Natural Climate Solutions Portfolios

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ABSTRACT

Natural climate solutions (NCS) have the potential to achieve up to one-third of emission reductions, but uncertainties surrounding their effectiveness hinder their full realization. Here we employ modern portfolio theory to build NCS portfolios (NCSPs) including a variety of pathways listed in Griscom et al.[1]. The different pathways are treated as risky assets within a 'carbon mitigation market' with their returns and risks defined by global estimates of mitigation potential. Our aim is to maximize carbon sequestration while minimizing the risk of carbon loss, thus effectively navigating the 'efficient frontier', where the best trade-off between maximum carbon sequestration and risk occurs. Diversifying pathways leads to decreased risk and enhanced resilience, particularly when risks of carbon loss due to environmental stressors are spatially or temporally uncorrelated. The optimal NCSPs provide valuable insights into distributing investments and land within pathway categories (forests, agriculture and wetlands), intervention types (e.g., manage, protect, restore), cost-effectiveness, and geographical contexts. We hope these results help inform policymakers to reduce risk while pursuing ambitious carbon mitigation targets.

Introduction

Harnessing the potential of natural climate solutions (NCS) remains crucial for the goals of the Paris Agreement, given the disparity between our carbon reduction targets and actual mitigation actions. However, the promise of up to one-third emission reduction via NCS[1] is marred by greenwashing controversies and shrouded with uncertainty[2]. Global potential estimates are widely divergent due to different underlying assumptions and even the most conservative ones often do not consider the risk of carbon loss by e.g., pests, fires, anthropogenic factors and leakage[3–5]. NCS have gathered attention because of their cost-effectiveness, implementation readiness and co-benefits. Among the NCS options, the most cost-effective pathways include forest-related strategies, encompassing managed forests, reforestation, and avoided reforestation. Additionally, the protection and restoration of wetlands and peatlands prove to be highly cost-effective. Notably, on a global scale, preserving intact ecosystems is estimated to be twice as effective as restoration[2]. In the United States, a study by Fargione et al.[6] estimated an annual sequestration potential of 1.2 PgCO2eq, which is aligned with the global NCS assessment[1]. Limiting factors to NCS deployment are not only land availability and the competition for food production, but also urban development and carbon mitigation alternatives, like wind and solar farms. Their resilience is challenged by more frequent and intense disturbances, which cause forest dieback[2] and increased uncertainty in carbon-stock resilience[7]. Droughts, fires, biotic agents, hurricanes and other disturbances increasingly affect both forest and coastal ecosystems[8,9], calling for a rigorous assessment of climate- and human-driven permanence risks in mitigation scenarios, from the research level to the policy and implementation fronts.

Modern Portfolio Theory (MPT) offers an effective methodology for selecting a diverse ensemble of assets to maximize returns while minimizing risk. MPT revolutionized investment management by acknowledging that risk could be tempered through the strategic combination of assets with varying returns and introducing the idea that systematic selection of asset combinations could yield maximum returns with minimal risk. In recent years, MPT has transcended the financial domain, including environmental applications for biodiversity conservation[10–12], fisheries management[13–15], forestry[16,17], agriculture[18,19], and many others[20–25]. In natural systems, a highly diversified 'portfolio' of species (biodiversity) maximizes an ecosystem's fitness[15] and effectively dampens the impact of natural variability[26,27]. Balvanera et al.[28] provide a comprehensive overview of the relationship between biological diversity and the stability of ecosystem service provision. In an environmental management context, the portfolio weights represent proportions of land designated for various land- or water-use options, the optimization of which translates into more informed decisions regarding land use and allocation as well as crop selection[23,29–31]. Similarly to financial assets, diversification has the most benefit when considering land uses that present uncorrelated risks, as they yield the most significant benefits in terms of returns and risk reduction. For NCS of interest here the goal is containing the risk

