NATURE-BASED SOLUTIONS FOR CLIMATE RESILIENT INFRASTRUCTURE PLANNING IN THE PHILIPPINES

The Sustainable Infrastructure Program in Asia (SIPA)

2025

AUTHORS

Ryan Bartlett, Shail Joshi, Becky Chaplin-Kramer, Rich Sharp, Gia Ibay, Dean Roxas.

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FOREWORD

KATE NEWMAN
Vice President, Forests, WWF United States

KATHERINE 'TRIN' CUSTODIO
Executive Director, WWF- Philippines

We are now seeing on a nearly weekly basis around the world more extreme climate hazards—flooding, landslides, hurricanes and typhoons—are destroying infrastructure built for a historical climate that no longer exists. It is clear that we need new approaches to planning and development that center resilience. At the same time, we are also seeing ever greater levels of biodiversity loss and wildlife population decline due to habitat conversion, pollution, and climate change. WWF's biennial analysis of planetary health, the Living Planet Report, now shows a 72% decline of wildlife populations globally and more than 50% in Asia. The importance of addressing both climate and biodiversity crises is now imperative, demonstrated by annual global negotiations to strengthen national commitments to the UN conventions on Biodiversity and Climate Change.

As a biodiversity hotspot home to some of the most globally important species and carbon stocks on earth, this is especially true for Philippines. Millions of Filipinos, however, still live in poverty with insufficient access to basic services like water, energy, or transportation. Increasing infrastructure development is important for not just creating economic opportunities and livelihoods diversity critical for Philippines' future growth but also building resilience to worsening climate shocks. Ensuring these developments are planned and built to maximize sustainability, including considerations for biodiversity and climate resilience, is essential.

Far too often, however, nature is seen only as an impediment to infrastructure development, rather than part of a stronger, more flexible solution. This report, built through collaboration between WWF and the Government of the Philippines, including the Department of Economy, Planning, and Development (DEPDev), Department of Public Works and Highways (DPWH), Department of Environment and Natural Resources (DENR) and the University of Philippines Los Baños Foundation Inc. (UPLBFI), aims to address this gap by demonstrating how and where nature can provide critical benefits to millions of Filipinos and thousands of kilometers of current and future road infrastructure through nature-based solutions. It shows how protecting and managing forests can maintain and enhance climate resilience by controlling erosion and sediments, recharging aquifers for water supplies, reducing flood risks by slowing water flows, and protecting coastlines from increasingly damaging storms and erosion.

Ensuring major infrastructure projects, including new national level roads and associated networks of new feeder roads, are built with maximum sustainability in mind to not just reduce environmental impact, but harness these benefits, is critical for Philippines in meeting its biodiversity, climate, and sustainable development goals. As this report shows, there are significant opportunities to both manage existing intact ecosystems but even more so to invest in restoration to support climate resilience for people and transportation infrastructure moving forward. Investing in nature on less than 30% of the country's land area impacted by road development could benefit nearly half of Philippines' population and the national road network.

In line with the administration's infrastructure goals, including the National Infrastructure Flagship Program (IFP), the Build Build More (BBM) programme, and the Philippine Development Plan (PDP 2023-208), nature-based solutions are specifically named as a key cross-cutting tool in support of their implementation. This report, along with data layers, maps, and an interactive mapping platform, aims to provide a critical resource for technical staff across ministries in planning sustainable and climate-resilient infrastructure projects.

This effort, as part of the Sustainable Infrastructure Programme in Asia (SIPA), led by the Organization of Economic Cooperation and Development (OECD), would not have been possible without support from the International Climate Initiative (IKI) under the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).

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KEY TERMS

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KEY TERMS

BIODIVERSITY

Biodiversity is the variety of life and the interactions between living things at all levels on land, in water, and in the sea and air – genes, populations, species and ecosystems.

CLIMATE RESILIENCE

The ability of a social-ecological system to absorb and recover from climate-related shocks and disturbances and maintain functionality and services by adapting to chronic climate stressors and transform when necessary.

ECOSYSTEM SERVICES

Ecosystem goods and services produce the many life-sustaining benefits we receive from nature—clean air and water, fertile soil for crop production, pollination, and flood control—important to environmental and human health and well-being.

HABITAT FRAGMENTATION

This is a consequence of development by which large and contiguous habitats get divided into smaller, isolated patches of ecosystems impacting the biodiversity, flow of ecosystem services, and wildlife movement.

