,000 annually. We set the "low" range of budget allocations at $50,000 (nearly $20,000 less than what would be required to perform only

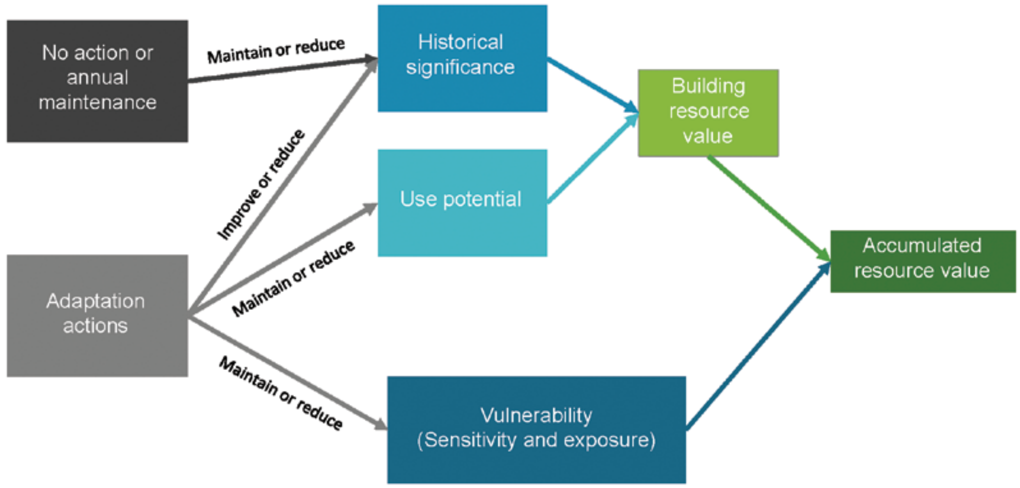

Figure 3. A conceptual diagram of the Optimal Preservation Model dynamics and the relations between actions, objectives, and values.

annual maintenance on each of the 17 buildings within a year). We set the "high" range of budget allocations at $500,000 (roughly twice the industry standard). To explore the uncertainty related to budget allocations, we ran 11 budget scenarios ranging from the low to the high allocations in $50,000 intervals, including one at $222,000.

Additionally, we included several other planning scenarios in the model runs. Specifically, we explored the outcome if annual budgets were substantially increased (for example, through competitive grants or donation funding) every 5 years. For this scenario, we set the annual allocation at $222,000 with $250,000 additional funding added in years 5, 10, 15, 20, 25, and 30. We ran a similar scenario with a reduced annual allocation of $70,000 (more realistic in terms of actual park budget funding received in recent years) and the same $250,000 increase every 5 years. In another scenario, we removed vulnerability from the model to explore how sensitive the model is to the vulnerability metrics. In a final scenario, we set the weight of the use potential value to zero so that the model only considers the buildings' historical significance when calculating total resource values. We used this last scenario to test the importance of use potential, which received a lower weight than historical significance and was not as dynamic a variable as historical significance in terms of the effect of actions.

Model Results and Interpretations

We tested the behavior and summarized the output of the OptiPres Model under five different planning scenarios: (1) a baseline scenario of expected dynamics if no actions are implemented to maintain buildings in the historic districts, (2) an uncertain budget, (3) periodic funding increases, (4) ignoring buildings' vulnerability, and (5) excluding buildings' use potential from the calculation of resource value. Resource value (that is, weighted sum of historical significance attributes and use potential attributes) is a measurement of overall management performance, where higher resource values mean better performance. The accumulated resource value 90 serves as the reference point for all scenarios because it is the sum of all 17 buildings' historical significance scores and use potential scores, divided by the buildings' vulnerability scores, in planning year 1.

The five planning scenarios were selected because NPS personnel perceived these as feasible future managerial contexts, they were eventualities that the NPS personnel involved in the study wanted to explore during this pilot project, or both. Limited and uncertain budgets are status quo for many cultural resource managers, and periodic budget allocations enable special projects. Exploring the exclusion of vulnerability and use potential allows managers to better understand the effect of these objectives on model outcomes and enables the research team to evaluate the model's performance. To assist in the interpretation of the results, we have included the costs of each action for the 17 buildings in appendix 1, table 1.7.

It is important to note that the modeling scenario results did not select some adaptation actions. The negative effect to overall resource value for two actions (that is, document and monitor, and active removal) seems to be driving the elimination of these actions for the optimal solutions, despite document and monitor having relatively low costs. Additionally, core and shell preservation with resilient materials did not appear in the modeling results. Because flooding is the primary climate-change effect included in the vulnerability attributes, a building's vulnerability score is not substantially affected by this action, which includes costs more likely affiliated with preventing rain and wind damage (for example, tin roofs and hurricane roof clips). Therefore, it is logical that the model finds the core and shell preservation with historic materials more optimal because historic materials do not negatively affect a building's resource value to the same extent as using more modern, storm-resistant materials.

Scenario 1—No Action

To illustrate the changes in resource values of buildings under different planning scenarios, a baseline scenario was created. Under this scenario, no actions are applied to any buildings over the 30-year period. We estimated the accumulated resource values of all buildings at the beginning of the 30-year period ("beginning values"=90) and the accumulated values of all buildings at the end of 30-year period ("ending values"=52; fig. 4). The accumulated resource value of the historic buildings decreases rapidly with no adaptation actions taken, resulting in less than 60 percent of the original value remaining at the end of 30-year period. The substantial decline of resource value is caused by continuous decay of the buildings' condition and the lack of improvement in vulnerability scores under the "no action" scenario.

We also estimate the percentage of current and future resource value for each building under the "no action" scenario (fig. 5). The percentages that each building contributes to the accumulated resource value at the beginning of 30-year period is displayed in the chart on the left side of figure 5; percentages at the end of 30-year period are displayed to the right. The individual resource values of buildings were nearly equivalent at the beginning of the period, whereas substantial differences in remaining value are expected by the end of the 30-year period with no actions applied. This finding suggests that dynamics of vulnerability and buildings' condition are operating asymmetrically across the study area. The Lighthouse, Galley, Lifesaving Station, and 1907 Keepers Quarters at Cape Lookout Village account for larger percentages of the accumulated resource value than other buildings, whereas several buildings at Cape Lookout Village (O'Boyle Bryant, Jetty Workers House 1, Jetty Workers House 2, and Gordon Willis House) account for relatively small percentages of resource values.

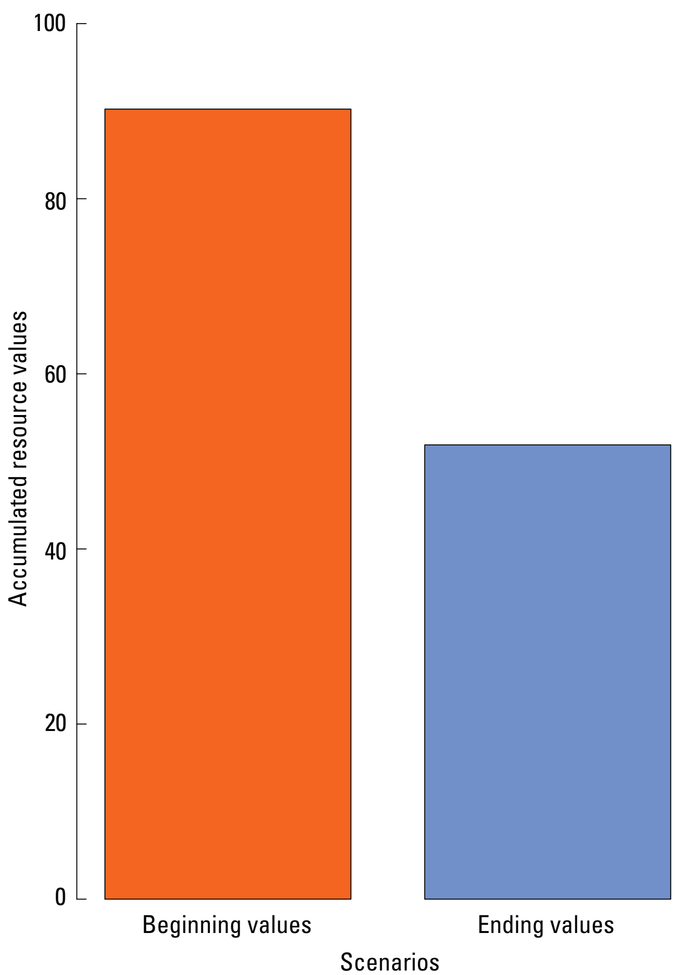

Figure 4. Accumulated resource values of all buildings at the beginning and end of the 30-year planning horizon under a "no action" scenario. Units of accumulated resource values are relative and on a constructed, composite scale.

Scenario 2—An Uncertain Budget

We simulated the effect of an uncertain budget by running the model under a range of budget levels, from $50,000 to $500,000 in steps of $50,000. The expected total resource value of the optimal portfolio of actions applied across the 17 historic buildings for the budget levels is displayed in figure 6. These results suggest at least three things: (1) that spending any money to manage even a subset of buildings is better than doing nothing; (2) that spending more money leads to improved management performance; and (3) that for this range of budgets examined, the relation between budget and expected benefit does not result in an obvious "shoulder" in the curve, making it difficult to identify the budget level at which the cost-benefit ratio changes. In the following sections, we present the management portfolios used to generate figure 6. Because the analysis of these portfolios requires examining multiple parts of the model, we will only present results for the $50,000, $222,000, and $500,000 budget levels.

Portfolio for a Budget of $50,000

The total annual costs for maintenance of all buildings, $67,800 (appendix 1, table 1.7), was more than available under this scenario, limiting the number of buildings that could receive even minimal attention. The optimal set of actions under the $50,000 budget suggests that a focus on maintaining 13 of the 17 buildings leads to the best management outcome (fig. 7). The percentage of total resource value and relative total cost of each building is provided in figure 8. The resource values of two unmanaged buildings (Gordon Willis House and O'Boyle Bryant House at Cape Lookout Village) declined substantially and accounted for approximately 1 percent of the accumulated resource value of all buildings. This budget allocation results in declining condition for all the buildings, declining significance for the four unmanaged buildings ("remaining significance" curve), stable use potential of all the buildings ("use potential" curve), and slightly declining resource value for each of the buildings, with most drastic declines for the four unmanaged buildings ("resource value" curve; appendix 2, fig. 2.1). Despite the relatively stable "use potential" curve, the declines in condition of all

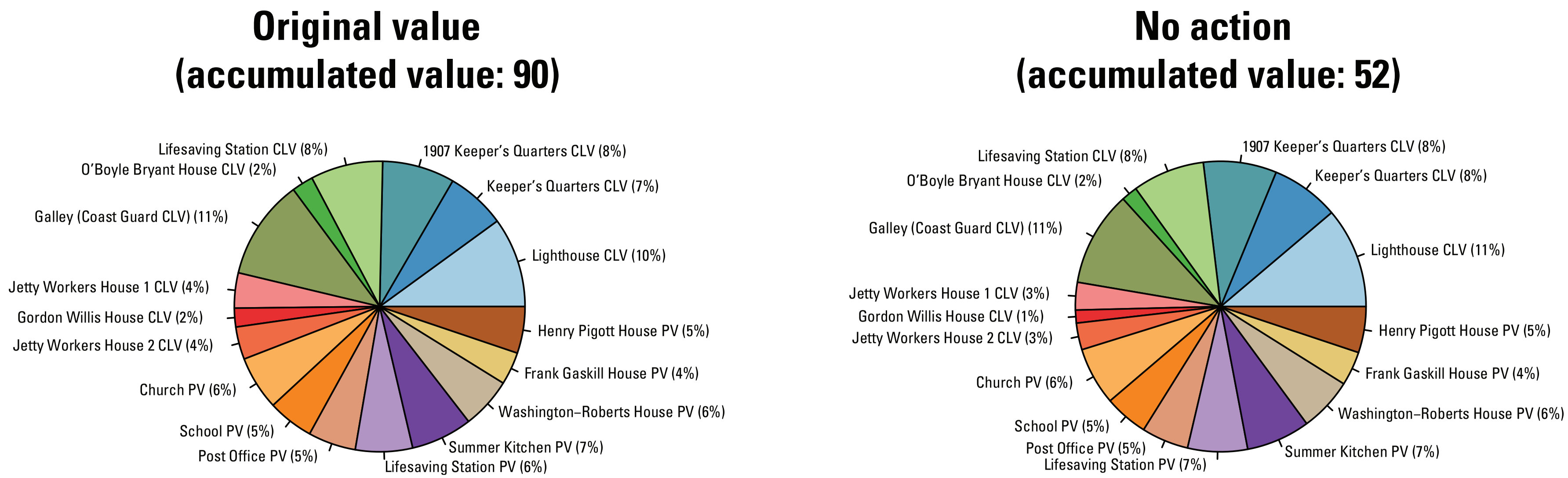

Figure 5. Percentages of total resource value for each building under a "no action" scenario. Units of accumulated value at beginning and end of the 30-year time horizon (90 and 52, respectively) are relative and on a constructed, composite scale. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

Caption. Methodist Church (circa 1840; 1915) in Portsmouth Village (photograph credit: Erin Seekamp, 2015)

Caption. Former U.S. Coast Guard Station in Cape Lookout Village (photograph credit: Erin Seekamp, 2015)

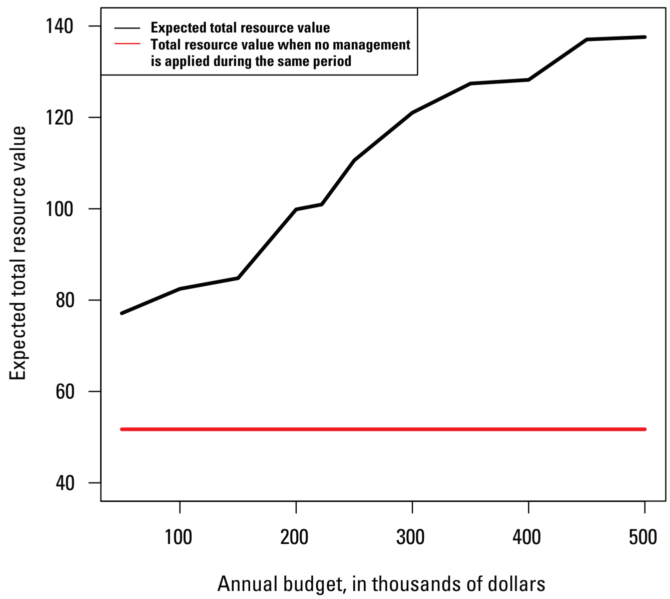

Figure 6. Expected total resource value of the optimal management portfolio at the end of the 30-year period, as a function of annual budget and compared to expected total resource value when no management is applied during the same period. Units of accumulated resource values are relative and on a constructed, composite scale.

17 buildings suggest that an annual budget of $50,000 is insufficient to enable the continued use of buildings for park operations, for public visitation, or both.

The optimal solution seems to suggest that two of the buildings (Gordon Willis House and O'Boyle Bryant House at Cape Lookout Village) with the lowest beginning significance scores (the "remaining significance" curve begins near 0.2), which also have low use potential scores (the "use potential" curve begins near 0.0), are not high-priority buildings (see appendix 2, fig. 2.1). However, the two other buildings selected to be unmaintained during the 30-year planning horizon (the Keeper's Quarters at Cape Lookout Village and the Church at Portsmouth Village) are likely high priorities for park managers, and the loss of significance could represent an undesired management situation because the Keeper's Quarters functions as a visitor center and houses volunteers, and the Church, an iconic building in Portsmouth Village, serves as a meeting place for the Friends of Portsmouth Island. It is important to note that this finding is likely related to the fact that managers placed higher weight on historical significance than on use potential. If use potential was given more weight, it is possible that buildings that are used for operations or open for visitation would be selected when annual budget allocations are insufficient to simply maintain all buildings. Given the current weighting scheme, the model prioritizes buildings and management options in such a way that (1) the full $50,000 annual budget is expended and (2) the highest total resource value can be achieved. This suggested that the four buildings selected for "no action" minimized losses to total resource value and—under the current specification of objectives, attributes, and their weights—should go unmanaged for the entire 30-year horizon. However, the declines in condition for all buildings (even those receiving annual maintenance) indicates that none will be suitable for park operations, visitor access, or third-party use within 20 years; we recognize that this model is not fully accounting for declines in use potential and are working to rectify this limitation for future applications of the OptiPres Model.