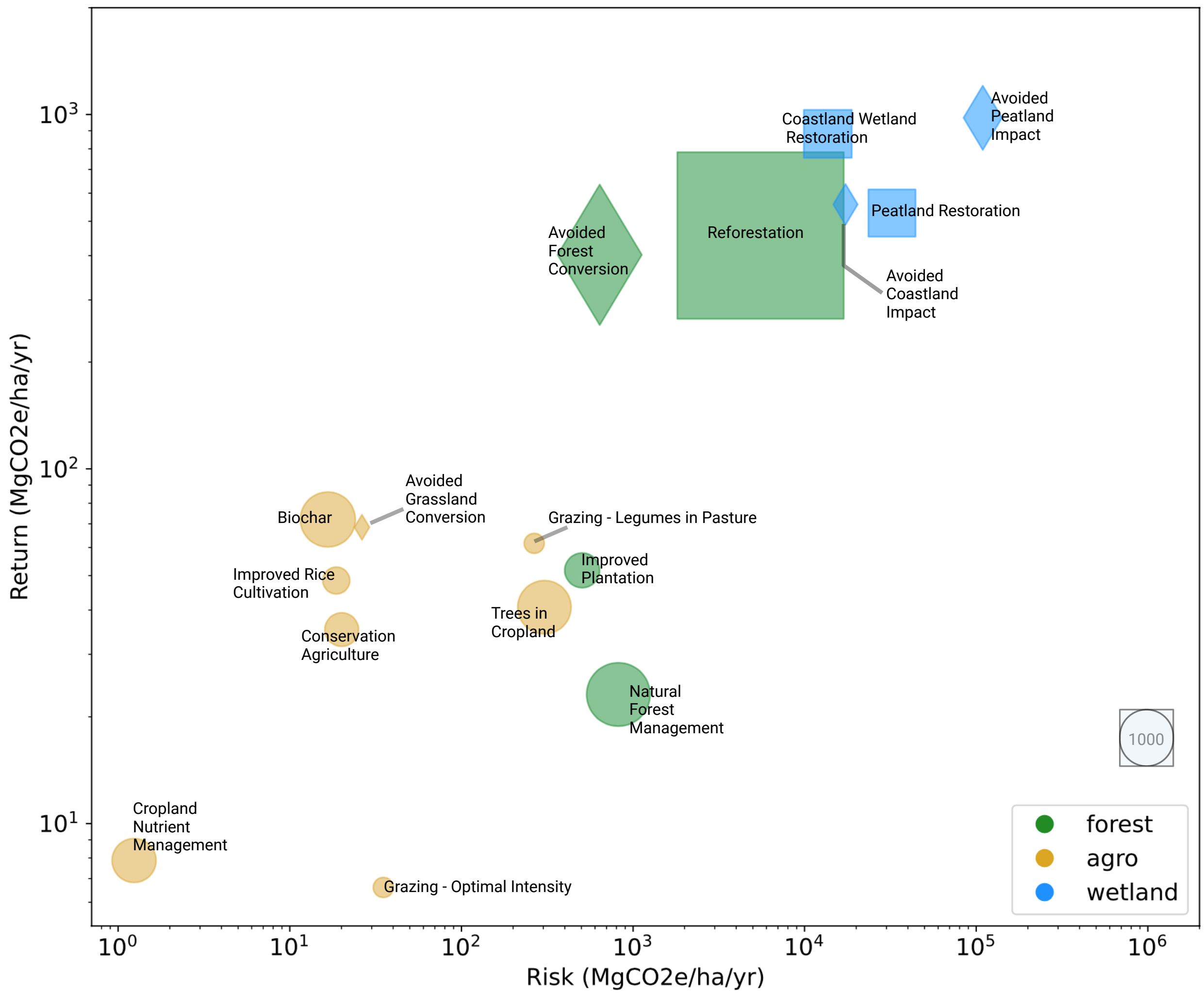

Figure 1. NCS pathways: mean return and associated risk of mitigation potentials. The size of each marker represents the global cumulative potential from Griscom et al.[1] in TgCO2e/yr. The marker color signals the cover type of each pathway: forest (green), agriculture (gold), wetland (blue). Marker shape signals the intervention category: protect (diamond), manage (circle), restore (square).

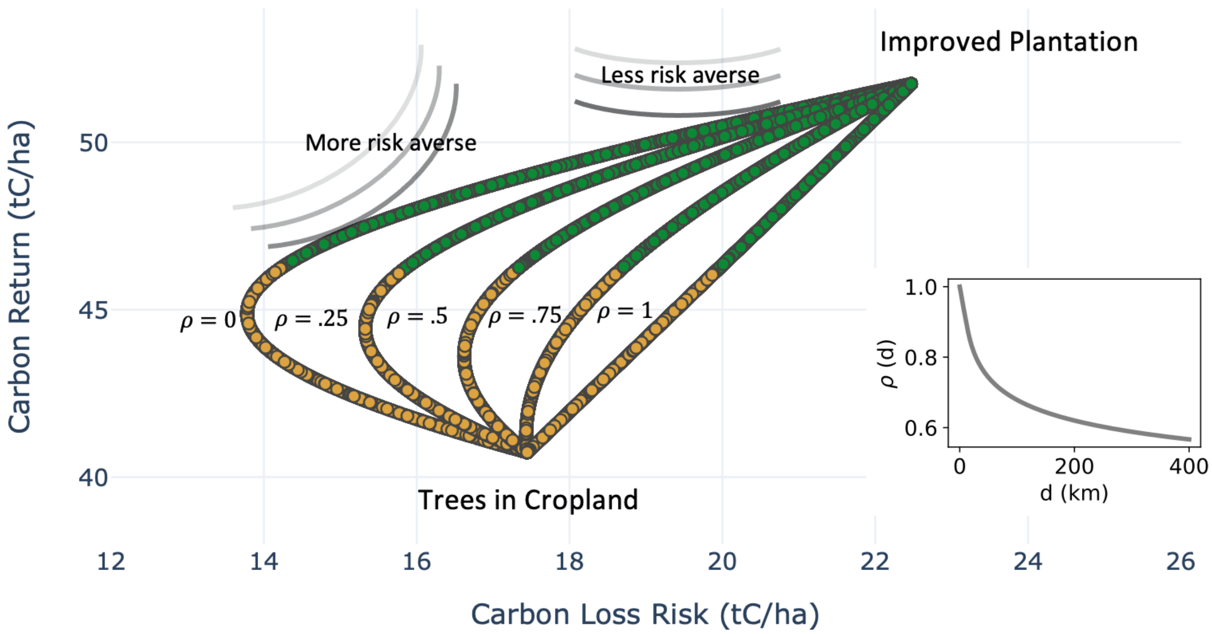

Figure 2. Carbon risk and return of two asset NCSP with varying correlation ρ. Each point represents a portfolio defined by a combination of weights between the two assets *Improved Plantation* and *Trees in Cropland* and indicated correlation coefficient ρ. Marker color represents a portfolio with >50% "forest" (green) or >50% "agro" (gold) cover type. Grey curves represent the indifference curves for "more risk averse" and "less risk averse" utility functions. Inset: spatial correlation function of rainfall with parameters taken from the Spatial Correlation Structure of Daily Rainfall analysis in Zorzetto & Marani[32].

of a global failure of NCS in order to make them more viable from a policy perspective. This logically leads to the question of how to construct optimal NCS portfolios (NCSPs) that maximize carbon sequestration, while minimizing the risk of carbon loss. Linking the financial asset portfolio theory to NCS modeling, our primary objective is to identify the optimal combination of NCS strategies, each characterized by distinct carbon 'returns' and associated risks.

To proceed in a concrete manner, we selected the NCS strategies included in the well-known work by Griscom et al.[1]. The specific mitigation potentials of such pathways are shown, along with their associated risks, in Figure 1 (see SI for details on each NCS strategy). Thus, our NCSP theory (NCSPT) leverages the concept of diversification to reduce the uncertainty surrounding future carbon benefits resulting from land policies and investments involving NCS. In that follows, we discuss how the weight distribution and the correlation among pathways shape the NCSP return and risk, what are the viable and preferred categories of intervention depending on the cost of implementation, and how diverse a portfolio needs to be to effectively reduce the risk. We proceed then by discussing how risk correlation can be reduced either by spatial distancing or by positive feedbacks that emerge by the colocation of NCS. We conclude with a discussion on the implications of our results for policymaking.

