**Supplementary materials**

***S1. Optimal budget allocation using single-objective stochastic optimization***

We maximize the total expected benefit of carbon storage by allocating a limited conservation budget to acquire eligible parcels as protected areas from the five selected clusters within Knox County, TN. The stochastic optimization, with the objective of maximizing the total expected benefit of carbon storage was shown in eq. (1) of the “*Step 4: Identify Spatially Optimal Budget Allocation*”in “2. Method and data” section with land availability and budgetary constraints imposed in eqns. (3)-(5).

***S2. Optimal budget allocation using deterministic optimization***

The deterministic optimization approach is framed in two ways: (*a*) aggregating all the future economic growth scenarios into a single scenario by taking the expected value of the uncertain parameters across the scenarios and solving the corresponding deterministic model (referred to as “expected-value approach”), and (*b*) three separate deterministic optimizations, one for each of the three economic growth scenarios (referred to as “wait-and-see approaches”). The expected-value approach uses the expected value of the uncertain future economic growth scenarios to produce an optimal solution. Alternatively, the concept of wait-and-see in deterministic optimization is equivalent to having perfect information about the future as if one could wait until the uncertain economic growth scenarios were revealed before making investment decisions. Regardless of the way each deterministic optimization approach is framed, the objective is to maximize the total benefit of carbon storage from the five clusters by acquiring eligible parcels as protected areas, constrained by the available land and conservation budget. The analytical framework is identical to the one described for single-objective stochastic optimization in section “S2”, except the scenarios and associated probabilities now have deterministic values corresponding to a single scenario.

**Table S1.** Summary of results from the single-objective stochastic optimization model for spatially optimal budget allocations for protected area acquisition to store carbon on the lands in the five clusters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Cluster 1** | **Cluster 2** | **Cluster 3** | **Cluster 4** | **Cluster 5** |
| Area (ha) | 1,172 | 2,830 | 2,577 | - | 1,741 |
| Carbon (tonne) | 277,310 | 596,529 | 307,866 | - | 317,133 |
| Cost ($) | 9,329,156 | 18,944,206 | 19,397,100 | - | 13,689,896 |
| Benefit ($) | 168,743,226 | 362,985,704 | 186,137,431 | - | 192,962,662 |
| ROI ($) | 18.09 | 19.16 | 9.60 | - | 14.10 |

Note: The numbers are the anticipated probability-weighted values *ex-post* optimization. ROI refers to return-on-investment.

**Table S2.** Scenario-dependent optimal benefits, acquisition costs, and ROIs for stochastic and deterministic (i.e., expected-value and wait-and-see) approaches

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Approach** | | | **Scenario** | **Benefit ($)** | **Cost ($)** | **ROI ($/$)** | **E(Benefit) ($)** | **E(Cost) ($)** | **E(ROI) ($/$)** |
| ***Stochastic*** | | | Strong | 885,580,497 | 64,455,219 | 13.74 | **910,829,022** | **61,360,358** | **14.84** |
| Weak | 876,478,183 | 52,312,061 | 16.75 |
| Moderate | 940,628,704 | 64,337,076 | 14.62 |
| ***Deterministic*** | *Wait-and-see* | *Strong* | Strong | **860,186,271** | **61,360,358** | **14.02** | 817,845,139 | 51,880,962 | 15.76 |
| Weak | 766,095,702 | 42,401,959 | 18.07 |
| Moderate | 822,549,292 | 51,880,765 | 15.85 |
| *Weak* | Strong | 1,035,304,128 | 90,913,859 | 11.39 | 984,361,254 | 76,138,173 | 12.93 |
| Weak | **922,093,569** | **61,360,358** | **15.03** |
| Moderate | 990,023,659 | 76,139,239 | 13.00 |
| *Moderate* | Strong | 954,238,389 | 72,799,526 | 13.11 | 907,234,911 | 61,360,930 | 14.79 |
| Weak | 849,796,791 | 49,923,478 | 17.02 |
| Moderate | **912,452,232** | **61,360,358** | **14.87** |
| *Expected-value* | |  | | | | **907,233,893** | **61,360,358** | **14.79** |

Note: The wait-and-see approach uses parameters specific to a particular scenario, anticipating *ex-ante* optimization. The expected-value approach uses parameters that are uniform probability-weighted values, *ex-ante* optimization. The scenario-specific numbers corresponding to the wait-and-see approach reflect what would have happened under different scenarios if the optimal decisions were based on anticipation of a particular scenario. E is the expectation operator. ROI refers to return-on-investment.

**Table S3.** Summary of results from the single-objective stochastic optimization model for spatially optimal budget allocations for protected area acquisition to store carbon on the lands in the five clusters as a sensitivity test using TN per capita GDP to approximate benefits

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Cluster 1** | **Cluster 2** | **Cluster 3** | **Cluster 4** | **Cluster 5** |
| Area (ha) | 1,172 | 2,830 | 2,577 | - | 1,741 |
| Carbon (tonne) | 277,310 | 596,529 | 307,866 | - | 317,133 |
| Cost ($) | 9,329,156 | 18,944,206 | 19,397,100 | - | 13,689,896 |
| Benefit ($) | 168,951,193 | 363,433,444 | 186,549,115 | - | 193,202,493 |
| ROI ($) | 18.11 | 19.18 | 9.62 | - | 14.11 |

Note: The numbers are the anticipated probability-weighted values *ex-post* optimization. ROI refers to return-on-investment.

**Table S4.** Scenario-dependent optimal benefits, acquisition costs, and ROIs for stochastic and deterministic (i.e., expected-value and wait-and-see) approaches as a sensitivity test using TN per capita GDP to approximate benefits

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Approach** | | | **Scenario** | **Benefit ($)** | **Cost ($)** | **ROI ($/$)** | **E(Benefit) ($)** | **E(Cost) ($)** | **E(ROI) ($/$)** |
| ***Stochastic*** | | | Strong | 880,045,619 | 64,455,219 | 13.65 | **912,136,245** | **61,360,358** | **14.87** |
| Weak | 887,241,950 | 52,312,061 | 16.96 |
| Moderate | 940,628,704 | 64,337,076 | 14.62 |
| ***Deterministic*** | *Wait-and-see* | *Strong* | Strong | **854,810,106** | **61,360,358** | **13.93** | 818,853,146 | 51,880,962 | 15.78 |
| Weak | 775,503,895 | 42,401,959 | 18.29 |
| Moderate | 822,549,292 | 51,880,765 | 15.85 |
| *Weak* | Strong | 1,028,833,477 | 90,913,859 | 11.32 | 985,574,580 | 76,138,173 | 12.94 |
| Weak | **933,417,525** | **61,360,358** | **15.21** |
| Moderate | 990,023,659 | 76,139,239 | 13.00 |
| *Moderate* | Strong | 948,274,399 | 72,799,526 | 13.03 | 908,352,939 | 61,360,930 | 14.80 |
| Weak | 860,232,892 | 49,923,478 | 17.23 |
| Moderate | **912,452,232** | **61,360,358** | **14.87** |
| *Expected-value* | |  | | | | **908,352,094** | **61,360,358** | **14.80** |

Note: The wait-and-see approach uses parameters specific to a particular scenario, anticipating *ex-ante* optimization. The expected-value approach uses parameters that are uniform probability-weighted values, *ex-ante* optimization. The scenario-specific numbers corresponding to the wait-and-see approach reflect what would have happened under different scenarios if the optimal decisions were based on anticipation of a particular scenario. E is the expectation operator. ROI refers to return-on-investment.