MITIGATION HIERARCHY

The mitigation hierarchy is a set of guidelines, established through the International Finance Corporation's (IFC) Performance Standard 6, meant to help development projects prepare for impacts and aim to achieve no net loss of biodiversity.[1] The hierarchy follows avoidance, minimization, restoration and offsets to reduce development impacts and control any negative effects on the environment.

NATURE-BASED SOLUTIONS (NbS)

Per IUCN, NbS "address societal challenges through actions to protect, sustainably manage, and restore natural and modified ecosystems, benefiting people and nature at the same time."[2] For this report, the societal challenge is climate change and its impacts in the form of increasingly extreme weather and hazards like droughts, floods, and coastal storms that affect people and infrastructure.

NATURE-POSITIVE

Per the Nature-Positive Initiative, developed by a coalition of leading global sustainable development and conservation organizations, it is "a global societal goal to 'halt and reverse nature Loss by 2030 on a 2020 baseline, and achieve full recovery by 2050'.[3] To put this more simply, it means ensuring more nature in the world in 2030 than in 2020 and continued recovery after that." In an infrastructure planning and development context, this means both avoiding critically important intact nature in routing and siting decisions and integrating restoration to contribute to a net increase in natural area.

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

CONTEXT

SHIFT AWAY FROM REDUCING NEGATIVE IMPACTS TO CENTERING ECOSYSTEMS AND CLIMATE

As climate change continues to intensify with increasing emissions and associated warming, alongside a worsening biodiversity crisis, the Philippines must balance trade-offs between continuing economic growth to support livelihoods for millions currently still in poverty and ecosystem conservation and restoration goals that are critical to its international commitments on biodiversity and climate change. The country's 2025 climate budget is projected to be highest in five years, with a significant portion of the funds allocated for climate resilience projects and programs (Figure 4).

At the same time, the government's infrastructure spending has steadily increased over the last decade, with the 2024 and 2025 budgets allocating PHP 1.5 trillion (approximately $27B) for essential national projects designed to stimulate economic growth.[4] While transportation infrastructure development is critical to development objectives in the Philippines, there is also growing recognition of its larger scale and longer-term unintended detrimental consequences, particularly on biodiversity and ecosystems and the services they support, i.e. "nature-based solutions". New toll roads, for example, are built to maximize connectivity and efficiency for transport, but also lead to additional secondary and tertiary roads with increased access, ultimately causing habitat degradation and deforestation over subsequent years and decades. Climate change exacerbates these impacts, both increasing the vulnerability of transportation infrastructure and communities as valuable erosion control and flood risk reduction benefits provided by intact forests and wetlands are lost.

NATURE-BASED SOLUTIONS COMPLEMENT AND ENHANCE PERFORMANCE OF TRANSPORTATION INFRASTRUCTURE ASSETS

Globally, there is increasing momentum in the transportation sector (alongside all major infrastructure sectors) to shift away from merely avoiding and reducing negative impacts to centering ecosystem and climate considerations in planning, design, construction, maintenance, and decommissioning. This shift has sparked a growing interest in integrating nature-based solutions (NbS) and nature-positive approaches that offer a broader range of advantages compared to traditional solely engineered approaches, including increased reliability, lower operations and maintenance costs, and ultimately performance over the long term.

These solutions, however, are still both relatively new in application both globally and in the Philippines across infrastructure sectors and also developed at relatively smaller scales within project footprints as part of hybrid "green-grey" approaches like constructed wetlands for drainage, culverts for wildlife passage, or roadside restoration to reduce erosion. While these can be highly effective solutions, especially if scaled across large areas, they are not the focus of this analysis. Planning that fundamentally connects to larger ecosystem processes at scale—i.e. intact forests or wetlands, or significant investments in restoration within a watershed that reduce erosion and landslide risk for a specific proposed road under increasing climate extremes—is still uncommon.

This report seeks to both fill that gap in the Philippines and influence future trends in infrastructure planning and development globally, demonstrating ecosystem values for climate resilience and spatially mapping where they can provide these significant benefits for inland and coastal road infrastructure and communities.

OBJECTIVE AND METHODS

Under the Sustainable Infrastructure Program in Asia (SIPA) project, WWF is collaborating with the Government of the Philippines (GOP) to integrate NbS strategies into national and subnational strategic infrastructure planning and policy frameworks. This report is a summary of our nationwide mapping and modeling analysis to:

01 Assess four priority ecosystem services nationwide that are essential for climate resilience for people and infrastructure—water provision, sediment retention, coastal protection, and flood risk reduction—to identify NbS investment opportunities and guide transportation infrastructure developers in siting decisions.