Results

Efficient Frontier for Carbon Return and Risk Tradeoff

The central outcome of the NCSPT is best illustrated with reference to the simple scenario involving only two assets, chosen from the cover categories: the 'Trees in Cropland' pathway and the 'Improved Plantation' pathway. This choice is based on the fact that both pathways can be implemented within the same geographical region. As is often the case, the asset associated with higher returns (here 'Improved Plantation') also carries a higher level of risk, implying greater uncertainty surrounding those returns. By combining these two risky assets, we establish a portfolio characterized by the weight assigned to each asset. Typically, these weights represent the allocation of an investor's wealth. In the

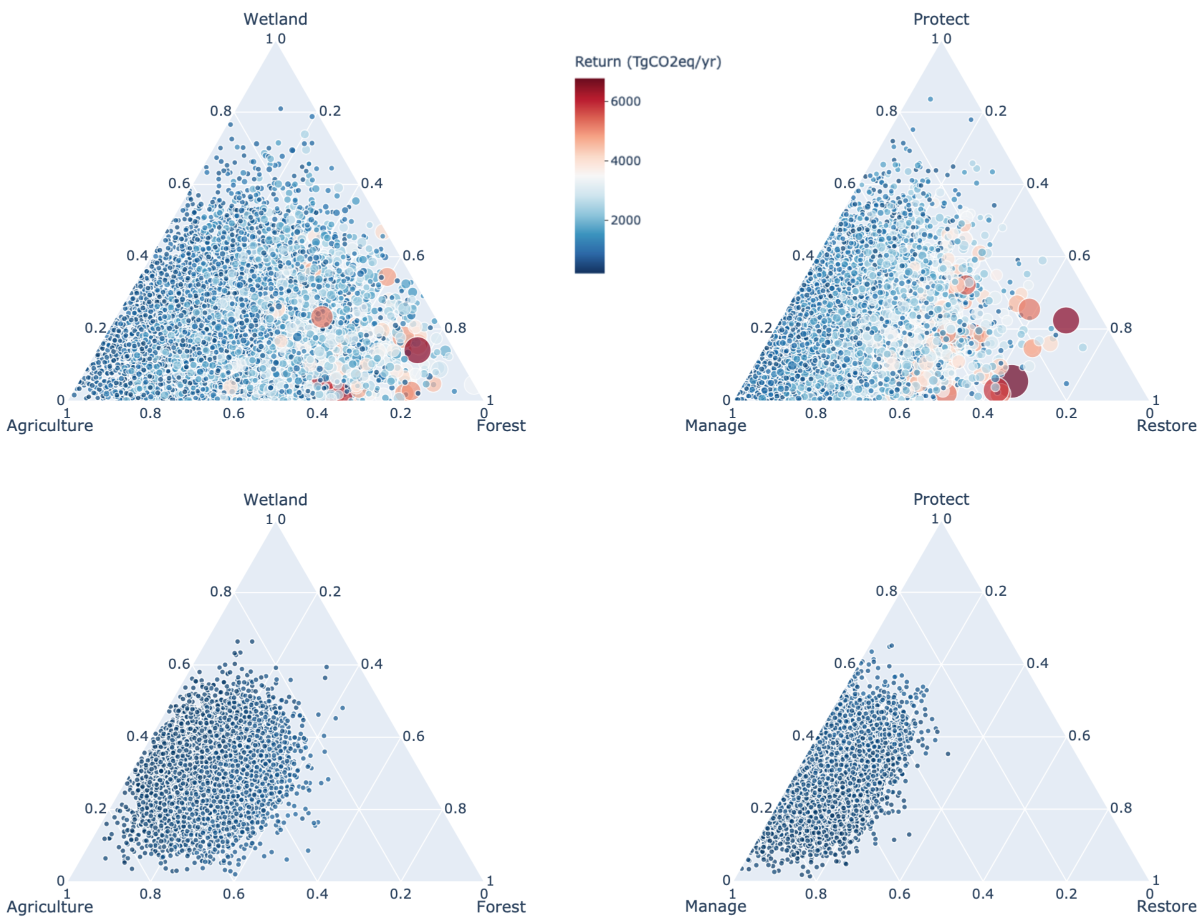

Figure 3. Multiple asset NCSP. Each marker represents a portfolio, the color grading being the portfolio return (TgCO2eq/ye) and the size being the portfolio risk. Correlation coefficient: $\rho = 0$. The cumulative weight of each cover type (left) or intervention type (right) categories define the position in the ternary plot. (Lower panels) Same but considering only cost-effective pathways.

context of NCS, these weights can be interpreted as the proportion of available land for NCS projects.

The return of a portfolio is calculated as the weighted sum of the returns of the individual assets within it, while its risk is determined by the weighted sum of the variances of the individual assets, along with the covariance between the two assets (see Methods section for explicit formulas). Thus, depending on the correlation between the assets, the portfolio risk may be lower than the individual asset risk. For NCS, spatial separation between projects often implies reduced correlation, since it is less likely that two pathways experience the same disturbances and carbon loss risks, due to decorrelation of environmental variables such as rainfall.

In Figure 2, we examine various correlations between the two assets. When assets are fully correlated ($\rho = 1$), the portfolio risk is a linear combination of the individual asset risks, resulting in diversification consistently leading to higher risk compared to the less risky asset. However, as the assets start to decorrelate, the risk decreases to the point where it becomes lower than that of the less risky asset. The combination of all these portfolio possibilities forms the efficient frontier, representing the trade-off between return and risk and offering a range of investment options for any type of investor. The inset of Figure 2) shows the typical correlation structure of rainfall[32], which implies that NCS projects should be separated by a distance of more than 200 km to reduce correlation to at least 0.5.

To illustrate how utility preferences impact the choice of portfolios along the efficient frontier, we also computed indifference curves (represented by a set of grey lines) for both more risk-averse and less risk-averse decision-makers. When risk aversion is low (see Methods for further details), the tangent point between the highest achievable utility and the efficient frontier leans toward the higher-risk side of the efficient frontier, signifying a decision-maker seeking risk for the prospect of higher returns. Conversely, high-risk aversion indicates a lower tolerance for risk, guiding the optimal portfolio closer to the 'bullet end' of the efficient frontier.