Portfolio for a Budget of $222,000

The optimal strategy under this budget allocation suggested relocation (or elevation and relocation) of some buildings during the planning period and that other buildings should receive core and shell preservation treatments early in the planning window (fig. 9). Funds to perform annual maintenance are sufficient for each of the 17 buildings under this scenario. However, foregoing annual maintenance on some buildings provided enough savings in some years to enable higher-cost adaptation actions (for example, relocation, elevation, and core and shell preservation) to be applied to other buildings; in this scenario, the budget was only large enough to consider those buildings that had the lowest costs for this class of actions. The consequence of trading off management of some buildings and not managing others, is that the resource value of those structures not receiving preservation or adaptation treatments (that is, those receiving 'no action' or 'annual maintenance') tended to decline slightly faster. Thus, actions that required short-term neglect of some buildings seemed to be pushed to the end of the planning horizon because that preserved the most resource value for the longest period.

Under this budget allocation, the Gordon Willis House and O'Boyle Bryant House at Cape Lookout Village are now candidates for relocation. This had the effect of increasing their condition, while simultaneously lowering their remaining historical significance (appendix 2, fig. 2.2). This same pattern of changes to condition and historical significance also occurred for the Frank Gaskill House and Summer Kitchen at Portsmouth Village and Jetty Worker's House 1 at Cape Lookout Village. The buildings selected are associated with relatively low costs for relocation (most cost-effective way to reduce vulnerability and improve accumulated resource value).

The total resource value under this scenario increased by nearly 50 percent of the value under the previous scenario of a $50,000 annual budget. The relative proportion of accumulated value of each building under this budget differed from the previous scenario (fig. 10). Relative to all buildings, the Summer Kitchen at Portsmouth Village had the highest accumulated value. The Galley Lighthouse at Cape Lookout Village and Frank Gaskill House at Portsmouth Village also

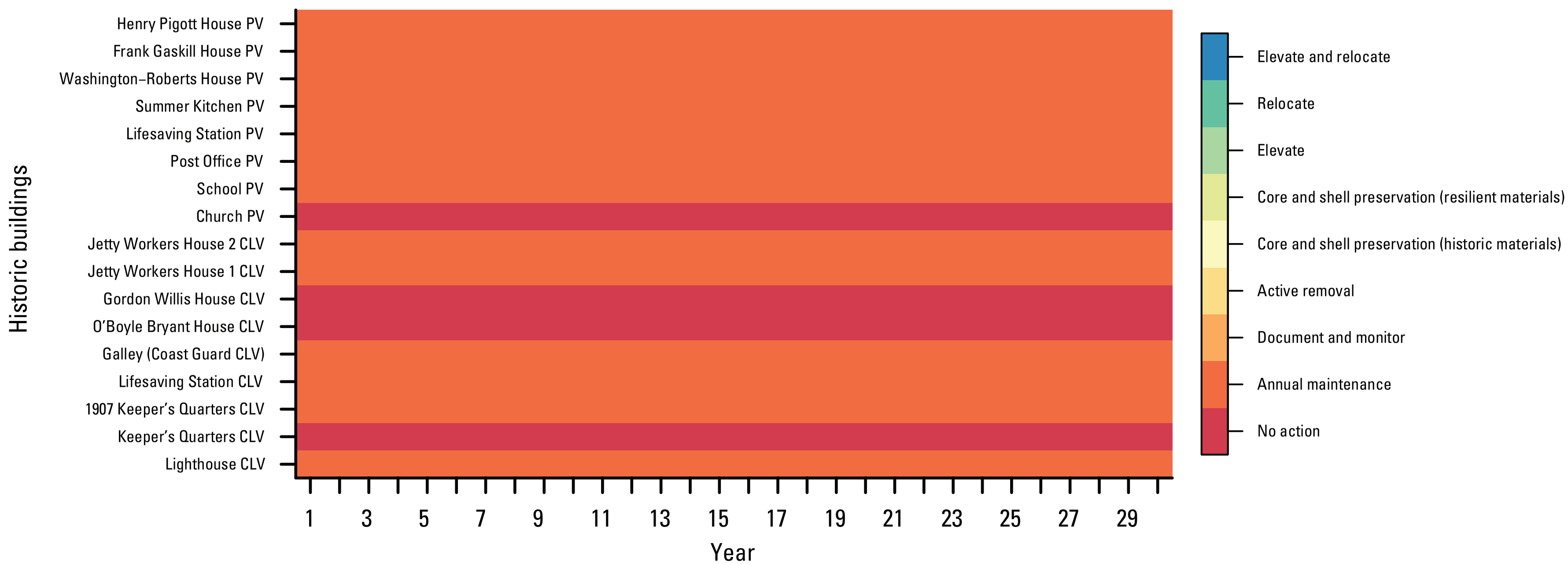

Figure 7. Optimal actions identified under scenario 2 and a $50,000 annual budget allocation. [CLV, Cape Lookout Village; PV, Portsmouth Village]

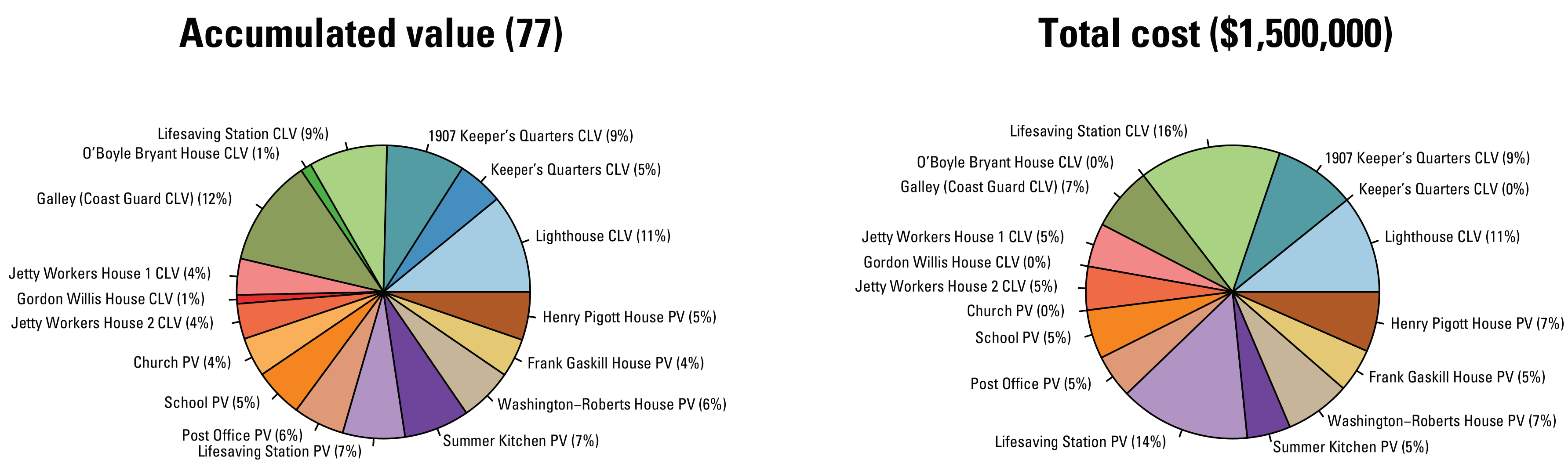

Figure 8. The proportion of each building's accumulated value and total cost under scenario 2 and an annual budget of $50,000. Total accumulated resource value and total scenario expenditure are provided in parentheses after the figure titles, respectively. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

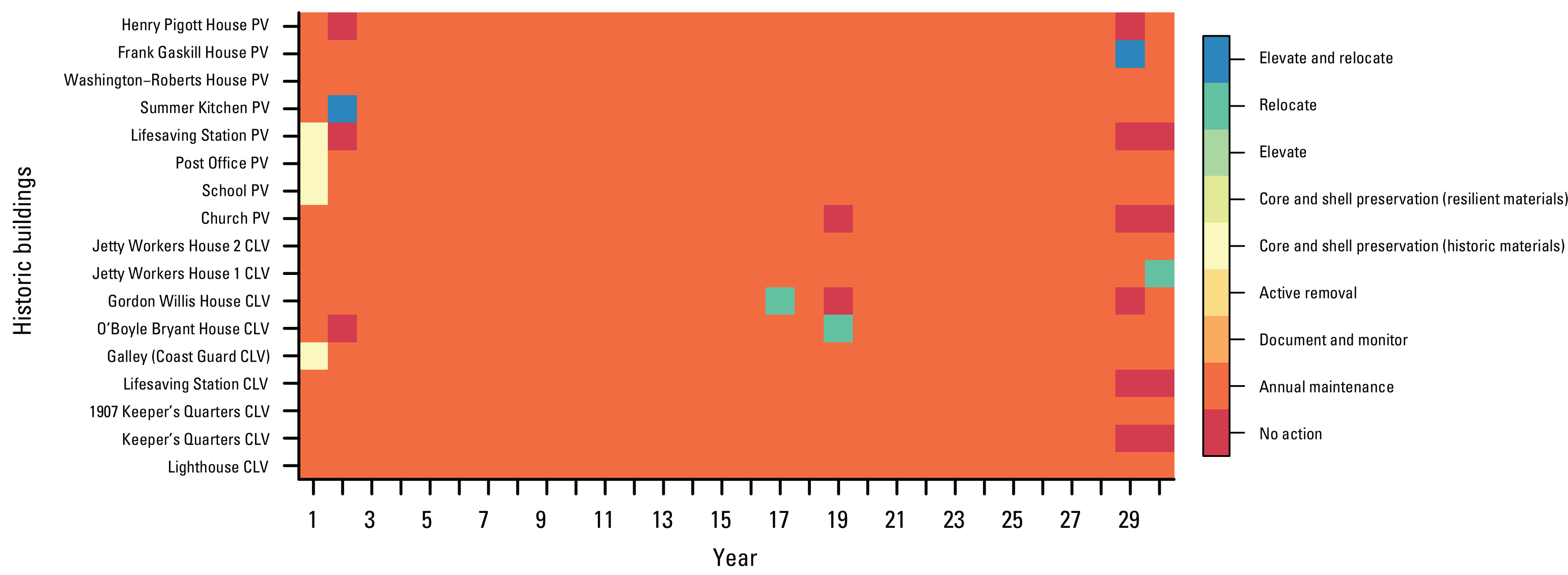

Figure 9. Optimal actions identified under Scenario 2 and a $222,000 annual budget allocation. [CLV, Cape Lookout Village; PV, Portsmouth Village]

Figure 10. The proportion of each building's accumulated value and total cost under scenario 2 and an annual budget of $222,000. Total accumulated resource value and total scenario expenditure are provided in parentheses after the figure titles, respectively. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

contributed disproportionately to accumulated resource value under this scenario.

This scenario's results (that is, the industry standard) illustrate that the available budget context affects the decision; that is, buildings regarded as not worth managing when budgets are low (figs. 7–8) may be worth managing when additional resources are available (figs. 9–10). Also, the additional funding made four structures (Lifesaving Station, Post Office, and School at Portsmouth Village; and Galley [Coast Guard] at Cape Lookout Village) eligible for core and shell preservation actions at the beginning of the planning period (fig. 9). Applying core and shell preservation actions earlier in the planning period seems to result in larger marginal gains of condition improvement for buildings than applying this action later.

Additionally, the timing of relocation actions seems to reflect the tradeoffs inherent in receiving a large boost in resource value from removing vulnerability and the reduction in relative value by lowering historical significance. The results specifically suggest that buildings that have high initial resource values and are more affordable to relocate (that is, those buildings that enable fewer tradeoffs by requiring a limited number of buildings to receive "do nothing" actions in the same year as relocations), should be moved earlier, whereas those that are more expensive to move should be moved later in the planning period (appendix 2, fig. 2.2). Buildings that have less resource value but also have more potential for large relative condition increases should be moved midway through the period for what seems to be the following reasons: they retain more relative resource value because it delays the decay rates, and they reduce long-term effects of not being able to maintain some buildings in the year during which relocation occurs.

To further explain these findings, we provide a couple specific examples to explain the pattern of results. The original significance value for the Summer Kitchen at Portsmouth Village was much higher than any of the other relocated buildings. However, relocating this building early reduced its significance but not by as much as the other relocated buildings. Therefore, more resource value could be maintained over time by relocating this building early in the planning period, whereas relocating the other four buildings earlier would have resulted in a larger penalty and lowered the ending accumulated resource value. In fact, in test runs (not presented), reducing the strength of the effect of relocation on historical significance resulted in relocation actions being applied earlier in the sequence. Additionally, some of the lower resource values were caused by the budget constraint. For example, relocating the O'Boyle Bryant House at Cape Lookout Village meant some other buildings could not be managed in the relocation year. The model seemed to be pushing this effect toward the end of the planning period, likely because the declines in historical significance were accumulated more slowly during the 30-year planning period.

Portfolio for a Budget of $500,000

The optimal portfolio for the largest budget we considered was very similar to the $222,000 budget outputs, except that the increase in potential spending meant more buildings could be managed (fig. 11). Relocation and annual maintenance actions dominated this solution, as in the $222,000 allocation, but "core and shell preservation (historic materials)" was chosen by the model for one building, the Galley (Coast Guard) at Cape Lookout Village. It is likely that this action was selected for the Galley because of the relatively low cost affiliated with this action for this building; the Galley (Coast Guard) at Cape Lookout Village and Summer Kitchen at Portsmouth Village have the lowest costs for core and shell preservation (historic materials). The Summer Kitchen at Portsmouth Village receives this preservation treatment as part of the relocate and elevate action applied in the same year. Therefore, this action alone seems to be a good strategy for improving the condition of a building, while maintaining its historical significance, for buildings already in low vulnerability locations (that is, the Galley [Coast Guard] at Cape Lookout Village).

The accumulated value of buildings under this scenario (fig. 12) increases by 37 percent of accumulated value under the scenario of annual allocation of $222,000 (fig. 10). The percentage contribution of resource value for each building was similar with the $222,000 scenario, except for the noticeable increase in relative value of a few buildings in Portsmouth Village, which were eligible for relocation and elevation under this budget scenario. Total expenditures under this scenario were about 70 percent higher than that spent under the $222,000 scenario.

The effect of this budget allocation on the aspect of resource value were virtually the same as those in the $222,000 budget scenario, with a few notable exceptions: the optimal timing of the relocation action for some buildings seems to have been moved earlier in the planning window (fig. 11 compared to fig. 9). For example, under a larger budget, moving the O'Boyle Bryant House at Cape Lookout Village occurs earlier in the planning period. This could be because the budget constraint under the previous $222,000 allocation caused two other buildings to go unmanaged when the O'Boyle Bryant House was moved. These results also are reflected in the total accumulated resource value (fig. 12) for this budget allocation, which was substantially higher than for the previous $222,000 allocation (fig. 10). Additional details on each building are provided in appendix 2, figure 2.3.