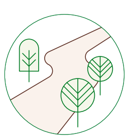
02 Evaluate these NbS opportunities under three scenarios to determine priority (top 10%) areas robust to climate change: first, conservation of functional ecosystems across the country that currently provide these services; second, conservation within zones most impacted by road development (within 15km) and settlement development (within 25km); and third, restoration of degraded lands back to forests to enhance resilience.

03 Provide examples of how these maps and analysis can be used in the infrastructure planning processes.

04 Provide policy recommendations for mainstreaming NbS in infrastructure planning moving forward in Philippines, across - government agencies and in support of national climate and biodiversity goals.

We hope the information herein is useful for planners at the Department of Economy, Planning, and Development (DEPDev), the Department of Public Works and Highways (DPWH), the Department of Environment and Natural Resources (DENR), local government units, and other relevant government agencies at the national and subnational levels in guiding infrastructure planning and siting decisions.

KEY FINDINGS



Ecosystems most impacted by road infrastructure and settlement development within 15-25km support climate resilience for nearly 54 million people and 66% of the road network on just 19% of Philippines' lands.

Evaluating all intact ecosystems nationwide that could support NbS benefits, **conserving priority areas on just 16% of Philippines' land area supports climate resilience for 43 million people and 42% of the road network.**

Restoring degraded forests to support multiple NbS to enhance climate resilience found on just 13% of the country would benefit about 51 million people and close to 52% of the road network.

Most of these priority areas are outside the protected area network, necessitating new regulatory approaches or land use management schemes for successful conservation or restoration efforts.

There are, however, immediate “win-win” opportunities for NbS investments under conservation or restoration inside protected areas and Key Biodiversity Areas that would simultaneously support climate resilience for people and infrastructure and biodiversity outcomes.

These analyses would be particularly useful for planning and prioritization processes of the DEPDev's Infrastructure Flagship Program, the next update of the Philippine Development Plan (PDP), and the ongoing update of the Philippine Biodiversity and Conservation Plan (PBSAP).

Achieving this requires investments in training and capacity building programs at all levels across these agencies and key departments on how to assess and integrate NbS in infrastructure planning. WWF and the University of Philippines Los Banos (UPLBFI) have developed such training materials for this purpose under the SIPA project.

To ensure maximum utility for planners across departments and ministries, maps and associated data should be integrated into existing key ministry and departmental web platforms and centralized national data and mapping platforms.

Maps and associated data should be integrated into existing key agencies and departmental web platforms and centralized national data and mapping platforms like the NAMRIA Geo Portal to ensure maximum utility for planners across departments and agencies.

CONTEXT

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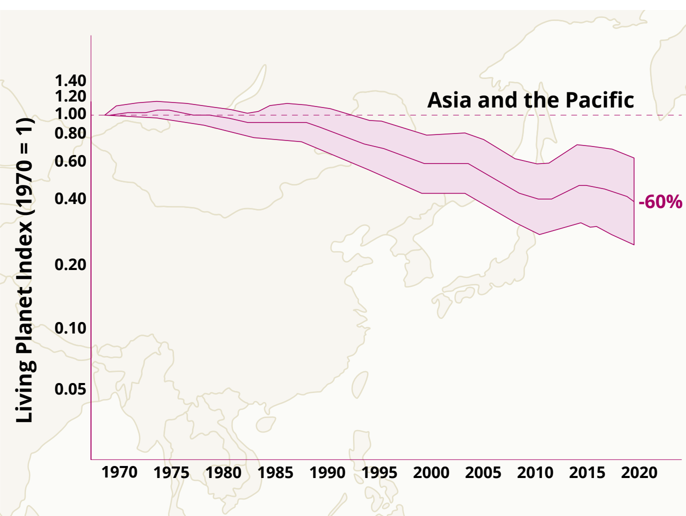
01 CONTEXT

THE PHILIPPINES IS HOME TO 70% TO 80% OF THE WORLD'S PLANT AND ANIMAL SPECIES

1.1 THE CHALLENGE: WORSENING BIODIVERSITY LOSS AND CLIMATE CHANGE IMPACTS

The Philippines, one of 18 mega-biodiverse countries, is home to significant biodiversity, including 70% to 80% of the world's plant and animal species, and ranks fifth in plant species diversity.[5] It is host to over 50,000 plant species and 100,000 animal species, of which 3,000 and 500 are endemic to the country respectively.[6] The country's ecosystem encompasses rainforests, mangrove forests, coral reefs across over 7,600 islands. These species and habitats in turn support critical services for millions of people and infrastructure assets like clean air and water and protect critical infrastructural assets such as roads, railways, and ports from current and future climate extremes through ecosystem services benefits like erosion and sediment control, flood risk reduction, and protection from increasingly extreme tropical storms.