Cost-Effectiveness and the Distribution of viable NCSPs

We form NCSPs using different pathways sorted based on either their cover (forest, agricultural lands, wetland) or intervention (restore, manage, protect) type. Their composition is determined by the cumulative weight of each category within that portfolio. The results for all portfolios (with fixed correlation, here $\rho = 0$) are summarized in Figure 3 in a ternary form based on the chosen categories. It is clear that portfolios exhibiting higher mean returns (darker red) are more prevalent when forest pathways dominate. This outcome aligns with expectations, given that three out of the six forest pathways - reforestation, natural forest management, and avoided forest conversion - offer the most substantial individual potential for carbon sequestration. In fact, when the asset choice is constrained by cover type, the three cover type categories occupy different portions of the portfolio space, with forest pathways comprising the high return/high-risk part (see in SM, Fig 7). The same high-return portfolios are typically associated with increased risk (larger marker size). However, it is interesting that high portfolio returns can also be achieved without a predominant presence of these high return/high risk forest pathways, but using a more balanced weight of agricultural and wetland pathways within the portfolio, as shown by the more central, red marks in Figure 3a.

When portfolios are considered based on the intervention category, the distribution reveals that high-return, high-risk portfolios are primarily associated with restoration pathways. This observation aligns with the inherent risk associated with the three restoration pathways: reforestation, peatland restoration, and coastal restoration (portfolio spaces associated with only one intervention type are shown in Figure 8).

Considering only cost-effective pathways (cap of \$100/tC) eliminates some of the pathways that offer higher carbon sequestration potential but also carry greater risk. As a result, the distribution is characterized by lower risk and lower carbon returns (lower panels in Figure 3). Notably, two out of three restoration pathways are excluded. Consequently, the distribution by intervention type mainly clusters between Protect and Manage pathways. This budget limitation encourages the deployment of portfolios primarily focused on improving the management of agricultural lands, including practices such as cropland nutrient management, conservation agriculture, improved rice cultivation, and improved grazing management, all of which come at a lower cost.

A Measure for NCSP Diversity

To provide a clearer representation of diversification within each portfolio, we utilize the Shannon diversity index[33], which has been used to measure community abundance (see Methods for details), e.g., measuring biodiversity[34,35]. Here it finds a natural application to reflect the weights of the assets in each NCS-folio. Figure 4 shows the relationship between diversification and risk. Portfolios with high risk and high return (red markers) exhibit low diversification. Progressing along the x-axis, the portfolios display a decreasing trend in both risk levels and returns. Higher diversification, characterized by a more equitable and balanced distribution of weights among assets in a portfolio, also often referred to as Shannon evenness (see Methods), is associated with portfolios with lower risk.

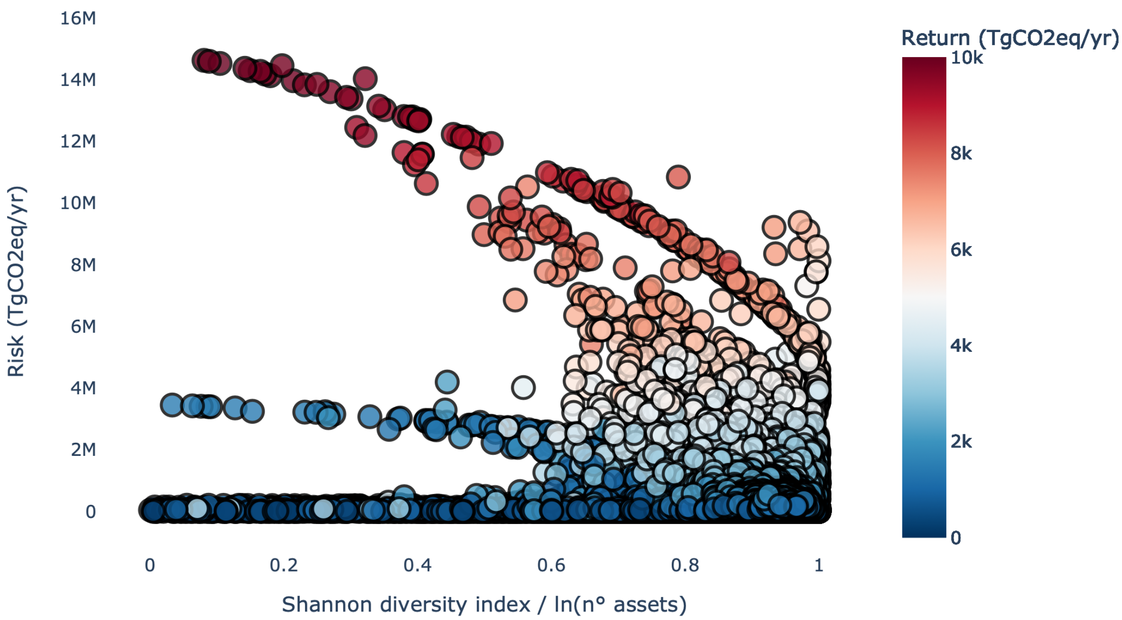

Figure 4. Diversification of portfolios. Each marker represents a portfolio and the color scale gives the return for each portfolio.