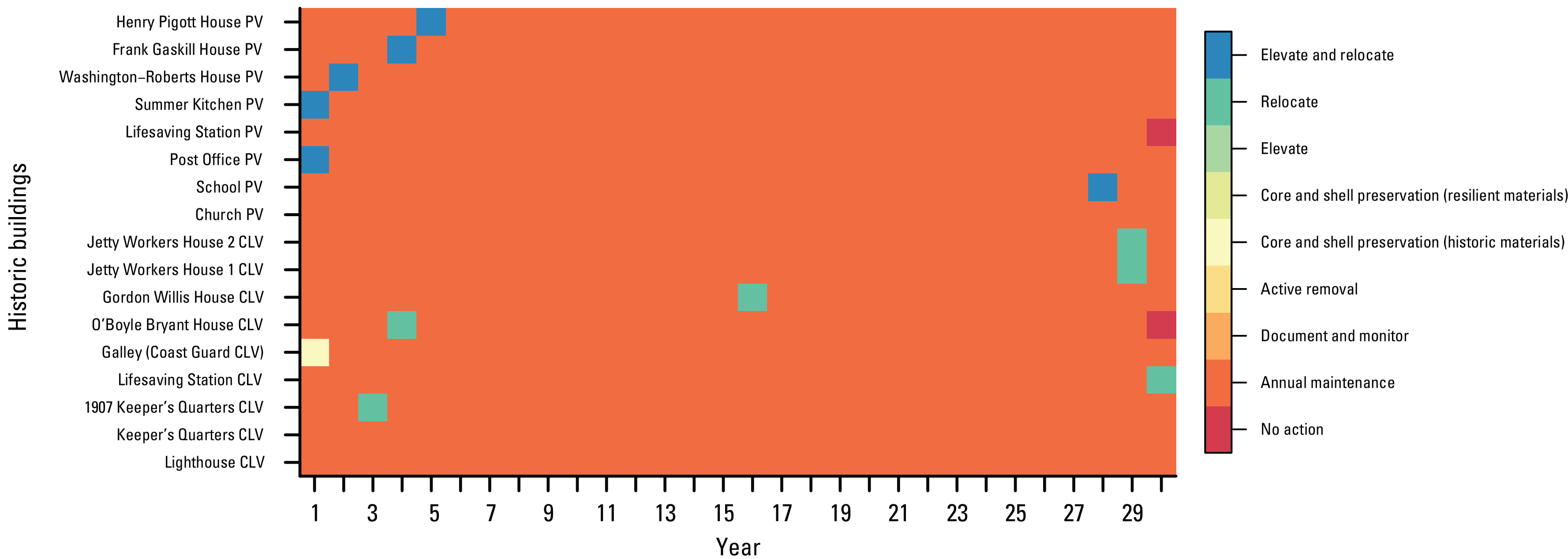

Figure 11. Optimal actions identified under scenario 2 and a $500,000 annual budget allocation. [CLV, Cape Lookout Village; PV, Portsmouth Village]

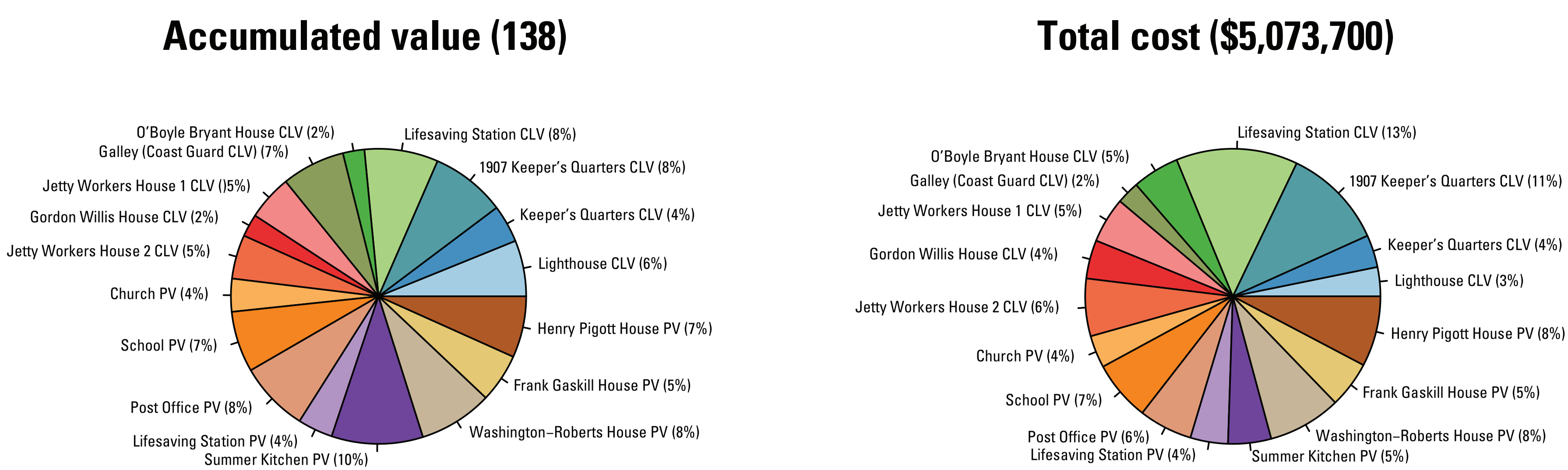

Figure 12. The proportion of each building's accumulated value and total cost under Scenario 2 and an annual budget of $500,000. Total accumulated resource value and total scenario expenditure are provided in parentheses after the figure titles, respectively. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

Scenario 3—Accounting For Periodic Funding Increases

Portfolio For A Budget Of $70,000 With A Surge Of $225,000 Every 5 Years

The optimal portfolio for this scenario with a low budget allocation (but one in which annual maintenance could be performed on all buildings in any given year) suggested that some buildings could be moved when a surge in total budget allocated occurred every 5 years (fig. 13). Under this scenario, all buildings were managed but not in every year of the planning period. Unlike the $222,000 scenario (fig. 9), which targeted relocation and elevation actions at the beginning or the end of the 30-year period, the optimal strategy of this scenario ($70,000 annually with $225,000 surges every 5 years) dispersed the action of relocation and elevation actions more evenly over time (fig. 13). Similarly, lower-cost relocations occurred early, and higher-cost relocations were postponed towards the end of the planning horizon.

The outcomes of a budget allocation that included periodic funding increases (appendix 2, fig. 2.4) were similar to those of the $222,000 scenario (appendix 2, fig. 2.2), with the exception of the relative significance losses for several of the buildings. The similarities in total accumulated resource value between these scenarios (slightly lower values for this budget allocation compared to the $222,000 scenario; figs. 14 and 10, respectively) may be caused by fact that the relocation and annual maintenance actions dominated the solutions for both scenarios.

Portfolio For A Budget Of $222,000 With A Surge Of $225,000 Every 5 Years

The optimal portfolio for this budget allocation (fig. 15) suggests that more buildings could be candidates for relocation or relocation and elevation actions than in the scenario of annual budget of $222,000 (fig. 9). Similar to the $70,000 annual budget allocation with additional funding (fig. 13), relocation or relocation and elevation actions were selected in the years when the additional funding was allocated.

Interestingly, the core and shell preservation using historic materials action was not selected in this budget allocation (it was selected for one building, the Galley at Cape Lookout Village, under the annual budget allocation of $500,000; fig. 11). It is possible that the marginal gain in resource value for these buildings under this budget allocation (fig. 16) compared to that of the $500,000 scenario (fig. 12) might be greater for the relocation or relocation and elevation adaptation strategies than for the core and shell preservation treatment. Although the actual expenditures under this scenario were about 87 percent of the actual expenditures of $500,000 annual allocation scenario (about $4.48 million compared to about $5.07 million), the total accumulated resource value under this scenario was very similar (130 compared to 138, respectively) with the scenario of annual budget of $500,000 (figs. 16 and 12, respectively). Additional information for each building's relative resource value is provided in appendix 2, figure 2.5.

Scenario 4—Ignoring Vulnerability

Portfolio For A Budget Of $222,000 Without Vulnerability

The optimal management strategy under this scenario is to select actions of core and shell preservation using historic materials and annual maintenance (fig. 17). Relocation and elevation actions were likely not selected under this scenario because these actions included the same historic preservation treatment (that is, they both increase the condition of the building to NPS standards) but would reduce the relative significance of the buildings. Because vulnerability was not considered, the additional costs for actions that address sea level rise and storm-related flooding were not justified. The buildings selected seem to be a function of cost (fig. 18) and condition (improved condition ratings; see appendix 2, fig. 2.6); however, it is not quite clear why the preservation treatments typically occurred in the middle of the planning horizon but it is likely related to reducing the effect of decay rates posttreatment.

In this scenario, the total accumulated resource value (fig. 18) is calculated by accumulating the annual resource value over the planning horizon but not penalizing the final score by a building's vulnerability assessment. As a result, the model does not attempt to lower a building's vulnerability and the resulting accumulated resource value for this scenario (fig. 18) is higher than in the $222,000 with vulnerability (fig. 10) scenario (305 compared to 101, respectively).

Scenario 5—Excluding The Attributes Of "Use Potential"

Portfolio For A Budget Of $222,000 Without Use Potential

The optimal portfolio for this scenario suggested that the core and shell preservation using the historic materials action was more likely to be chosen if the historical significance of buildings were given more weight (fig. 19). Four buildings with high historical significance (the Life-Saving Station, Post Office, and School at Portsmouth Village; and Galley at Cape Lookout Village) were candidates for historical preservation action at the beginning of 30-year period. Unlike the earlier $222,000 scenario with use potential in which relocation and elevation was selected for the Summer Kitchen at Portsmouth Village at the beginning of the planning horizon (fig. 9), this action was selected for the Summer Kitchen at the end of 30-year period under this scenario (fig. 19). We infer that

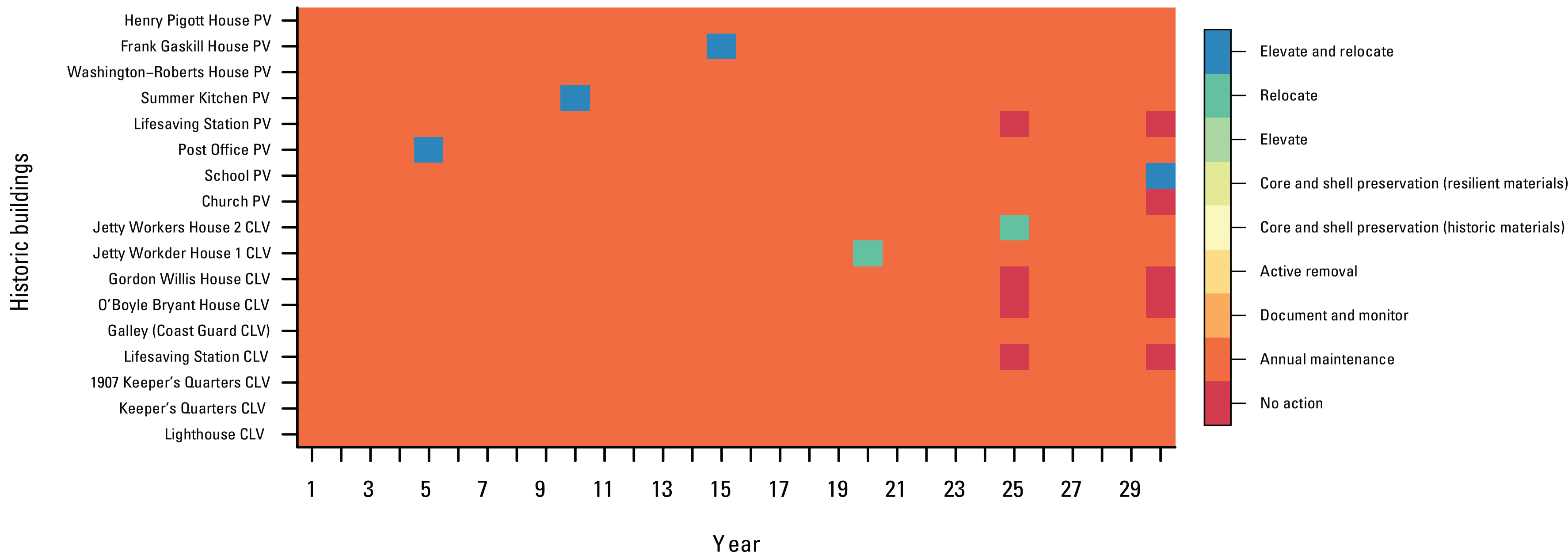

Figure 13. Optimal actions identified under scenario 3 and a $70,000 annual budget allocation with an additional $225,000 every 5 years. [CLV, Cape Lookout Village; PV, Portsmouth Village]

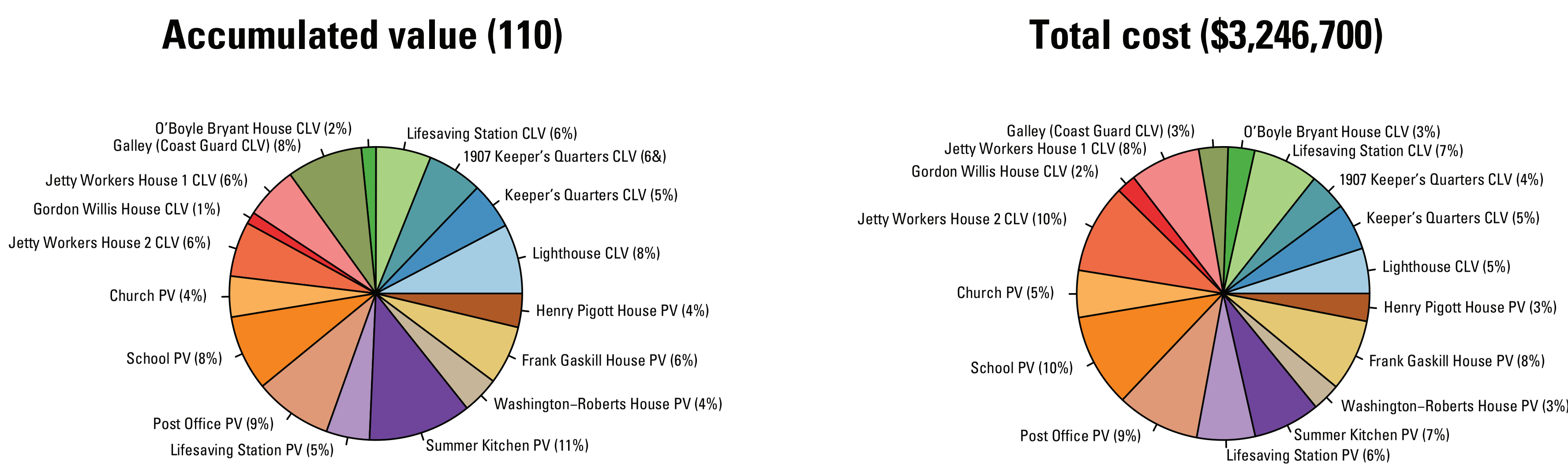

Figure 14. The proportion of each building's accumulated value and total cost under scenario 3 and an annual budget of $70,000 with an additional $225,000 every 5 years. Total accumulated resource value and total scenario expenditure are provided in parentheses after the figure titles, respectively. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

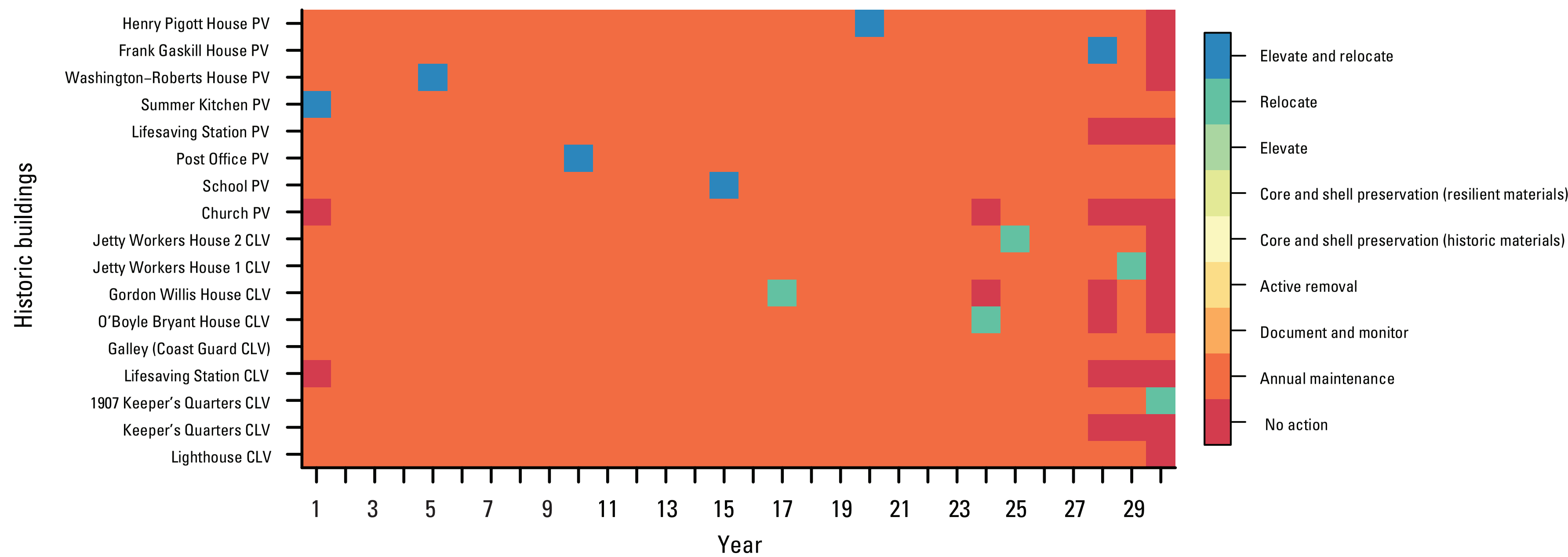

Figure 15. Optimal actions identified under scenario 3 and a $222,000 annual budget allocation with an additional $225,000 every 5 years. [CLV, Cape Lookout Village; PV, Portsmouth Village]