These benefits are, however, increasingly under threat. Wildlife populations have declined globally by nearly 70% since 1970 due to habitat loss, deforestation and land degradation, pollution, and climate change.[7] Asia has seen similarly significant declines, losing more than half or 60% since 1970 (Figure 1). In the last two decades, the Philippines has lost 190 kha of primary forest cover, with the largest deforestation occurring in 2023 of about 27.3 kha primary forests. Overall, the country has lost about 1.47 Mha of tree cover representing about 8% decrease since the turn of the century.[8] Even though the National Greening Program (NGP) has had positive impacts in reforesting large swaths of degraded lands, the rate of reforestation has reduced since 2019.[9] Agricultural expansion, infrastructure development, increased tourism, and forestry are some of the key drivers of the deforestation.[10]



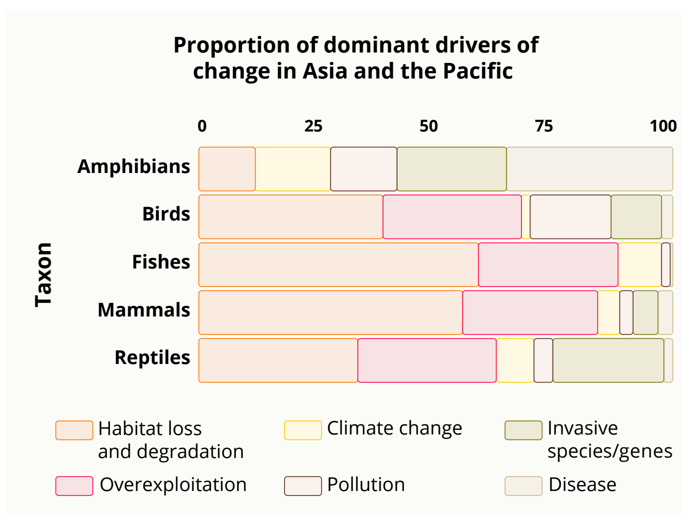


Figure 1. WWF's Living Planet Report 2024 reveals an average decline of 73% in species populations since 1970 globally and 60% in Asia and the Pacific, driven largely by habitat loss and degradation, overexploitation, pollution and climate change. Source: Living Planet Report.[11]

Forests are essential for maintaining ecological balance, acting as carbon sinks, habitats for diverse species, and providers of crucial environmental services like water regulation, flood risk reduction, sediment retention, clean water supply, coastal protection, and carbon storage. However, transportation infrastructure such as roads significantly impacts surrounding ecosystems and biodiversity. Planning and construction of roads opens access to intact forest ecosystems increasing their susceptibility to land use conversion. Between 1934 to 1988 about 9.8 Mha of forest was lost of which 78% (2.1 Mha) deforestation occurring within 1.5km of road development.[12] A study analyzing the impacts of roads on the Upper Marikina River Basin in Rizal showed that between 2005-2020 the forest cover in this region decreased by over 15% when the road networks in the region increased by fivefold.[13]