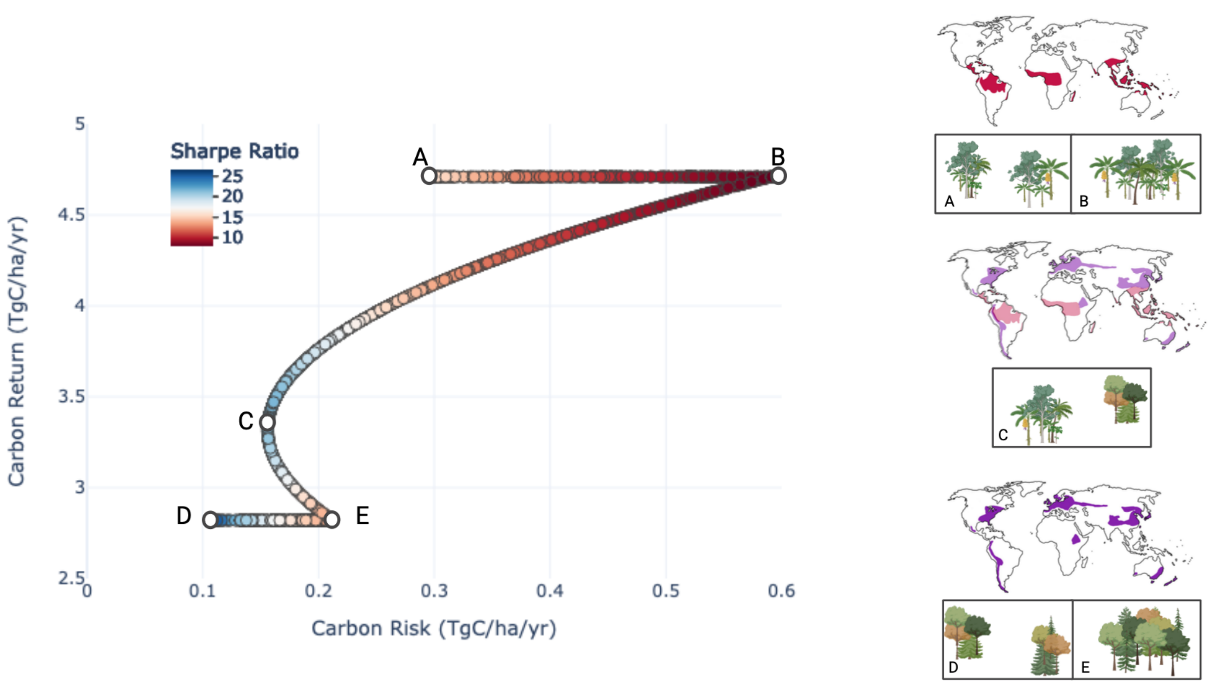

Figure 5. Forest NCSP. Each marker represented a portfolio and the color scale is associated with the portfolio Sharpe-Ratio. The letters locate interesting scenarios depending on geographical area and spacing between projects.

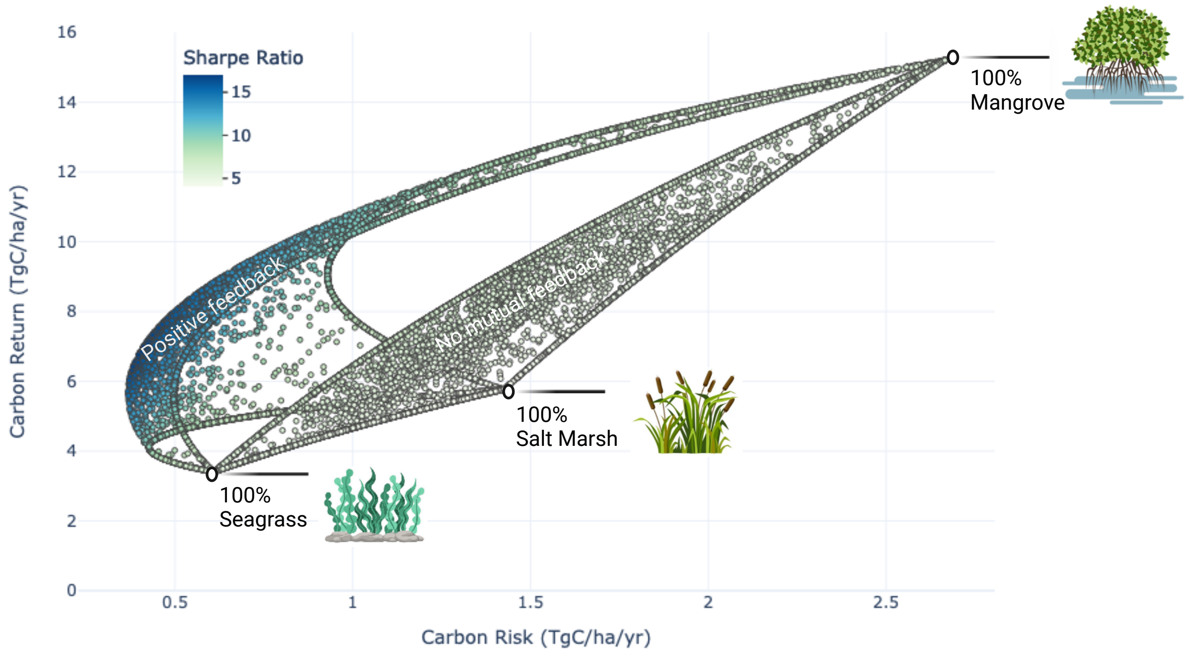

Figure 6. Wetland NCSP. Each marker represents a portfolio and the color scale is associated with the portfolio Sharpe-Ratio.

Role of Geographic Diversification in NCSPs

Since each NCS carries a certain level of risk stemming from environmental disturbances, deploying them within the same geographic area implies an increased risk of exposure to similar disturbances (i.e., $\rho \sim 1$). Conversely, when the same pathway is deployed in two geographically distant areas, beyond the spatial scale of correlation characterizing these disturbances, the combined risk may be greatly reduced. As an example, we consider reforestation portfolios with varying degrees of risk correlations related to distance.

Temperate forests exhibit on average lower carbon fluxes compared to tropical ones. Referring to Figure 5, reforestation portfolios in tropical areas encompass all the points between point A and B in Figure 5. The return remains constant in terms of mitigation intensity per unit area, but moving from point B to A increases the distance between applications and this reduces the correlation coefficient and the combined risk; a similar situation applies to points between E and D for temperate forests. As an example, for trees planted in geographically distant areas, a complete destruction by fire is obviously much less likely that when the forests are interconnected. The range from points B to E represents portfolios that involve both temperate and tropical forests, in which case a close correlation is less likely, allowing for even lower risk levels coupled with high returns. The Sharpe Ratio for optimal portfolios, defined as the ratio between the excess return earned by an investment and the risk taken with a portfolio choice, is also shown in Figure 5. The maximum Sharpe Ratio obtained with a combination of temperate and tropical reforestation projects is represented by point C in the figure, which is characterized by the best risk-adjusted performance of a 68% temperate reforestation and 32% tropical reforestation portfolio.