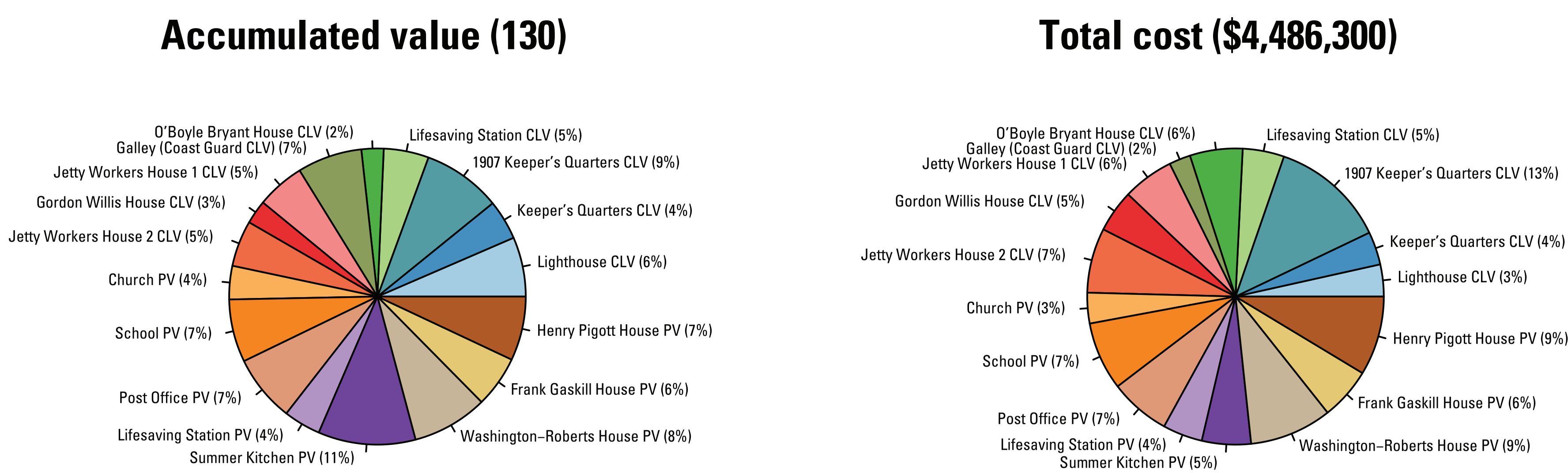

Figure 16. The proportion of each building's accumulated value and total cost under scenario 3 and an annual budget of $222,000 with an additional $225,000 every 5 years. Total accumulated resource value and total scenario expenditure are provided in parentheses after the figure titles, respectively. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

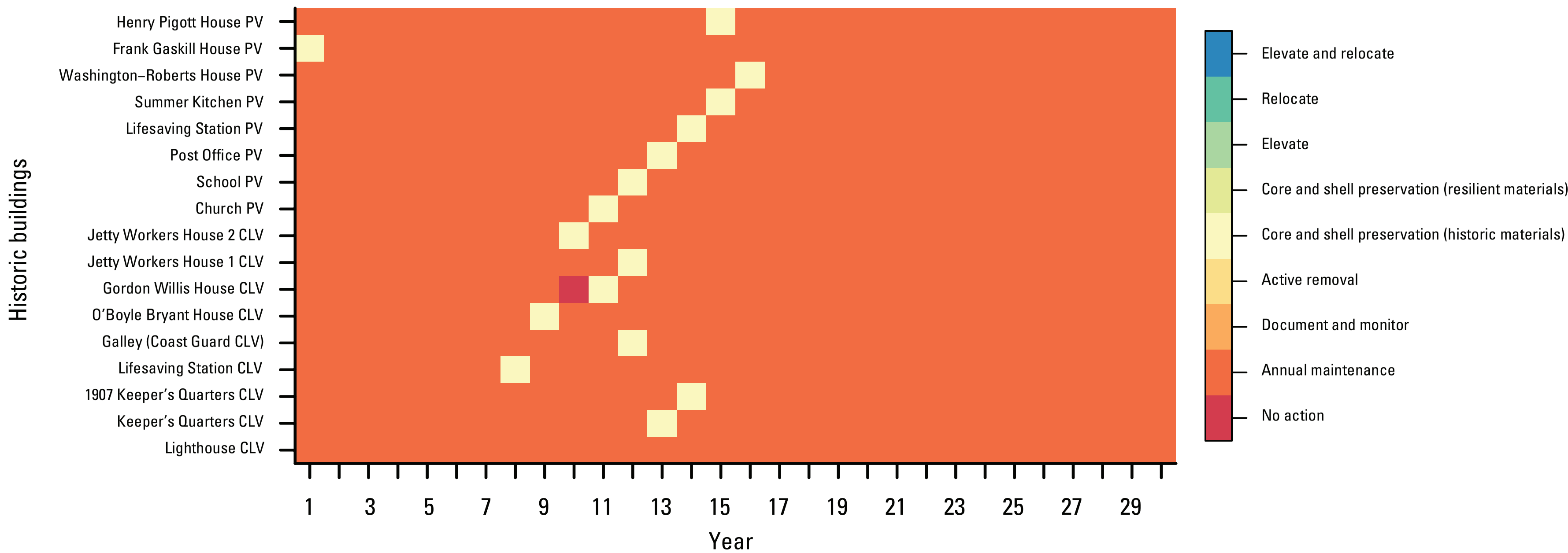

Figure 17. Optimal actions identified under scenario 4 and a $222,000 annual budget allocation without consideration of vulnerability. [CLV, Cape Lookout Village; PV, Portsmouth Village]

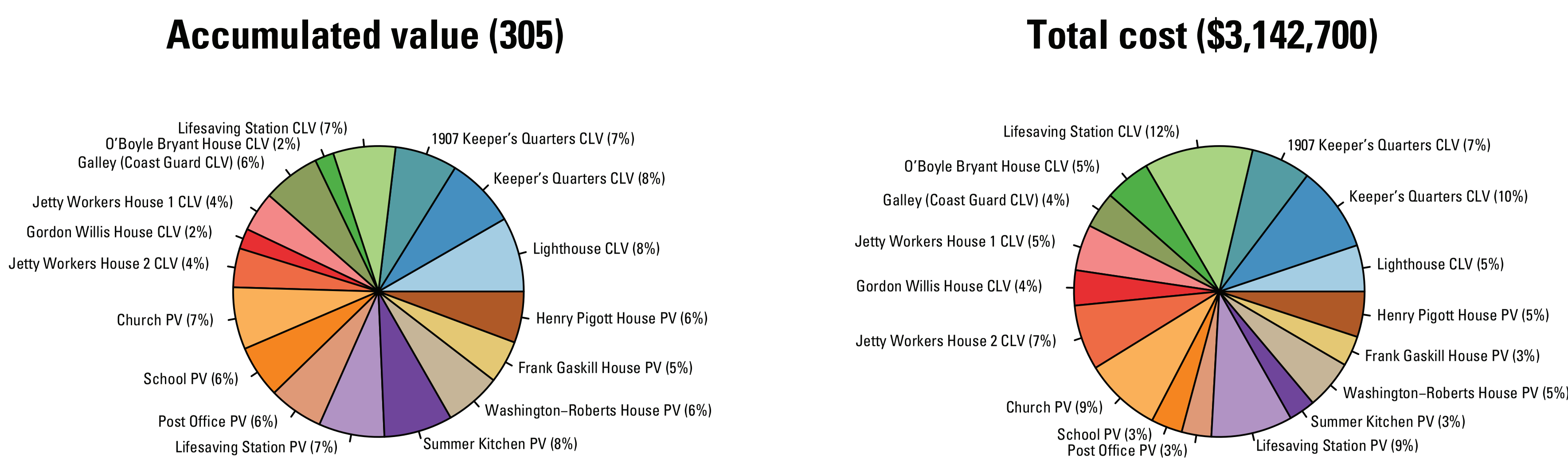

Figure 18. The proportion of each building's accumulated value and total cost under scenario 4 and an annual budget of $222,000 without consideration of vulnerability. Total accumulated resource value and total scenario expenditure are provided in parentheses after the figure titles, respectively. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

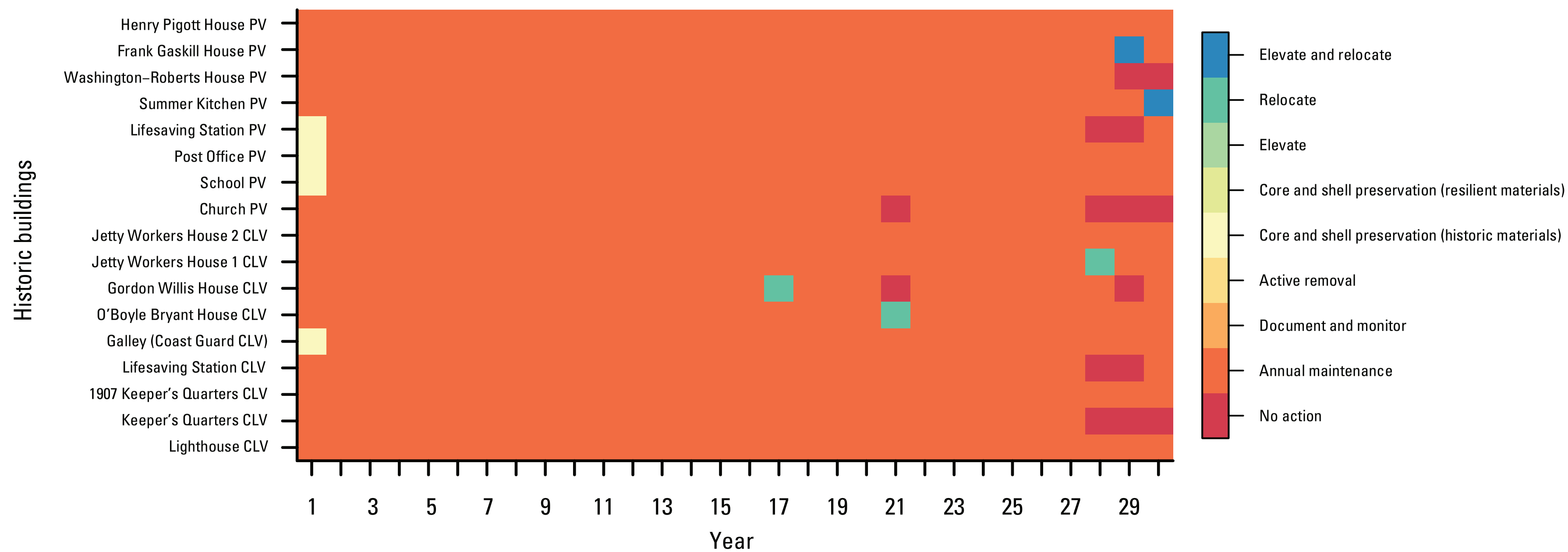

Figure 19. Optimal actions identified under scenario 5 and a $222,000 annual budget allocation without consideration of use potential. [CLV, Cape Lookout Village; PV, Portsmouth Village]

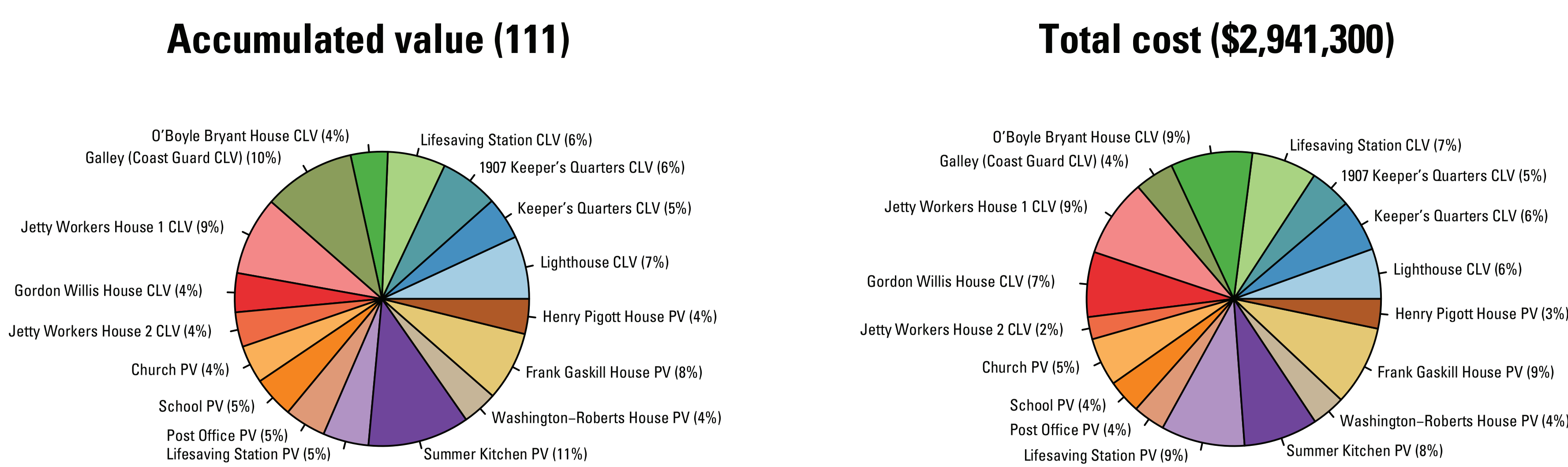

Figure 20. The proportion of each building's accumulated value and total cost under scenario 5 and an annual budget of $222,000 without consideration of use potential. Total accumulated resource value and total scenario expenditure are provided in parentheses after the figure titles, respectively. [CLV, Cape Lookout Village; %, percent; PV, Portsmouth Village]

relocating this building earlier in the planning horizon would have resulted in a larger penalty on the resource value because of the greater weight on historical significance in this scenario (appendix 2, fig. 2.7) than the scenario that included use potential (appendix 2, fig. 2.2).

The total accumulated resource value (fig. 20) was computed as in the other scenarios except that use potential was not included in the calculation. We accomplished this by allocating all the weight to historical significance. Therefore, the accumulated resource values displayed in figure 20 are not directly comparable to the other scenarios' accumulated resource value because it reflects an optimal strategy assuming only historical significance was to be maximized; yet, comparing this solution to the others indicates how much use potential affected the optimal strategy.

Comparing Scenarios

To compare effects of applied actions on the resource values of buildings under different scenarios, we created a figure to show the composite, accumulated values of all buildings and total expenditures under the eight scenarios (fig. 21; the resource values by building for each of the scenarios can be viewed in appendix 2, fig. 2.8). The resource values of all buildings under the scenarios of "no action" and annual allocation of $50,000 were lower than the original value of all buildings. The scenarios with higher budget allocations (scenarios 3–8) could improve the original resource values of all buildings, which suggests that adaptation actions can help maintain and (or) enhance historical significance and use potential of historic buildings.

Generally, a higher budget allocation results in higher accumulated resource value. However, the accumulated resource value of the scenario of allocation of $70,000 every year with an additional fund of $225,000 every 5 years was higher than the scenario of allocation of $222,000 every year. This finding is caused by the fact that the allocated budgets are not fully spent in several scenarios; for example, the scenario with a periodic funding increase uses 94 percent of allocated budget, whereas the constant funding scenario uses only 44 percent of the total allocated budget (fig. 22). The periodic allocation of additional funding makes efficient use of larger, more costly adaption actions for several buildings, resulting in slightly higher total accumulated resource value relative to the constant budget scenario. In addition, the high accumulated resource value achieved when disregarding vulnerability indicates that, based on current model specification, the quantification of resource value may be highly sensitive to vulnerability scores.

Insights From The Pilot Study

Building the OptiPres Model in its current state was completed by using the best available data and iteratively examining the model assumptions. The model was constructed based on the objective of maximizing the total resource value of 17 buildings. Additionally, we ran four broad scenarios, including two with multiple budget allocations, to test the model's assumptions, dynamics, and constraints with the goal of providing decision-making insights for managers and other relevant NPS personnel.

It is important to note that, for any optimization problem, there is a tradeoff between computational speed and closeness to some global optimum. In conservation planning, finding one exact, optimum solution is not essential, but it is important to generate many good solutions in a reasonable amount of time using the iterative heuristics for optimization problems. The simulated annealing algorithm is nondeterministic; each run will generate a different solution. For each scenario in this study, we ran the algorithm 100 times, which was aligned with the run times in other studies about conservation planning using the simulated annealing algorithm (Westphal and others, 2007).

Additionally, it is important to note that, as with any modeling effort, we iterated through several revisions of model dynamics and associated metrics based on new information obtained during the project period. However, we could not address all considerations and limitations, but several key insights were gained through model exploration. These insights are described below.