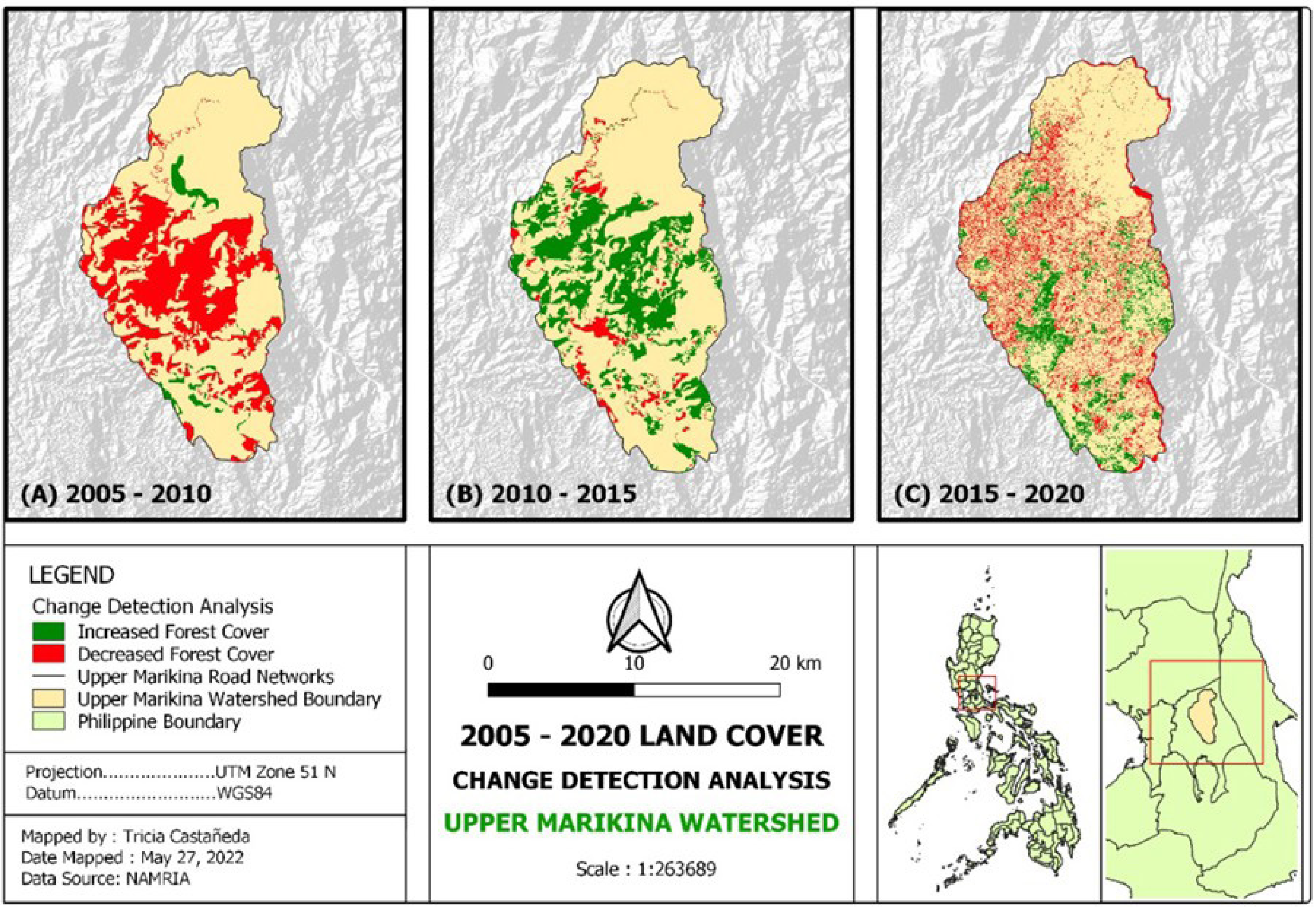


Figure 2. Change of forest cover in Upper Marikina Watershed from 2005 to 2020. Source: Impact assessment of road development on forest cover in the Upper Marikina Watershed, Philippines.[14]

OVER 60% OF THE LAND IS VULNERABLE TO CLIMATE HAZARDS

Climate related disasters are intensifying the effects of environmental degradation due to human activities. The Philippines which is considered as one of the most disaster-prone countries faces increasing threats from future climate hazards such as floods, typhoons, droughts, landslides, and mud slides.[15] Over 60% of the land area is vulnerable to one or more of these climate hazards exposing over 74% of the population to climate extremes.[16] Local communities believe that human activities is one of the primary causes of climate change, with over half indicating that they are concerned with its impacts in future.[17]