Mutually Reinforcing Assets in the Coastal Restoration Pathway

In special cases, asset diversification may be beneficial because of positive feedback among assets, leading to an overall portfolio reinforcement. This happens for NCSs in the coastal restoration pathway, which involves the restoration of vital ecosystems such as mangroves, salt marshes, and seagrass beds. Mangroves are predominantly found in tropical or subtropical regions, while salt marshes and seagrass beds span from tropical to arctic climates. When these vegetation types coexist locally, they tend to create mutually beneficial ecotonal communities in the intertidal zone of low-energy coastlines[36], bringing about a mutually reinforcing effect. Previous studies provide evidence of mangroves and salt marshes mitigating the impact of increased nitrogen levels on seagrass meadows[37]. The close association of habitats indirectly enhances carbon storage through various mechanisms, including protection from waves by seagrass, trophic control of bioturbation and herbivory, or direct carbon transfers[36,38,39]. The risk associated with the carbon return from these ecosystems is then lowered by the mutual benefit and enhanced resilience to disturbances.

Figure 6 shows the coastal restoration portfolios diversified between the seagrass, mangrove and salt marshes with and without the positive feedback due to colocation. In instances where ecosystem interconnection yields mutual benefits, the portfolios exhibit higher Sharpe Ratios (see Methods), signifying a superior choice due to lower risk for the same the obtainable return. While the outcomes for mutually beneficial NCSs resemble those of the NCS portfolio with low correlation (as in Figure 5), in this context, the reduced risk stems from colocation rather than spatial separation. This underscores the importance of considering natural feedback when planning restoration efforts, in order to maximize the project resilience.

Discussion

Our findings underscore the effectiveness of diversifying and allocating resources across various NCS options in mitigating the risk of carbon-benefit loss. This strategy, akin to the principles of market diversification, ensures that one's 'capital' is not concentrated in a single NCS pathway. As shown in the different applications above, in the NCS context diversification has several dimensions: diversification among NCS assets, geographic diversification within the portfolio, and diversification to exploit mutually reinforcing assets.

The overall risk of NCSPs can be attributed to the inherent risk of each pathway and the relative presence of that pathway in the portfolio. Additionally, the total risk is influenced by the correlation between NCS assets. A deliberate effort to decorrelate risks among options in NCS may result in considerable benefits. Considering spatial distances that exceed the correlation of the environmental forcing, which serve as indicators of disturbances such as droughts, floods, fires, pests, etc., produces much safer portfolios. It is likely that the risk of carbon loss for individual NCS pathways will increase with climate change intensification. Addressing this nonstationarity requires further research to refine mitigation potential estimates, factoring in the heightened potential for disturbances. This adaptable framework provides the foundation for incorporating revised risk estimates, featuring a valuable risk-sensitive tool for policymakers with diverse preferences and risk tolerances. A recent study of NCS implementation in California supports our finding that simultaneous deployment of different suitable pathways helps to have more stable carbon benefits at the end of the considered horizon, even for the worst climate scenarios[40].

The theory assumes normally distributed risks around their mean values, but this may be a conservative assumption when accounting for extreme events in the context of increasing disturbance intensity due to climate change. Events like megadroughts[41], spanning spatial and temporal scales much larger than the average disturbance scale, may be considered outliers with higher associated risks. Adjusting risk assessments for each pathway should involve considering higher tail statistics and more localized estimates to better address these challenges. More research is also needed to understand the feedback between colocated NCS pathways. As exemplified by the coastal restoration example above, the co-location of different species of wetland vegetation strengthens the resilience to disturbances that each species is subject to, thus decreasing the risk of an NCSP that includes a combination of those. It is then crucial to estimate and promote these positive feedbacks in order to maximize the return and the resilience of a NCSP project. For even greater benefits and resilience, identifying NCS pathways with negative correlations would be exceptionally rewarding. A negative correlation would originate once a NCS presents increasing carbon return when another NCS presents carbon loss, meaning that in the impacts disturbance balance, pushing the efficient frontier and the minimum risk portfolio to even lower values.

Methods

NCS Portfolio Theory

The Nobel-prize winning MPT[42] fundamentally revolves around the concept of assets and portfolios: assets are items owned or controlled with the intent of generating value or returns over time, while portfolios are collections of assets held concurrently. The portfolio risk depends on both the standard deviations of individual asset returns and their covariances. Hence, diversification relies on distributing risk exposure, ensuring that poor performance of a single asset does not lead to the loss of the entire investment.

A portfolio can be represented by a set of values, denoted as x_i, signifying the weights or decision variables. In this study, assets are NCS pathways and the weights defining each portfolio represent proportions of available land or carbon mitigation investment. Following the categorization done in previous studies[1,6,43], we select the most relevant NCS pathways. A complete list is reported in Table 1.

In order to apply MPT, we define the "return" R_i of each NCS pathway i as the estimate of mean carbon mitigation potential and the "variance" s_i in terms of the risk of losing the sequestered carbon. We derive these values from global estimates such as those presented by Griscom et al.[1]. First, we obtain the returns (cumulative, annual, or per unit area) from Griscom et al.'s estimates and then extract a reasonable risk estimate from the provided uncertainty. Griscom et al. provide the 95% confidence interval on the mean estimates for mitigation potential. Details on how these intervals were calculated are described in detail in their supporting information (Table S1). Assuming a normal distribution, we calculate the variance s^2 associated with the mean estimate for each pathway as

$$(1-p)CI = \bar{R} \pm t_{p/2}\sqrt{s^2/n}, \tag{1}$$

where p=5% here and $\bar{R}$ is the estimate for the mean carbon return, and n represents the sample size.