Sufficient annual budget allocations are necessary to implement climate adaptation actions to historic buildings. Adaptation actions are costly and if park personnel are to maintain at least the current accumulated resource value, then sufficient fiscal appropriations (minimum of the industry standard) are necessary. Additionally, our results suggest that additional appropriations provided on regular intervals when annual appropriations are at the industry standard are nearly as efficient as annual appropriations at twice the rate of industry standards and increase the amount of accumulated resource value maintained to nearly the same level. However, periodic increases in funding may increase the risks posed to buildings from the probability of a natural hazard (that is, damage or loss from a hurricane). Therefore, the OptiPres Model has planning utility related to fiscal efficiency by identifying a budget threshold necessary to maintain the historical significance and use potential of historical buildings while reducing vulnerability. Nevertheless, it will be important for managers to continue seeking additional stakeholder input to ensure that the adaptation actions selected align with the values of stakeholder groups and (or) are applied to buildings that hold relatively high importance for stakeholder groups. For the latter, it will be important to update the model to weight the adaptation actions by acceptability to a variety of external stakeholders (for example, community members, partner organizations, and visitors) because certain actions may alter the

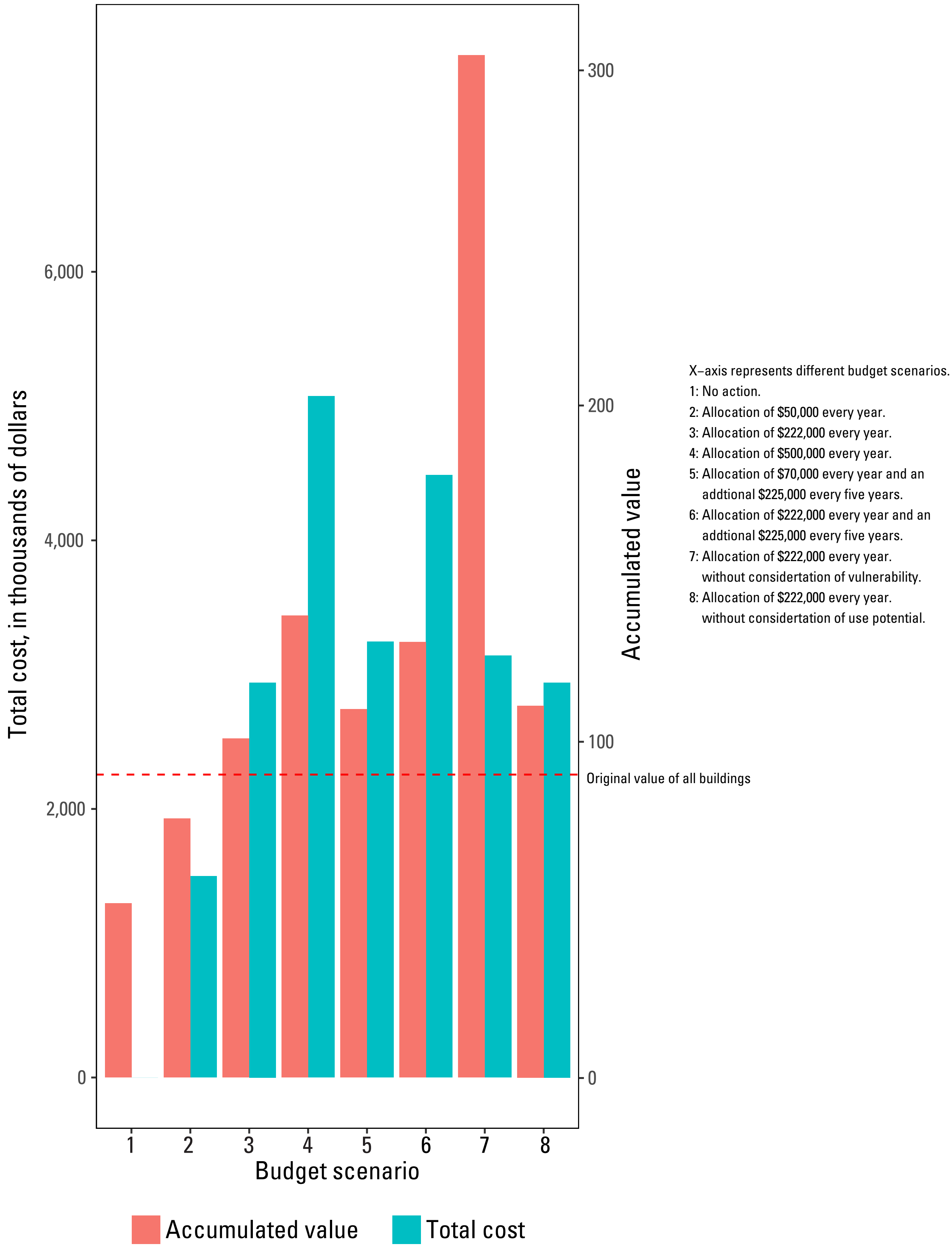

Figure 21. Accumulated value and total cost of all buildings for all budget scenarios. Units of accumulated values are on relative and on a constructed, composite scale.

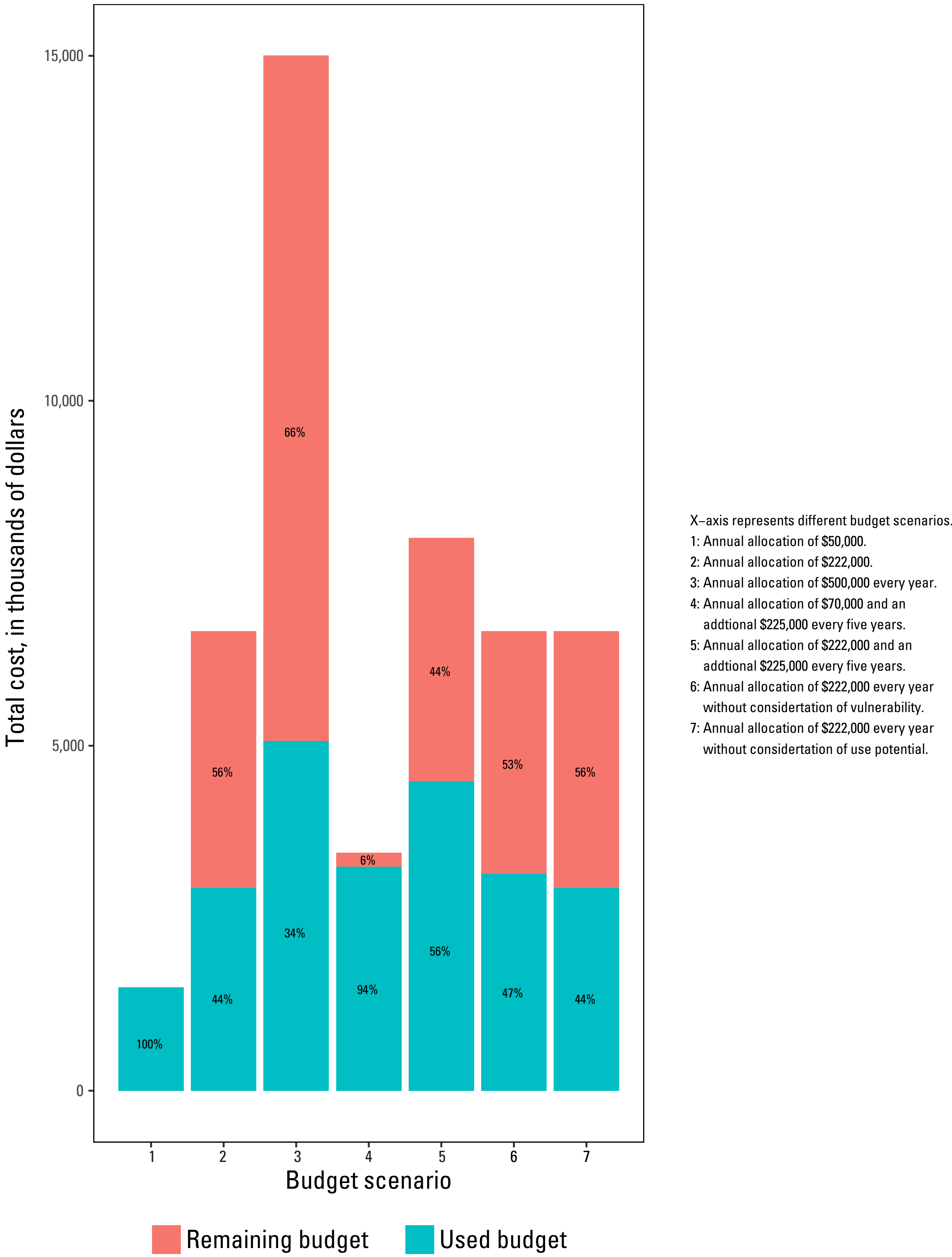

Figure 22. Comparison of allocated budget versus actual expenditures for all budget scenarios.

intangible resource values associated with people's connections to specific buildings.

Preferences regarding the valuation of a cultural resource (that is, weights applied to historical significance and use potential) affect the optimal adaptation strategies identified. Because maximizing total resource value of 17 buildings was the purpose behind our development of the OptiPres Model, the relative effect of each objective (based on weighting of historical significance and use potential, including associated attributes) must be clearly understood. We suggest that park managers, and perhaps cultural resource management personnel at the national NPS Headquarters and (or) personnel at the National State Historic Preservation Office, have focused discussions about their preferences regarding historical resources and how these values relate to each of the attributes and subattributes before future applications of the OptiPres Model. Because objective weights reflect statements of subjective values, they represent an additional source of variability and uncertainty in decision modeling. This uncertainty can be addressed in several ways, including a facilitated, consensus-based approach, surveying multiple stakeholders and calculating average weights (that is, the method applied in this pilot study), and (or) grouping weights into several representative stakeholder "types" and conducting a sensitivity analysis of the effect on the portfolio strategy of variation in values.

Considerations For Advancing The Optipres Model

The NPS's Climate Change Response Program perceives utility in the OptiPres Model for enhancing national park management and supporting climate adaptation decision-making. After the conclusion of the second workshop at Cape Lookout National Seashore (see fig. 1), the Climate Change Response Program managers decided to provide funding to determine the transferability of the OptiPres Model by applying it to another National Park System unit. We have determined some additional considerations to include as improvements in subsequent model development. These considerations include the following:

- *Clearly outlining how current replacement value data can be integrated with other data from standard Federal databases to refine the cost estimates for the various actions.*—We found that considerable effort from NPS staff was needed to determine the adaptation costs for buildings because of a high degree of variability in reporting to the various NPS facilities management databases. To reduce the burden on NPS staff in future applications of the OptiPres Model, continual work will be needed to determine standard costs per square footage based on dominant building materials.
- *Development of a metric framework for assessing the current historic integrity of buildings to include in the historical significance calculations.*—This model advancement may enable us to change the structure of the significance calculations by replacing the attribute "building condition" with "historic integrity" and integrating "building condition" into the cost estimates for the various adaptation actions (particularly, if it is integrated with the current replacement value of specific buildings). This advancement may also help us deal with the fact that "building condition" and "use potential" are correlated but that the relations are not fully accounted for in this version of the OptiPres Model (that is, buildings in poor and perhaps some in fair condition would not have operational, visitor, or third-party use but may retain some degree of use potential depending on anticipated budget allocations).
- *Integrating social values data as a potential model input or lens through which to interpret model outputs.*—For example, social values data collected at Cape Lookout National Seashore as part of a parallel research project suggests that specific adaptation actions (for example, moving or elevating buildings) are viewed unfavorably by several stakeholder groups and that the managers may benefit from OptiPres Model scenarios that remove or discount the value of these adaptation actions as options. Although replication of these social values data will likely not be feasible for the second park site to test the model because of the timeframe of review processes for studies that involve members of the public, we will seek opportunities to explore how stakeholders' values can be used to affect and (or) interpret the model outputs.
- *Development of additional objectives.*—In ongoing discussions, we continue to sense that specifying additional objectives could enhance the usefulness of the model. Examples could be objectives related to minimizing "public risk" (for example, removing buildings in poor condition) or increasing "public enjoyment" (for example, prioritizing a building present on the landscape in good condition).
- *Refining vulnerability data.*—The limited differences observed in the vulnerability scores of the buildings at Cape Lookout National Seashore suggest that refining the vulnerability analysis to a more localized scale could be advantageous. Specifically, the vulnerability assessment methodology bins raw scores for exposure and raw scores for sensitivity, adds those binned scores together, and then bins the total score to develop the final static vulnerability metric on a 1–4 scale; additionally, the attributes that com-

pose the exposure and sensitivity metrics are added together without first weighting the scores based on different degrees of effect risk or damage. Reconfiguring how the vulnerability scores are computed may increase the model's sensitivity, but using raw scores may not be particularly meaningful given the uncertainty in the data used to score the attributes and the stochastic nature of storm-related effects. Other considerations to increase model sensitivity include (1) changing the current vulnerability metric to a time-dependent persistence (risk) metric or (2) penalizing adaptation action costs (for example, moving or elevating buildings) to reflect the time-dependent likelihood for increased risk of inundation at the time an action is applied (costlier if already inundated or greatly impacted by a storm event). Additionally, there will be a need to periodically re-estimate the vulnerability metrics because climate scenarios and projections of land cover change evolve with time.

- *Incorporating stochastic storms and wind effects.*—Coastal cultural resources—particularly those on barrier islands—are at risk from effects associated with natural hazards. These natural hazards are becoming exacerbated (in frequency, intensity, or both) by climate change, which highlights the importance of advancing the model to capture random events such as hurricanes and nor'easters. Integrating storms, with associated flooding and wind effects, as a random variable into the model also will allow us to explore nuances of climate change impacts—particularly to the condition class of a building—and adaptation actions for historic buildings because the model currently only accounts for chronic flooding effects. Moreover, incorporating stochastic events of natural hazards in the OptiPres Model will provide more information for decision makers and park managers about how to prioritize actions after a natural hazard. As more complete assessments of climate change effects are integrated into the model (for example, storm-related effects from wind and precipitation that penetrates buildings), specific adaptation actions that target nonflooding effects (for example, core and shell preservation treatments to improve adaptability that use resilient materials) may become favored within the model (rather than ignored).
- *Enhance visualization and interpretations of model outputs.*—Enhancing our data visualization and interpretation efforts may facilitate further thinking and application of the model results, which may ultimately improve the usability of the model. Visualizations of data that illustrate how significance, use potential, vulnerability, and adaptation costs drive the model and interact across the 30-year forecast window will allow cultural resource managers and NPS officials to determine optimal (that is, most efficient) annual budget levels. This will be particularly important as more buildings are included in any given modeling effort. Ultimately, the ability to clearly communicate data-driven support for specific budgets may enhance the NPS's ability to receive the appropriations necessary to meet its cultural heritage preservation mandates.
- *Incorporating dynamic outputs of vulnerability across the planning horizon.*—Although the vulnerability scores for the historic buildings at Cape Lookout National Seashore only have slight changes between 2030 and 2050, the adaptation actions (for example, elevation and relocation) can dramatically change the vulnerability scores of historic buildings. Incorporating the dynamic outputs of vulnerability at each time step (that is, year) will help NPS officials understand the cultural resource vulnerability changes across the 30-year planning horizon. More importantly, combining the dynamic outputs of conditions, integrity, use potential, and vulnerability would enable the calculation of annual accumulated resource values. These data could then be visualized as a running average of annual accumulated resource values across the 30-year planning horizon to help NPS officials understand the relative increases and decreases in resource values across the assortment of historic buildings under various budget scenarios.

Additionally, the OptiPres Model also could be used in adaptation planning of other cultural resources (for example, archeological resources), other types of park assets (for example, facilities and roads), or efforts that consider other types of climate change effects (for example, fire and drought). However, considerable effort would be needed to first develop the associated measurement frameworks for other cultural resources and assets to determine the relative importance of those resources and assets.

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Appendixes

Caption. Jetty Workers House I (circa 1915) with 1907 Keeper's Quarters (circa 1907) in the background (photograph credit: Erin Seekamp)

Caption. Jetty Workers House II (circa 1920) in Cape Lookout Village (photograph credit: Erin Seekamp, 2015)

Appendix 1. Optimal Preservation Model Objectives, Attributes, Weights, Actions, and Costs

This appendix provides additional details of the multiple data sources that are used to populate the Optimal Preservation (OptiPres) Model. The OptiPres Model includes measures of a building's resource value (historical significance and use potential) and vulnerability (sensitivity and exposure), and cost estimates for adaptation actions. Additionally, some adaptation actions affect the attributes, subattributes, or both for resource value and vulnerability. In table 1.1, the objective "historical significance" is presented with descriptions of attributes and subattributes, the metrics and associated scores, and the relative weights assigned to the attributes and subattributes. In table 1.2, the objective "use potential" is presented with descriptions of attributes and subattributes, the metrics and associated scores, and the relative weights assigned to the attributes and subattributes. In table 1.3, the attribute "exposure" is presented with descriptions of subattributes and associated data sources. In table 1.4, the attribute "sensitivity" is presented with descriptions of subattributes and associated data sources. In table 1.5, the objective "vulnerability" is presented to illustrate how the two attributes (exposure and sensitivity) are combined to create a final binned vulnerability score. In table 1.6, the actions included within the OptiPres Model are defined and the associated model dynamics (changes to a building's condition, the historic integrity of a building, and the vulnerability of a building). In table 1.7, the total costs for each action to be performed on each building are presented.