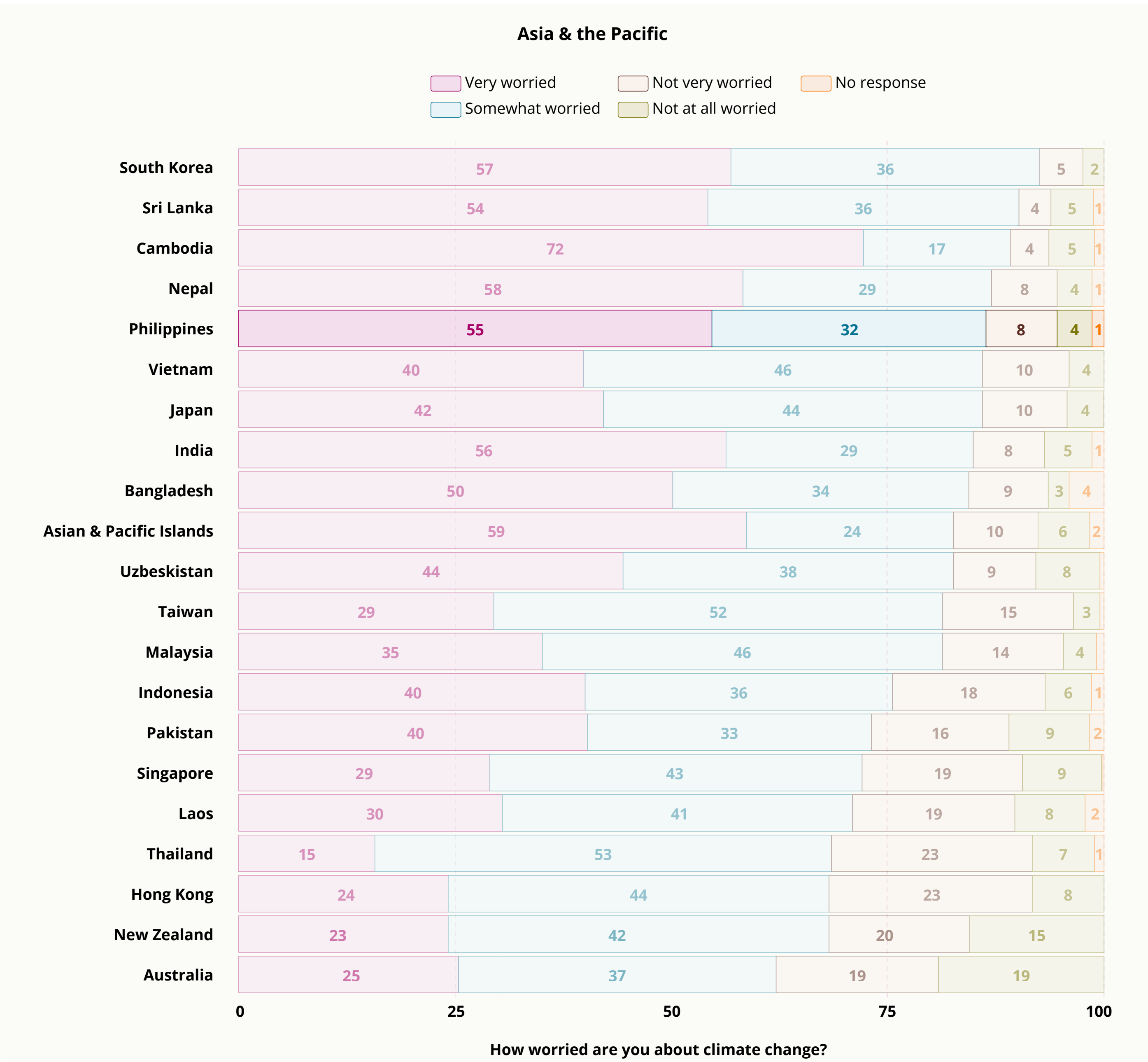


Figure 3. Percentage of Filipinos concerned about climate change. Source: International Public Opinion Climate Change, 2023.[18]

On an average, over a million people have been impacted due to a combination of the climate hazards in the Philippines.[19] And the future projection suggests a strong shift to more frequent and intense hazards annually. The average maximum daily precipitation is slated to increase by 8.5% and 17% under the SSP 4.5 and 8.5 scenarios posing greater threat to people and ecosystems lying in vulnerable areas.[20] More rainfall could exacerbate the risk of landslides and floods in heavily deforested areas, as the degraded land would reduce capacity to retain water due to loose topsoil. Also, post road construction land use changes, such as the conversion of pristine ecosystems to agriculture or settlements, can significantly reduce soil permeability, increasing the likelihood of flooding during intense rainfall events.[21]

Under a multi-hazard scenario, the economy of the Philippines would face significant challenges due to increasing costs associated with risk reduction, maintenance, and disaster response. The Philippines' high population density in areas prone to natural hazards, combined with its heavy dependence on natural resources, makes it particularly vulnerable to the impacts of climate variability and change. This susceptibility is further exacerbated by the country's geographic location, which exposes it to frequent typhoons, floods, and other extreme weather events. For example, Philippines has been incurring economic losses of between 2 to 3% annually due to the impacts of floods, typhoons, and tropical storms.[22] If no action is taken, then these impacts could cost about 18% of the GDP by 2070 under a high emission scenario.[23]

1.2 THE OPPORTUNITY: NATURE-BASED SOLUTIONS FOR INFRASTRUCTURE RESILIENCE

Planners and decision makers at DEPDev, DENR, DPWH, and other key national level planning agencies are facing these challenges as they aim to achieve Philippines' global climate commitments in alignment with national economic goals. They must balance trade-offs between preserving important ecosystems and biodiversity hotspots that support valuable ecosystem services while developing large-scale transport infrastructure in support of sustainable economic development. The national budget reflects this, with increasing allocations for climate and environment in recent years while infrastructure continues to remain significant (Figure 4).[24][25][26][27]