The total return of the portfolio is the weighted sum of the returns of each asset in the portfolio and it is given by

$$\sum_{i=1}^{n} R_i x_i = R \qquad \text{where} \qquad \sum_{i=1}^{n} x_i = 1\,, \qquad x_i \geq 0. \tag{2}$$

The associated risk is expressed through the sum of covariances

$$V(x_1,\ldots,x_n) = \sum_{i=1}^{n}\sum_{j=1}^{m} \sigma_{ij}^2 x_i x_j \tag{3}$$

with

$$\sigma_{ij}^2 = cov_{ij} = \rho_{ij} s_i s_j\,, \qquad \sigma_{ii}^2 = var_i, \tag{4}$$

where cov_{ij} is the covariance between the ith and jth assets (if $i = j$ then it is the variance), var_i is the variance for the ith asset, ρ_{ij} is the correlation coefficient between the ith and jth assets, s_i is the standard deviation for the ith asset, and i, j are indices for the different asset options. The risk of a portfolio then depends on the weights given to each asset, the specific risk of each asset, and the correlation between pairs of assets.

The optimal portfolio hinges on the decision maker's utility function, which characterizes the level of satisfaction derived from improved outcomes. This satisfaction typically exhibits non-linear growth, with marginal utility diminishing, signifying a concave utility function. The degree of concavity is governed by the risk-aversion coefficient a which quantifies an individual's willingness to assume risk in pursuit of an additional unit of return.

Commonly employed utility functions feature either constant absolute risk aversion (CARA) or constant relative risk aversion (CRRA). In the context of MPT, which assumes risk-averse investors, the inclination is toward less risky portfolios when faced with two portfolios offering the same expected return. Thus, investors will only embrace increased risk if it comes with the promise of greater expected returns, with the specific trade-off being contingent on their individual risk aversion characteristics. An effective metric to compare portfolios is the Sharpe Ratio[44], which provides a way to evaluate the return of a portfolio commensurate to its level of risk. It is defined as

$$\text{Sharpe Ratio} = \frac{R_p - R_f}{\sigma_p} \tag{5}$$

where the numerator is gain one can expect from considering the return of the portfolio R_p compared to a risk-free asset return R_f and σ_p is the portfolio risk. A higher Sharpe Ratio indicates a better risk-adjusted performance.

Diversification Index

We use the Shannon diversity index to assess the diversity within each portfolio, expressed as

$$H' = -\sum_{i=1}^{R} x_i \ln x_i, \tag{6}$$

where x_i is the weight of the pathway i in the portfolio. The higher the value of H the higher the diversity of assets. A value of $H = 0$ means that there is only one pathway in a portfolio. One could also consider the Shannon Equitability, which is a measure of "evenness" that refers to how similar are the weights within the portfolio.

$$E = H/\ln S \tag{7}$$

where s is the total number of assets and it ranges between 0 and 1 (complete evenness).

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Author contributions statement

S.C. and A.P. conceived the study, S.C. conducted the analyses. S.C. wrote the first draft. S.C. and A.P. revised the manuscript.

Supplementary information

Table 1. Natural Climate Solutions (NCS) considered in Griscom[1].

Mitigation Category	Pathway	Description	Mitigation Potential (TgCO2e/yr)	Mitigation Uncertainty 95%CI bounds (TgCO2e/yr)	Low Cost Potential (TgCO2e/yr)	Intensity (MgCO2/ha)
Forests	Avoided Forest Conversion	Emissions of CO2 avoided by avoiding forest (>25% tree cover) conversion	366	2999 - 4209	1816	402
	Reforestation	Additional carbon sequestration by converting non-forest (< 25% tree cover) to forest (> 25% tree cover (6)) in areas where forests are the native cover type	10124	2727 - 17867	0	455
	Natural Forest Management	Avoided emissions and enhanced sequestration for native forests improved management (reduced logging, harvest rotation)	1470	921 - 8224	441	23
	Improved Plantation	Enhanced sequestration by limited extension of economically optimal rotation lengths to biologically optimal yield rotation lengths in even-aged intensively managed wood production forests.	443	168 - 1009	0	52
	Fire Management	Enhanced sequestration and avoided emissions due to prescribed fires to reduce the likelihood of more intense wildfires, fire control practices (e.g. fire breaks) in Amazonia, use of early season fires in savanna ecosystems	212	166 - 411	0	-
	Avoided Woodfuel Harvest	Avoided emissions due to reduced harvest of woodfuel used for cooking and heating, without reducing heating or cooking utility	367	326 - 407	0	-
Agro	Avoided Grassland Conversion	Avoided soil carbon emissions by avoiding the conversion of grasslands (including savannas and shrublands) to cropland	116	75 - 373	0	68
	Biochar	Additional carbon sequestration by amending agricultural soils with biochar, which increases the agricultural soil carbon pool by converting non-recalcitrant carbon (crop residue biomass) to recalcitrant carbon (charcoal) through pyrolysis.	1102	642 - 1455	0	72
	Cropland Nutrient Management	Avoided N2O emissions due to reduced fertilizer use and improved application methods on croplands.	706	399 - 959	635	8
	Conservation Agriculture	Additional soil carbon sequestration by planting cover crops during the part of the year when the main crop is not growing	413	310 - 516	248	35
	Trees in Cropland	Enhanced sequestration in above- and below-ground tree biomass and soil carbon due to integration of trees into croplands at levels that do not reduce crop yields (windbreaks/shelterbelts, alley cropping, and farmer managed natural regeneration)	1040	469 - 1855	0	41
	Grazing - Optimal Intensity	Enhanced soil carbon sequestration due to grazing optimization on rangeland and planted pastures, Grazing optimization prescribes a decrease in stocking rates in areas that are overgrazed and an increase in stocking rates in areas that are under-grazed	148	148 - 699	45	7
	Grazing - Legumes in Pastures	Additional soil carbon sequestration due to sowing legumes in planted pastures. Restricted to planted pastures and to where sowing legumes would result in net sequestration after taking into account the increases in N2O emissions associated with the planted legumes.	147	14 - 1500	88	62
	Grazing - Improved Feed	Avoided methane emissions due to reduced enteric fermentation from the use of more energy-dense feed and the associated reduction in total animal numbers needed to supply the same level of meat and milk demand	680	35 - 1014	0	-
	Grazing - Animal Management	Avoided methane emissions due to reduced enteric fermentation as a result of improved livestock breeds and management techniques that increase reproductive performance, animal health, and weight gain, and the associated reduction in total animal numbers needed to supply the same level of meat and milk demand	200	75 - 214	0	-
	Improved Rice Cultivation	Avoided emissions of methane and N2O associated with anaerobic decomposition by employing periodic draining of rice soils and removal of rice residues in flooded and upland rice production lands	265	227 - 319	80	48
Wetlands	Coastal Restoration	Avoided emissions due to avoided degradation and/or loss of salt-water wetlands (mangroves, salt marshes, and seagrass beds)	841	621 - 1064	0	558
	Peatland Restoration	Avoided emissions due to avoided degradation and/or loss of freshwater wetlands (tropical, temperate, and boreal peatlands)	815	705 - 2471	149	989
	Avoided Peatland Impacts	Avoided oxidation of soil carbon and enhanced soil carbon sink due to soil re-wetting in mangroves, salt marshes, and seagrass beds. Additional sequestration also included for mangroves due to restored tree growth.	754	237 - 1212	452	882
	Avoided Coastal Impacts	Avoided oxidation of soil carbon due to soil re-wetting in freshwater wetlands (tropical, temperate, and boreal peatlands).	304	141 - 466	182	527