Table 1.1. Historical significance's attributes, subattributes, and metrics with scores including weights among the attributes and subattributes.

Attributes and subattributes					
Association to fundamental purpose	Condition of building	Character		National register	
		Defining character	Uniqueness to park	Spatial significance	Eligibility
Description					
This attribute uses the information on listed fundamental resource(s) in the park's foundation document[1] to determine if a historic building is considered a fundamental or nonfundamental resource.	The National Park Service database List of Classified Structures (LCS)[2] is used to assess the condition of the building.	This subattribute evaluates if a building is the primary (historic) reason that resulted in the development (or resettlement) of the historic district or is part of the secondary development (or resettlement) of the district that occurred because of the original construction.	This subattribute considers the original (historic) function of the building, if its function was unique within the park, or if there are a number of buildings with the same or similar function.	The geographical scale of a building's historic context listed in the National Register of Historic Places (NRHP)[3] is used to assess the subattribute of spatial significance.	The eligibility subattribute assesses if the historic building is eligible for listing in the NRHP.
Metrics and scores[4]					
Fundamental resource (2.2) Nonfundamental resource (0.9)	Good condition (2.9) Fair condition (1.9) Poor condition (1.1)	Building as primary reason for the historic development of the district (2.3) Building as secondary reason for the historic development of the district (1.1)	Being unique building to the region (4.2) Being the only building of this type in the park (3.1) Few (2–3) similar types of building present in the park (1.9) Many (>3) similar types of building present in the park (1.0)	National significance (3.4) State significance (2.1) Local significance (1.1)	Eligible (2.0) Noneligible (0.0)
Attribute or subattribute weight[5]					
0.26	0.17	0.27		0.30	
		0.475	0.525	0.41	0.59

[1]Foundation documents for national parks are available at https://parkplanning.nps.gov/foundationDocuments.cfm.

[2]The List of Classified Structures (LCS) is available at https://hscl.cr.nps.gov/insidenps/search.asp.

[3]The National Register of Historic Places (NRHP) is available at https://npgallery.nps.gov/nrhp.

[4]Scores were derived using an elicitation of National Park Service (NPS) and State Historic Preservation Office (SHPO) staff and reflect the mean value calculated for each metric from the elicitation.

[5]Weights were derived using an elicitation of NPS and SHPO staff and reflect the mean value calculated for each metric from the elicitation.

Table 1.2. Use potential's attributes and metrics with scores including weights among the attributes.

Use potential's attributes				
Operational use	**Third party use**	**Visitor use**	**Interpretive use**	**Scientific use**
Description				
This attribute evaluates if the historic building is used for park operations or has potential for it in the future. It also evaluates possible investment in the historic building for park operations to reduce the operational use of nonhistoric (noncontributing) building.	This attribute assesses the current and potential future use of the building by the third party through lease agreements and concessions.	This attribute explores current and future active uses of the building for public visitation in the historic district (or other specified area) of the park.	The park's Long-Range Interpretive Plan[1] is used to assess current and future active uses of the building for communicating stories and educating visitors of the park. This attribute determines whether the building's interpretive plan conveys primary or secondary interpretive themes.	This attribute evaluates if the building has a potential to yield new scientific information and value.
Metrics and scores[2]				
Building currently in use (4.1) Investment in historic building for operations can reduce nonhistoric building's use (2.8) Building has no current use but potential use in next 5 years (2.1) Building has no current use nor potential use in next 5 years (1.1)	Building currently in use (1.5) Expressed potential to use building (1.0) No expressed potential to use building (0.25)	Building open to public with high visitation (4.9) Building open to public with moderate visitation (3.9) Building open to public with low visitation (3.0) Building closed to public but likely to open in the next 5 years (2.1) Building closed to public and unlikely to open in the next 5 years (1.0)	Primary themes interpreted currently or in the next 5 years (3.2) Secondary themes interpreted currently or in the next 5 years (2.1) No current nor potential link to interpretive plan in next 5 years (1.1)	Building has potential to yield new scientific information (1.0) Building's new scientific information is not determined yet (0.5)
Weight[3]				
0.17	0.12	0.17	0.26	0.28

[1]Long-Range Interpretive Plans are available at https://www.nps.gov/subjects/hfc/interpretive-planning.htm.

[2]Scores were derived using an elicitation of National Park Service (NPS) and State Historic Preservation Office (SHPO) staff and reflect the mean value calculated for each metric from the elicitation.

[3]Weights were derived using an elicitation of NPS and SHPO staff and reflect the mean value calculated for each metric from the elicitation. Historical significance's weight is 0.79, whereas use potential's weight is 0.29. This indicates that historical significance is nearly three times as important as use potential.

Table 1.3. Use potential's attributes and metrics with scores including weights among the attributes. Exposure's subattributes and corresponding data sources.

Exposure's subattributes				
Flooding	**Storm surge**	**Sea level rise**	**Erosion and coastal proximity**	**Historical flooding**
Data source[1]				
Federal Emergency Management Agency Flood Maps (primary) Light detection and ranging digital elevation model or other elevation model	National Park Service-specific Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model results (primary) Light detection and ranging digital elevation model or other elevation model	National Park Service-specific sea level rise modeling (primary) Light detection and ranging digital elevation model or other elevation model	State or U.S. Geological Survey erosion rate buffers (primary) Shoreline proximity buffers	Park questionnaire (primary) Storm imagery or reconnaissance

[1]Methods described in Peek and others (2017).

Table 1.4. Sensitivity's subattributes and corresponding data sources.

Sensitivity's subattributes			
Flood damage potential (elevated)	**Storm resistance (condition)**	**Historical damage**	**Protective engineering**
Data source[1]			
Park questionnaire (primary) Direct measurements of threshold elevation	Park questionnaire (primary) Facility Management Software System database	Park questionnaire (primary) Discussion with park staf	Park questionnaire (primary) Field and aerial imagery analysis Western Carolina University Engineering Inventory

[1]Methods described in Peek and others (2017).

Table 1.5. Vulnerability's metrics and scores.

Score level (ranging from 2 to 8)	Vulnerability's metrics: Binned exposure attribute score (ranging from 1 to 4)	Vulnerability's metrics: Binned sensitivity attribute score (ranging from 1 to 4)	Vulnerability score[1]	Binned vulnerability score (ranging from 1 to 4)
High	4	4	≥7	4
Moderate	3	3	6	3
Low	2	2	4 to 5	2
Minimal	1	1	<4	1

[1]Vulnerability score = binned exposure score + binned sensitivity score (Peek and others, 2017).

Table 1.6. Optimal Preservation Model adaptation actions and model dynamics.

Action[1]	Definition	Model dynamics			
		Depreciation of building condition[2]	Improvement in building condition[3]	Loss of historic integrity[4]	Reduced vulnerability
No action	This option allows managers to repurpose annual maintenance from one building to another to "capture" enough money in any given year to apply a costly adaptation action to another building.	Low (8-percent annual loss)—Applied to buildings in "good" condition (List of Classified Structures [LCS] condition class score of 3). Medium (17-percent annual loss)—Applied to buildings in "fair" condition (LCS score of 2). High (25-percent annual loss)—Applied to buildings in "poor" condition (LCS score of 1).	No change (apply annual depreciation rate based on current condition)	5-percent loss in integrity (reduction in overall significance score at time of action).	No change.
Annual maintenance	Regular, annual maintenance that is supposed to keep buildings in good condition (base funded operations; inspections, corrective maintenance, and preventative maintenance). Note: values are lower corrective maintenance costs than for core and shell preservation because they reflect the bare minimum or maintenance of the status quo through application of small fixes.	Low (6-percent annual loss)—Applied to buildings in "good" condition (LCS score of 3). Medium (10-percent annual loss)—Applied to buildings in "fair" condition (LCS score of 2). High (15-percent annual loss)—Applied to buildings in "poor" condition (LCS score of 1).	No change (apply annual depreciation rate based on current condition).	0 percent	No change.

Table 1.6. Optimal Preservation Model adaptation actions and model dynamics.—Continued

Action[1]	Definition	Model dynamics			
		Depreciation of building condition[2]	Improvement in building condition[3]	Loss of historic integrity[4]	Reduced vulnerability
Core and shell preservation—historic materials	Maintenance of historic character of the building and its historic materials (that is, similar as possible to the materials used in the original construction), which includes annual maintenance (inspection, full corrective maintenance, and preventive maintenance) and nonannual maintenance to bring to standard (cyclic maintenance and recurring maintenance, also referred to as deferred maintenance). This action also included costs affiliated with fully (extensively) documenting the resource in its new condition (conditions report).	0 percent	Building changes to "good" condition class.	0 percent	No change.
Core and shell preservation—resilient materials	Maintenance using high quality, innovative, and functional materials (metal roofing and fiber cement siding); and additional renovations to improve the physical resiliency of the building (installing hurricane clips, stainless-steel nails, and window clips). This action also included costs affiliated with fully (extensively) documenting the resource in its new condition (conditions report), as well as minimal interpretation (for example, one panel sign that addresses adapting to climate change).	0 percent	Building changes to "good" condition class.	31-percent loss in integrity (reduction in overall significance score at time of action).	No change.
Elevate	This action consists of (1) bringing the building to standard (core and shell preservation—historic materials) and (2) raising the minimum floor elevation to reduce the likelihood of structural damage from storm-related flooding, sea level rise, or both. This action also included costs affiliated with fully (extensively) documenting the resource in its new condition (historic structure report), as well as minimal interpretation (for example, one panel sign that addresses adapting to climate change).	0 percent	Building changes to "good" condition class.	43-percent loss in integrity (reduction in overall significance score at time of action, assuming historic materials used in preservation).	Sensitivity changed to "low" (1).

Table 1.6. Optimal Preservation Model adaptation actions and model dynamics.—Continued

Action[1]	Definition	Model dynamics			
		Depreciation of building condition[2]	Improvement in building condition[3]	Loss of historic integrity[4]	Reduced vulnerability
Relocate	This action consists of (1) bringing the building to standard (core and shell preservation—historic materials) and (2) moving the building to a less vulnerable location (within the historic district) to reduce the likelihood of structural damage from storm-related flooding, sea level rise, or both. This action also included costs affiliated with fully (extensively) documenting the resource in its new location (conditions report), as well as extensive interpretation (for example, multiple panel signs that address adapting to climate change).	0 percent	Building changes to "good" condition class.	30-percent loss in integrity (reduction in overall significance score at time of action, assuming historic materials used in preservation).	Sensitivity changed to "low" (1). Exposure changed to "low" (1).
Elevate and relocate	This action consists of (1) bringing the building to standard (core and shell preservation—historic materials), (2) moving the building to a less vulnerable location (within the historic district), and (3) raising the minimum floor elevation to reduce the likelihood of structural damage from storm-related flooding, sea level rise, or both. This action also included costs affiliated with fully (extensively) documenting the resource in its new condition (conditions report), as well as extensive interpretation (for example, multiple panel signs that address adapting to climate change).	0 percent	Building changes to "good" condition class.	61-percent loss in integrity (reduction in overall significance score at time of action, assuming historic materials used in preservation).	Sensitivity changed to "low" (1). Exposure changed to "low" (1).

Table 1.6. Optimal Preservation Model adaptation actions and model dynamics.—Continued

Action[1]	Definition	Model dynamics			
		Depreciation of building condition[2]	Improvement in building condition[3]	Loss of historic integrity[4]	Reduced vulnerability
Document and monitor	This action includes costs associated with fully (extensively) documenting the resource (historic structures report) and erecting a 6-foot chain-link fence around a building and monitoring the condition. The fencing reduces the potential for human injury as there is potential for the building to deteriorate by the natural elements. This action also includes costs affiliated with extensive interpretation (for example, multiple panel signs that address adapting to climate change).	Low (4-percent annual loss)—Applied to buildings in "good" condition (LCS score of 3). Medium (5-percent annual loss)—Applied to buildings in "fair" condition (LCS score of 2). High (6-percent annual loss)—Applied to buildings in "poor" condition (LCS score of 1).	No change (apply annual depreciation rate based on current condition).	5-percent loss in integrity applied annually from year of decision forward.	No change.
Active removal	This action consists of physically removing the building from the historic district (debris and hazard demolition) and disposing the materials according to Federal guidelines (debris and hazard disposal). This action also included costs affiliated extensive interpretation (for example, multiple panel signs that address adapting to climate change).	N/A	N/A; condition score set to 0.	90-percent permanent loss in integrity (building removed from landscape; extensive interpretation to "tell the story;" retains 10 percent integrity from interpretive panels).	Sensitivity removed (0). Exposure removed (0).

[1]Any building that does not have a Historic Structure Report (HSR) also includes associated costs to develop one for all actions except "no action" and "annual maintenance."

[2]An estimate of how much a building's condition would annually decay over a 30-year planning horizon. Rates determined through consultation with National Park Service (NPS) personnel. The rate is applied to only the "condition of the building" attribute but affects the building's historical significance and, thus, the building's resource value. N/A is not applicable.

[3]An estimate of how much a building's condition would improve in the year an adaptation action is applied. In the year an action is applied, the model would not include the depreciation rate; however, in the subsequent years (if no action is applied to that building), the decay rate would be reintroduced to the model. Rates determined through consultation with NPS personnel. The rate is applied to only the "condition of the building" attribute but affects the building's historical significance and, thus, the building's resource value. N/A is not applicable.

[4]An estimate of how much historical integrity would be lost by applying specific actions, with the assumption that any action would change the historic fabric of the building and, consequently, decrease its integrity. Rates determined through consultation with NPS personnel, then updated to reflect values that account for percentage of integrity loss to the seven criteria of integrity. This rate is applied to each of the historical significance attributes at the time of action, except for condition of the building (because actions either improve or depreciate the condition of the building), affecting both the building's historical significance score and the building's resource value.

Table 1.7. Adaptation actions and maintenance costs for each of the 17 historic buildings.

Historic building	Maintenance cost[1] by adaptation action						
	Active removal	Core and shell—Historic materials	Core and shell—Resilient materials	Relocate the building	Elevate the building	Document and monitor	Annual maintenance
Cape Lookout Village							
Lighthouse	$10,050,000.00	$1,018,000.00	$13,126,000.00	N/A	$10,626,000.00	$74,000.00	$5,400.00
Keepers Quarters	$112,500.00	$125,000.00	$1,086,000.00	N/A	$311,000.00	$42,500.00	$6,000.00
1907 Keepers Quarters	$95,000.00	$78,000.00	$656,000.00	$435,000.00	$199,000.00	$37,000.00	$4,500.00
Live-Saving Station	$122,000.00	$154,000.00	$796,000.00	$450,000.00	$264,000.00	$40,000.00	$7,800.00
Galley (Coast Guard)	$70,000.00	$25,000.00	$271,000.00	N/A	$81,000.00	$22,000.00	$3,500.00
O'Boyle Bryant House	$105,000.00	$65,500.00	$301,000.00	$166,000.00	$127,000.00	$25,000.00	$3,400.00
Gordan Willis House	$95,000.00	$53,000.00	$251,000.00	$145,000.00	$111,000.00	$25,000.00	$2,400.00
Jetty Workers House 1	$95,000.00	$91,000.00	$251,000.00	$183,000.00	$149,000.00	$25,000.00	$2,400.00
Jetty Workers House 2	$95,000.00	$158,000.00	$251,000.00	$250,000.00	$216,000.00	$25,000.00	$2,400.00
Portsmouth Village							
Church	$234,000.00	$95,000.00	$1,111,000.00	$2,819,000.00	$306,000.00	$38,000.00	$6,000.00
School	$94,500.00	$31,000.00	$397,500.00	$256,000.00	$98,500.00	$33,500.00	$2,700.00
Post Office	$84,500.00	$34,000.00	$374,500.00	$228,000.00	$95,500.00	$33,500.00	$2,400.00
Lifesaving Station	$320,000.00	$76,000.00	$1,611,000.00	$952,000.00	$273,000.00	$58,000.00	$7,200.00
Summer Kitchen (Live-Saving Station)	$70,000.00	$23,000.00	$165,000.00	$170,000.00	$86,000.00	$24,000.00	$2,400.00
Washington-Roberts House	$125,500.00	$67,000.00	$524,500.00	$302,000.00	$144,500.00	$33,500.00	$3,600.00
Frank Gaskill House	$75,000.00	$36,000.00	$321,000.00	$188,000.00	$104,000.00	$27,000.00	$2,400.00
Henry Pigott House	$82,500.00	$63,000.00	$366,000.00	$295,500.00	$133,000.00	$33,500.00	$3,300.00

[1]Maintenance costs were estimated by Cape Lookout National Seashore cultural resource management personnel. The estimated costs are likely conservative (actual costs would likely be greater due to transportation and lodging requirements); however, the costs were estimated in a consistently across building types (that is, the estimates are reliable). The individual charged with developing the cost estimates first grouped buildings based on type of structure, then consulted National Park Service databases (Facility Management Software System, Project Management Information System, Asset Management Reporting System, and the "Optimizer") and used prior knowledge to estimate costs by building, type, location (that is, districts have different distances to Park Headquarters) and square footage. The cost estimation task for the 17 buildings took roughly 20 hours to complete.