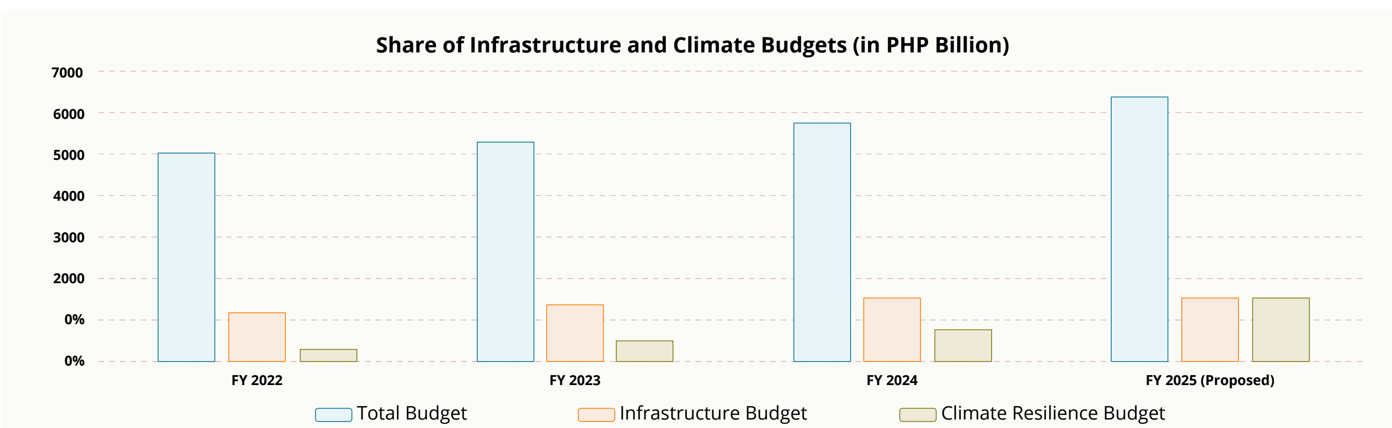


Figure 4. Share of the budget for climate programs and disaster risk reduction in Philippines national budget from 2022-25. Source: Department of Budget and Management.

This spending presents a significant opportunity to avoid mistakes of the past that failed to properly account for impacts on, and benefits of, nature in infrastructure development. There is ever greater awareness across sectors about the "win-wins" or even triple wins that nature-based solutions can provide in addressing climate change (both emissions and impacts from new hazards), biodiversity loss, and simultaneously create economic opportunities.[28] While there are multiple similar terms and definitions, for this report, we define nature-based solutions for climate resilience as the functional or restored ecosystems at scale that provide benefits that support resilience to climate hazards.[a]

These include inland forests that maintain hillsides and reduce landslides and flooding risk, or provide clean water for populations and roads downstream, and coastal mangroves and reefs protect against ever stronger storms.

Integrating these NbS in infrastructure development planning and effectively evaluating both their synergies and costs and benefits, either as integrated components, replacements, or compliments to engineered systems is an on-going challenge. Countries often lack the data, information, sector-specific guidance and capacity to evaluate and spatially prioritize habitats that provide the greatest opportunity to support resilience for both people and infrastructure to worsening climate hazards like landslides, flooding, drought, and coastal storms. However, governments around the world, including the Philippines, are increasingly prioritizing nature's resilience benefits for multiple reasons, including often higher overall economic performance compared to investments in solely engineered assets.