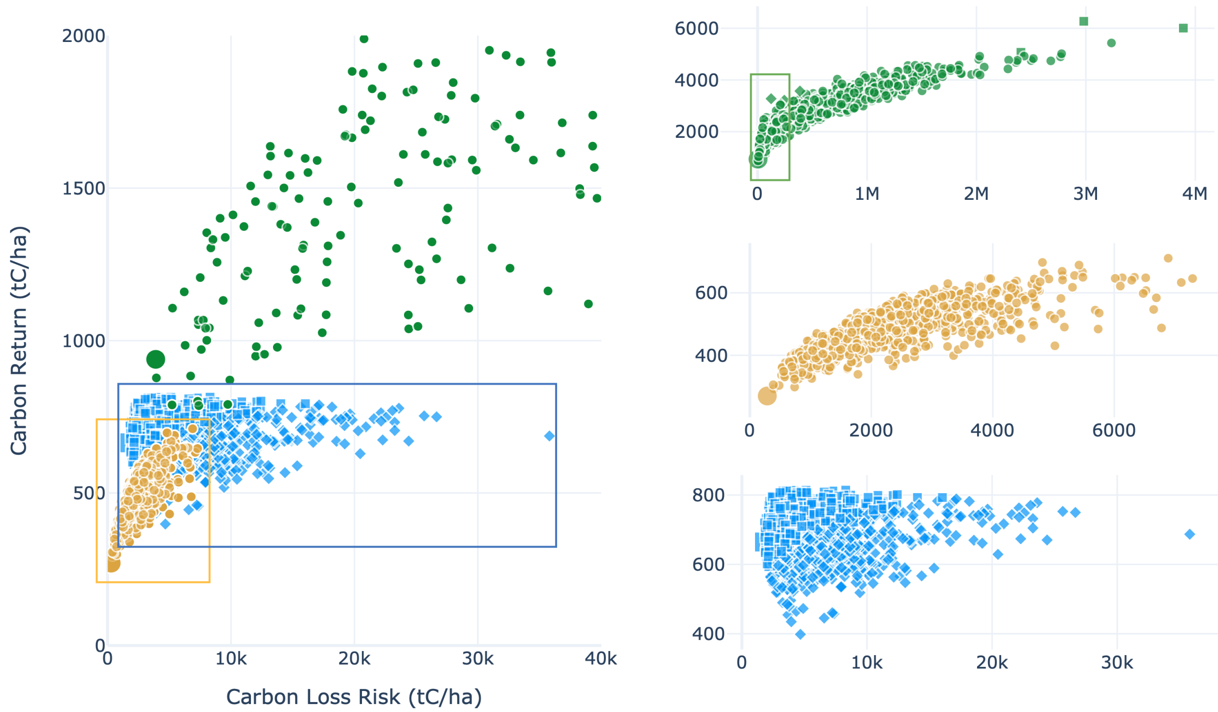

Figure 7. Forest, agriculture and wetland pathways portfolios.

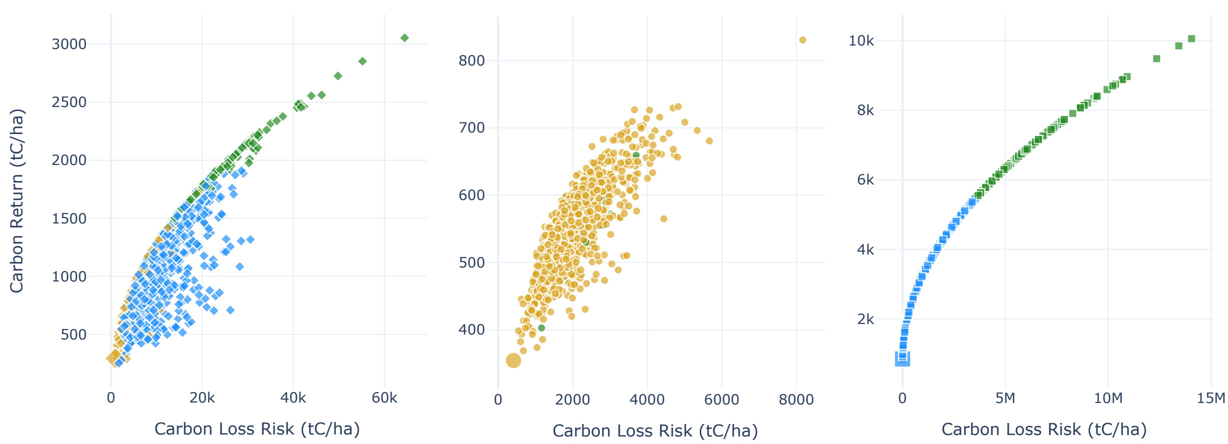

Figure 8. Portfolio based on intervention type: (a) manage; (b) protect; (c) restore