Appendix 2. Value of Condition, Remaining Significance, and Use Potential for 17 Buildings Among Different Scenarios

In this appendix, the relative value for each historic building is presented by year for each scenario, with the relative value displayed in terms of the building's condition, remaining significance, and use potential. In the Optimal Preservation (OptiPres) Model, we separate the historical significance attribute "condition" in this presentation because it is directly altered by the application of different actions. Condition has a weight of 0.17 within the historical significance score. The remaining significance includes three other components of historical significance: association to fundamental purpose, character, and national register (total weight 0.83 of historical significance). Historical significance accounts for 0.71 of relative value, and use potential accounts for 0.21 of relative value. The model dynamics for changes in conditions, remaining significance, and use potential by different adaptation actions are described in appendix 1, table 1.6.

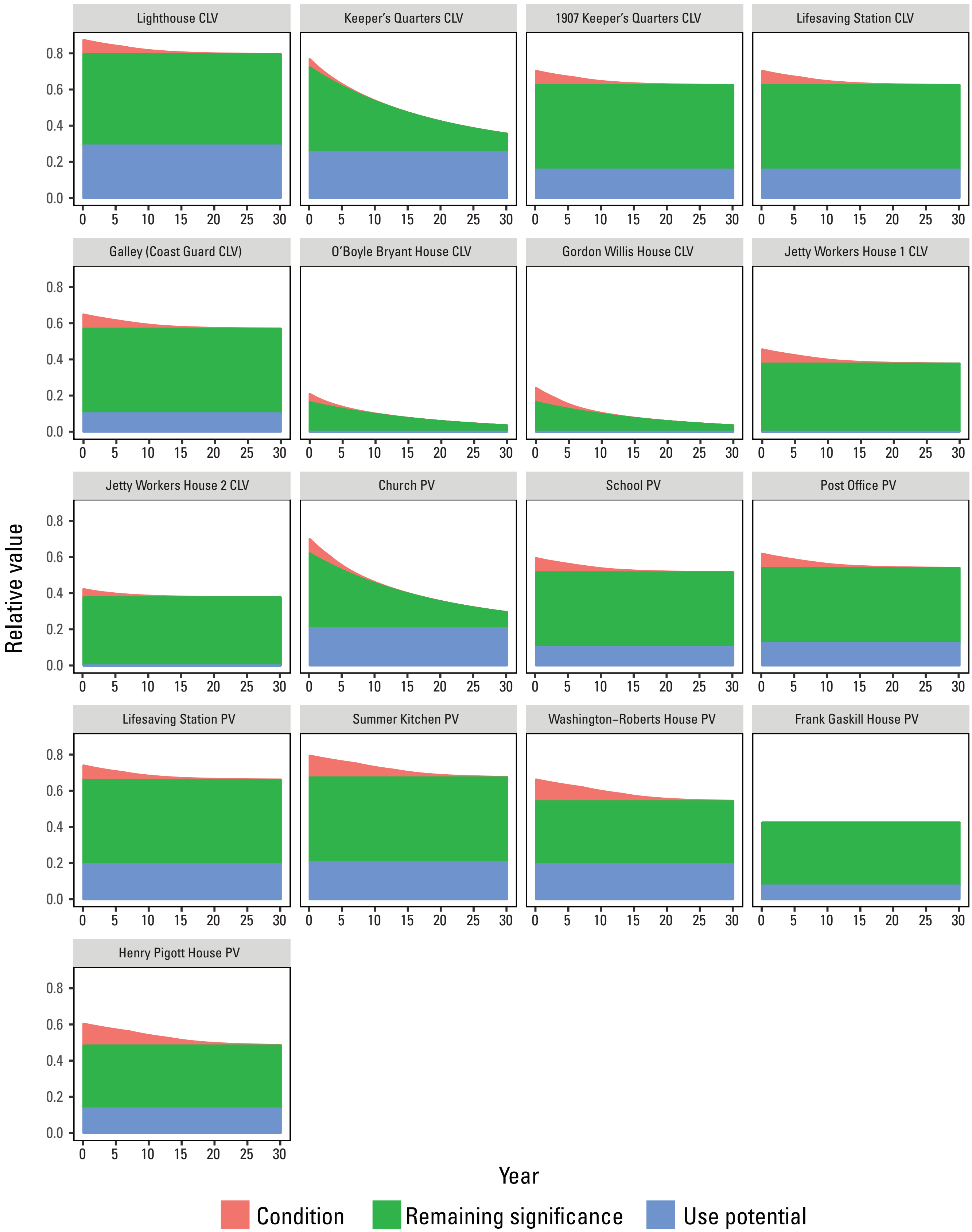

Figure 2.1. Components of resource value under annual allocation of $50,000. Relative value is the weighted scores of utility for each building. [CLV, Cape Lookout Village; PV, Portsmouth Village]

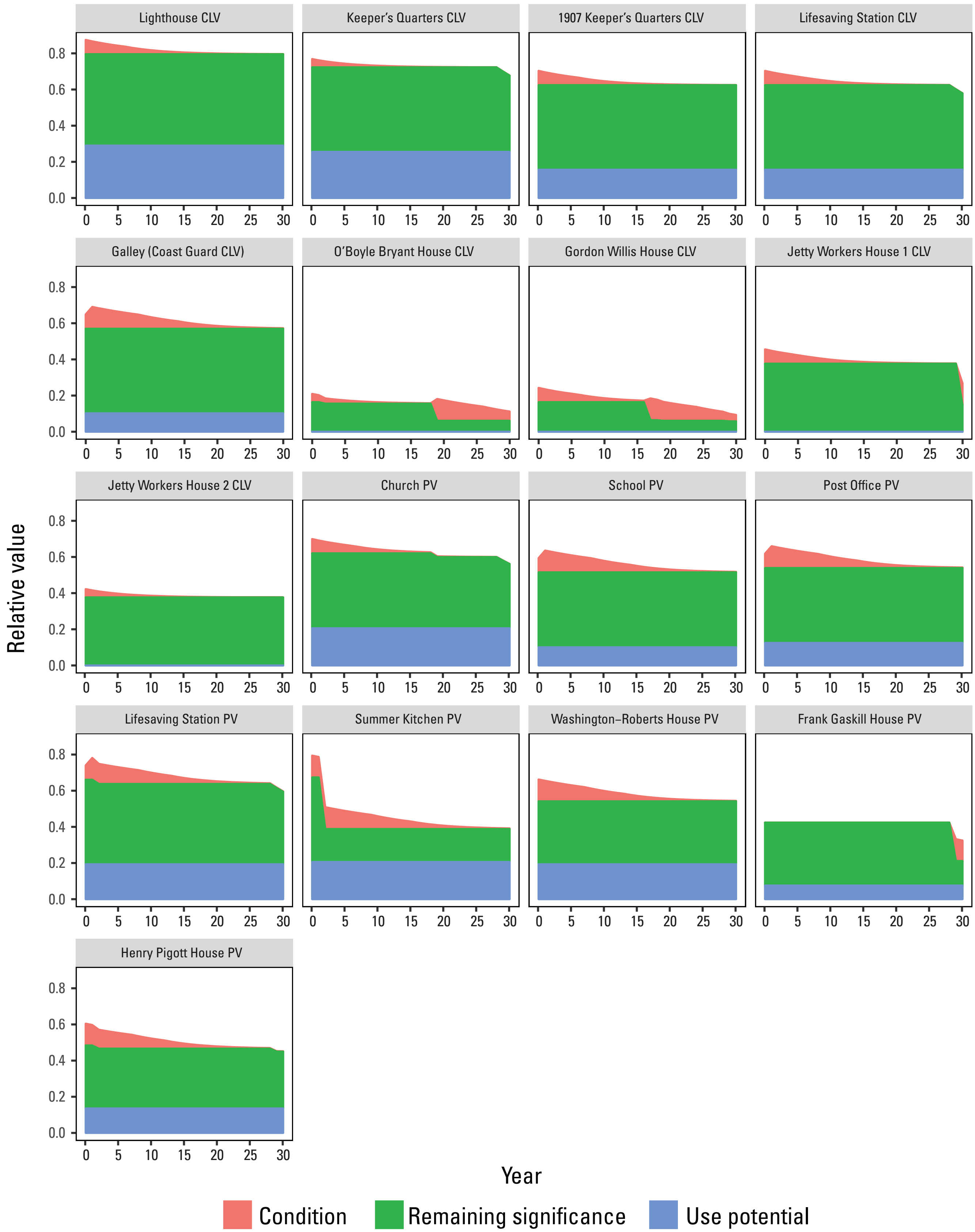

Figure 2.2. Components of resource value under annual allocation of $222,000. Relative value is the weighted scores of utility for each building. [CLV, Cape Lookout Village; PV, Portsmouth Village]

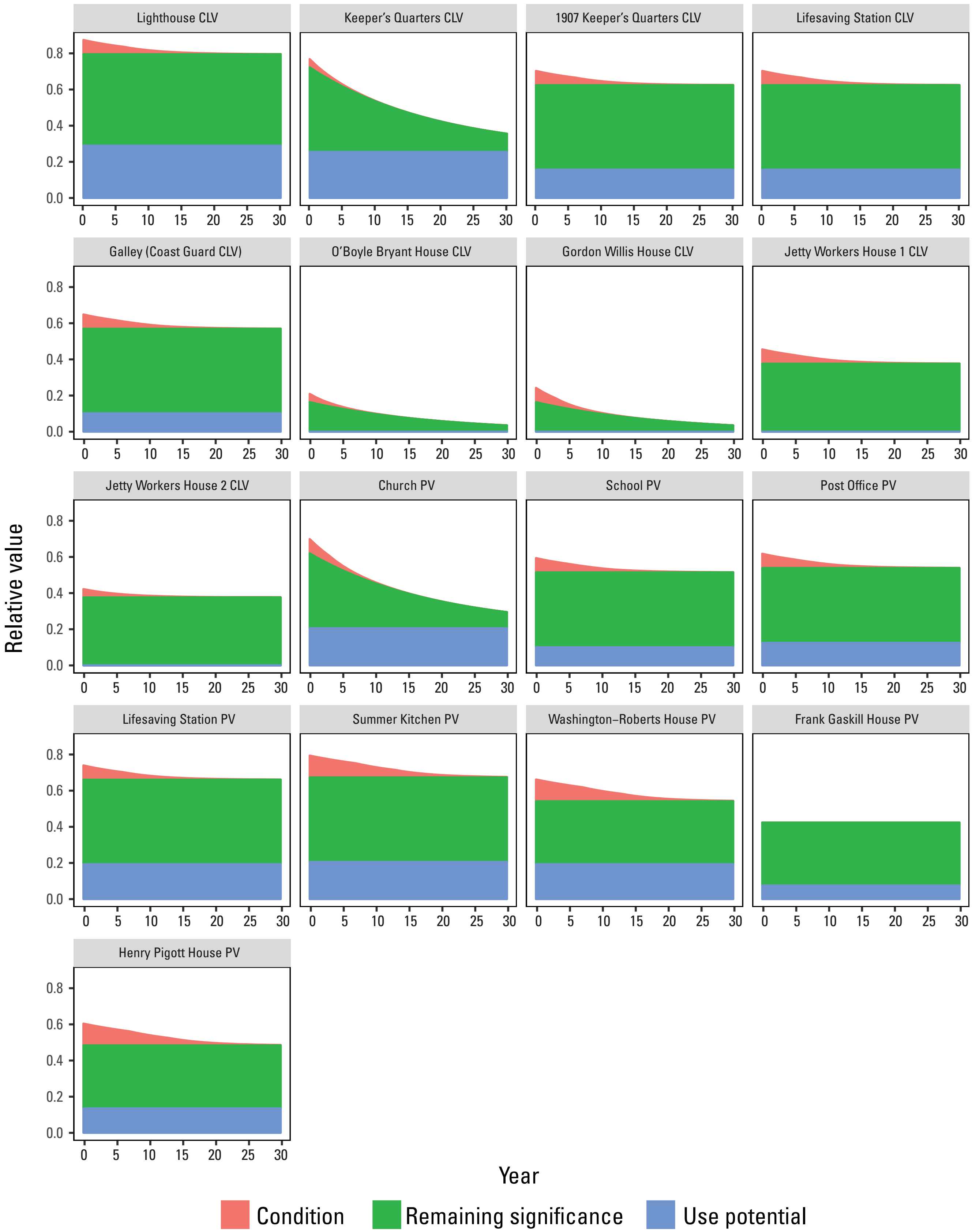

Figure 2.3. Components of resource value under annual allocation of $500,000. Relative value is the weighted scores of utility for each building. [CLV, Cape Lookout Village; PV, Portsmouth Village]

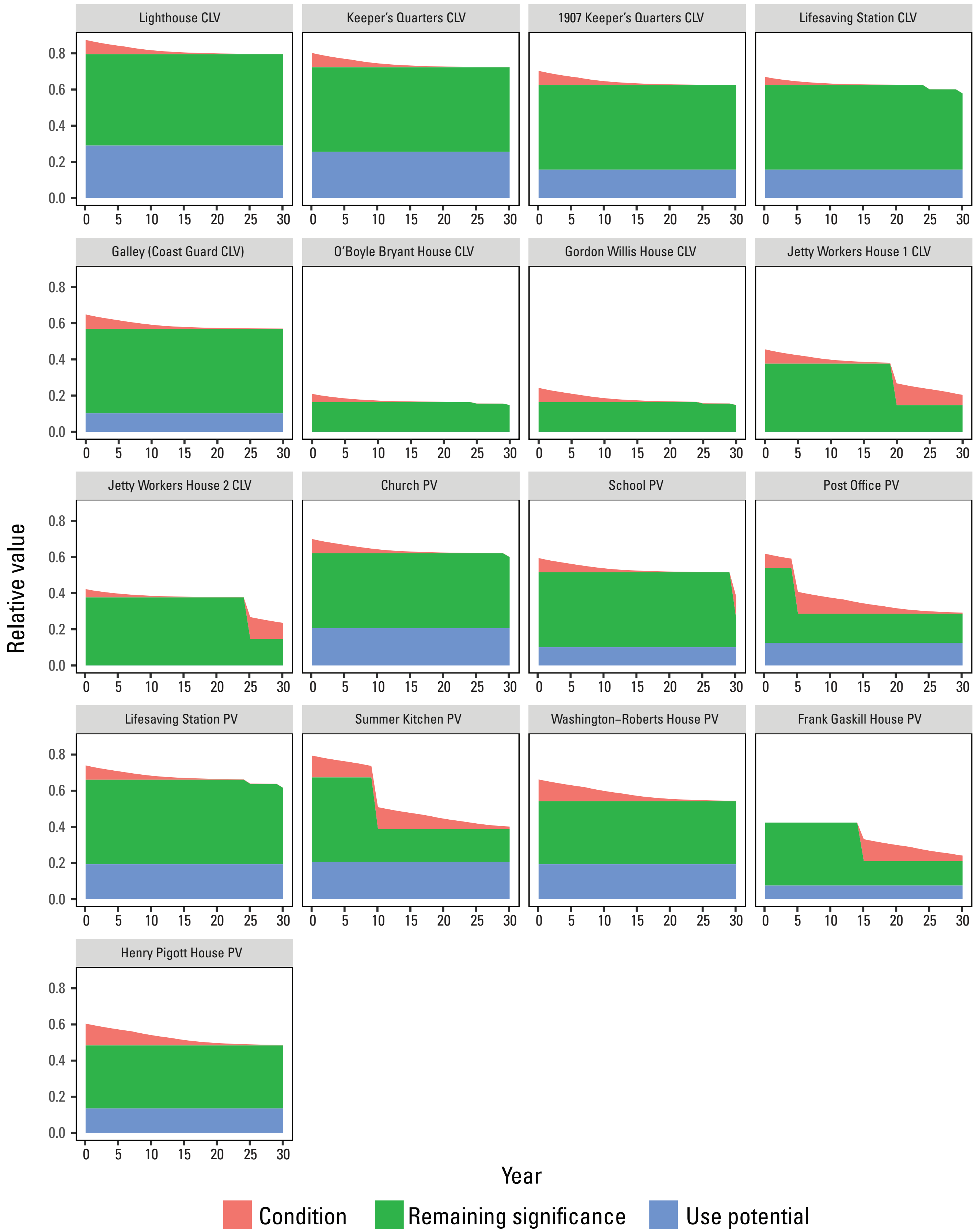

Figure 2.4. Components of resource value under annual allocation of $70,000 with an additional $225,000 every 5 years. Relative value is the weighted scores of utility for each building. [CLV, Cape Lookout Village; PV, Portsmouth Village]

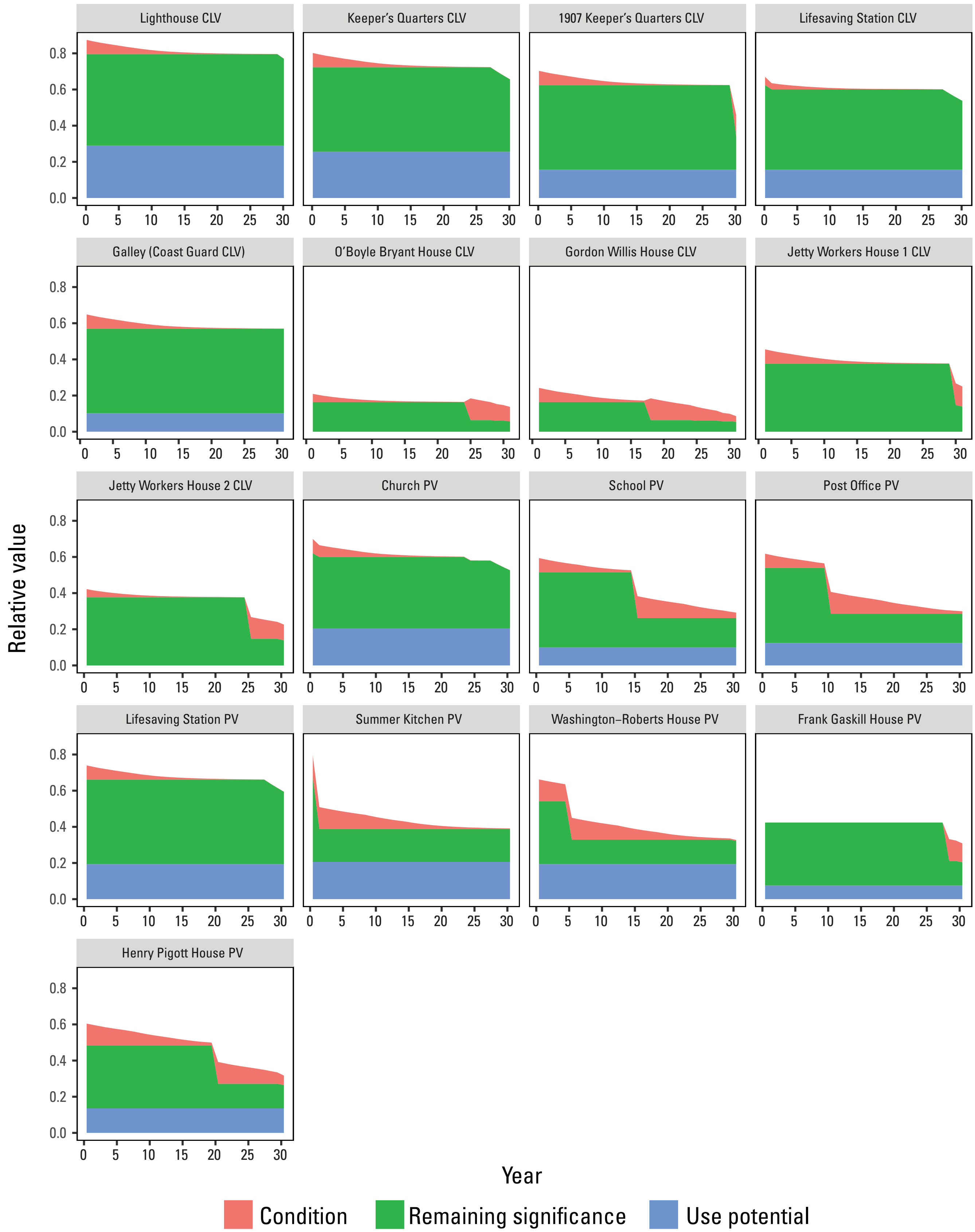

Figure 2.5. Components of resource value under annual allocation of $222,000 with an additional $225,000 every 5 years. Relative value is the weighted scores of utility for each building. [CLV, Cape Lookout Village; PV, Portsmouth Village]

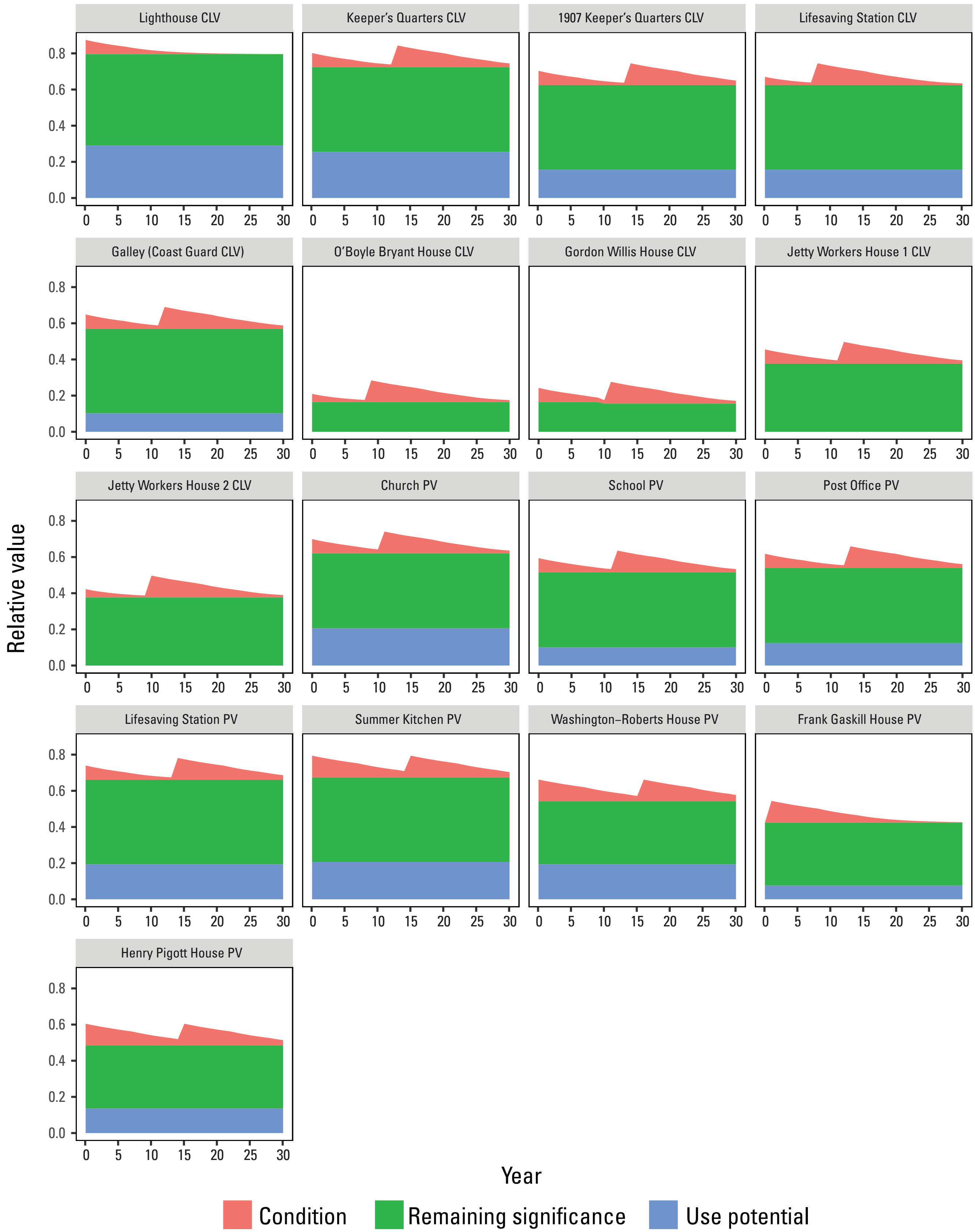

Figure 2.6. Components of resource value under annual allocation of $222,000 assuming no vulnerability. Relative value is the weighted scores of utility for each building. [CLV, Cape Lookout Village; PV, Portsmouth Village]

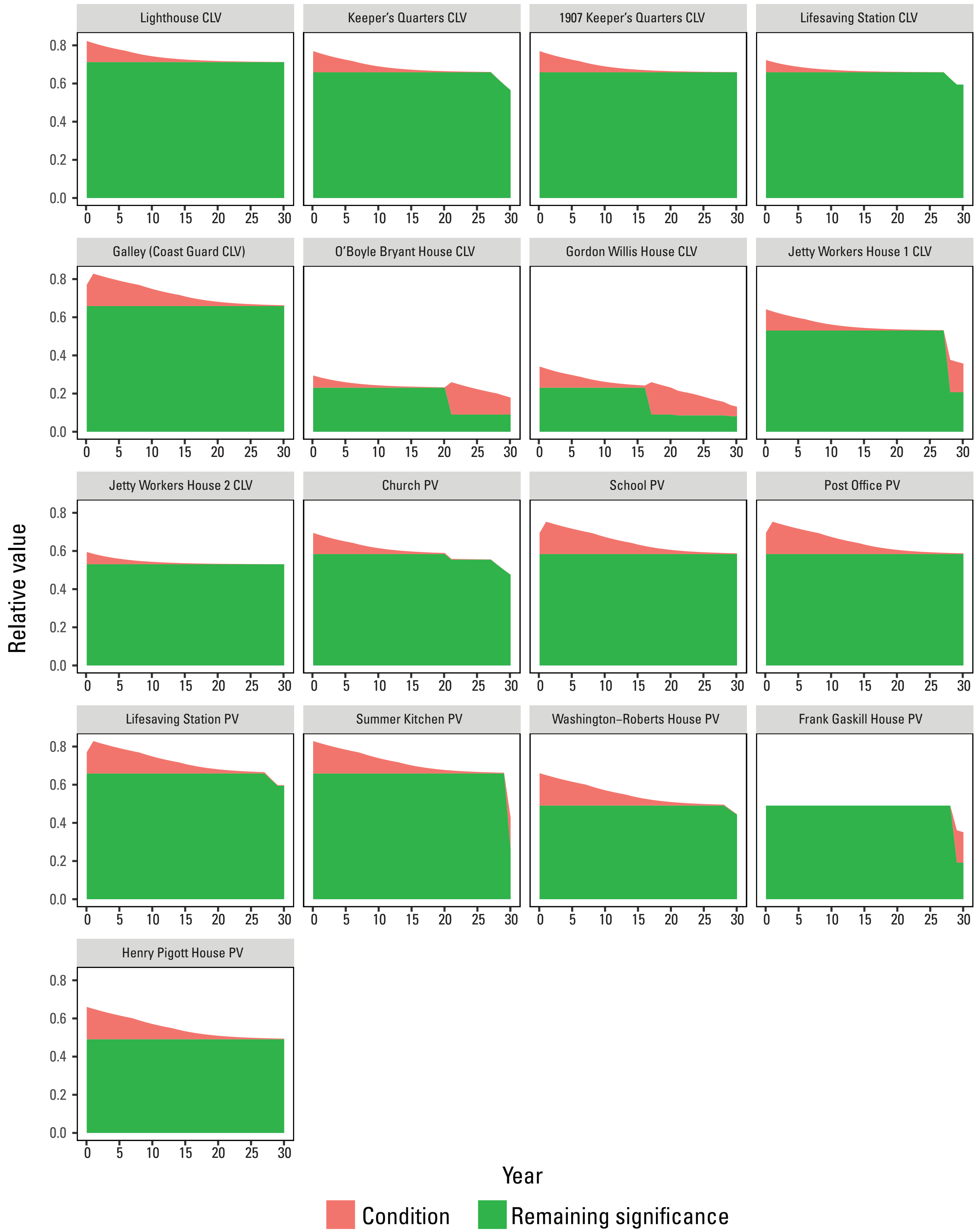

Figure 2.7. Components of resource value under annual allocation of $222,000 assuming no use potential. Relative value is the weighted scores of utility for each building. [CLV, Cape Lookout Village; PV, Portsmouth Village]

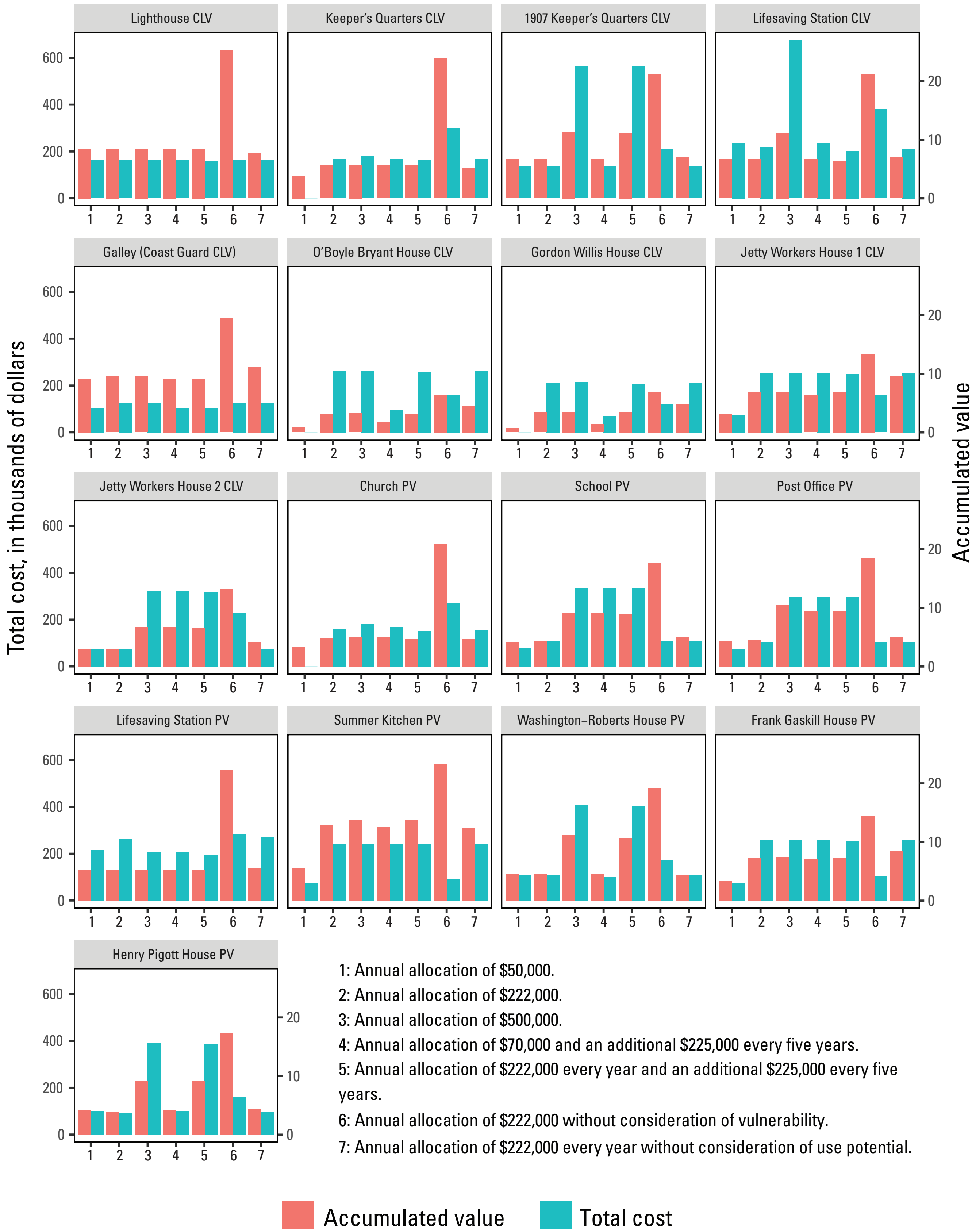

Figure 2.8. Accumulated values and total costs of individual buildings predicted under each scenario. X-axis identifies the scenario. [CLV, Cape Lookout Village; PV, Portsmouth Village]

Appendix 3. Computer Code for Optimal Preservation Model

Two documents of computer code for the Optimal Preservation Model are available for download at https://doi.org/10.3133/ofr20181180.

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