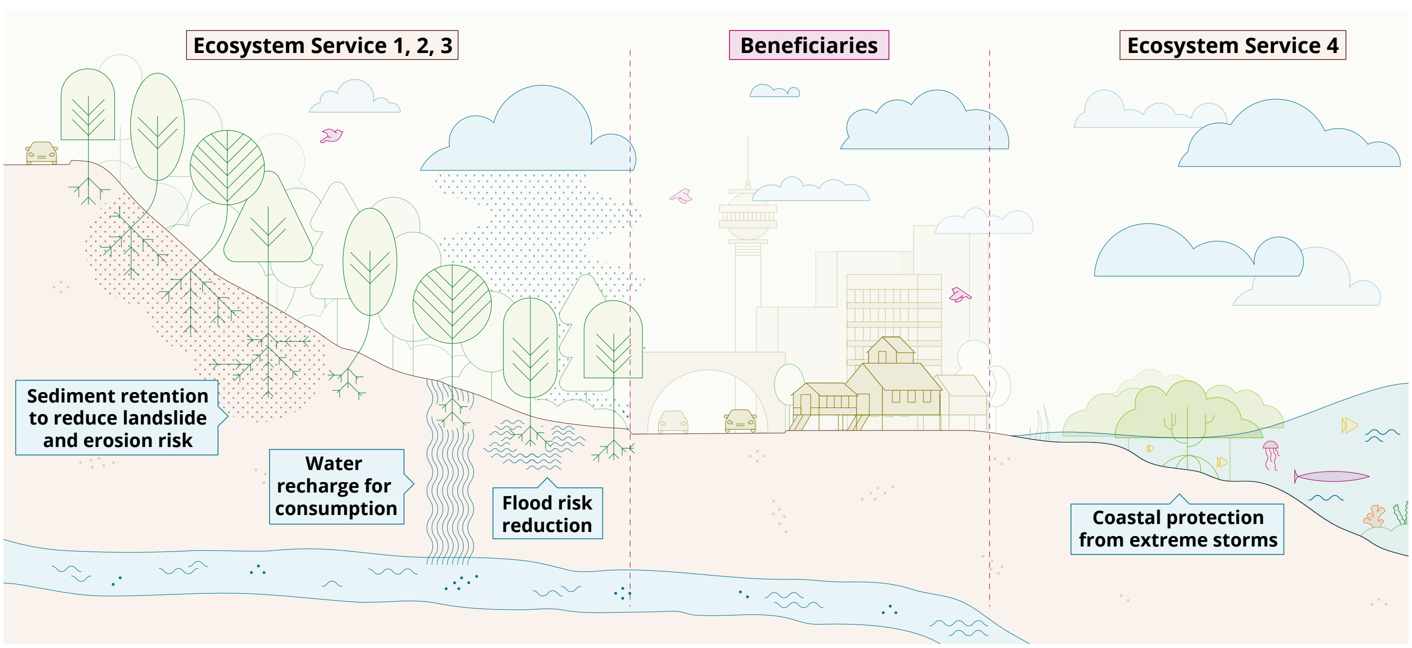


Figure 5. The four ecosystem services analyzed in this report that act as nature-based solutions for climate resilience.

[a] Multiple additional terms have the same or very similar meaning—ecosystem-based adaptation (EbA), nature-based infrastructure (NBI), ecosystem-based disaster risk reduction (Eco-DRR).

For example, enhancing infrastructure resilience, protecting communities and their livelihoods, and scaling NbS are some of the priority strategies in the National Adaptation Plan (NAP). The NAP's goal is to build resilience and adaptive capacity to minimize climate-related losses by 2050.[29] In line with the NAP, DENR has been championing the need for greater climate finance for NbS by signing several MoUs and agreements with the Department of Energy, the Government of Canada, and UNDP.[30 31] The National Biodiversity Strategy and Action Plan (NBSAP) aims to restore 1 million ha of degraded forests, improve conservation of key biodiversity areas, and achieve no net loss in forest cover by 2028.[32] The Philippine Development Plan also explicitly calls for the use of NbS in planning and design, including in goals in expanding and upgrading infrastructure and strengthening disaster resilience.[33]

The Government of the Philippines (GOP) has enacted several national level programs and policies to protect forests through sustainable management in line with the national environmental goals. The Enhanced NGP aims to restore 1.2 million ha of degraded forests to expand the forest cover which can serve as carbon sink and help in achieving the nation's GHG commitments.[34] To support the NGP, the Reforestation Information Management System (RIMS) was developed to enable efficient and systematic data management for the ENGP and other departmental reforestation initiatives.[35] And specifically as part of the infrastructure planning process, DPWH's social and environmental management system manual provides templatized guidance to collect information on environmentally sensitive and critical areas during the lifecycle of road development projects.

1.3 INTEGRATING NbS IN "UPSTREAM" PLANNING

While integrating nature-based solutions is critical at multiple stages, the analysis in this report is optimally used "upstream" prior to individual project design, to guide strategic planning and prioritization across multiple projects.

It is, however, also useful for the upstream stages of individual projects, routing/siting in particular, by identifying core conservation areas to avoid so they continue to provide climate resilience services (Figure 6). These earlier stages of the lifecycle provide not only the most important opportunity to avoid the greatest risks but also identify the most significant opportunities for investments in NbS that provide the greatest benefits at scale.

As decision-makers, designers, and developers move farther into the lifecycle, the opportunity to avoid risks declines as costs for changing either siting or design to either avoid or mitigate them increase (Figure 7). Far too often in project development, environmental impacts, risks, and NbS opportunities are considered at later stages when it becomes too costly to realistically integrate them in the project.

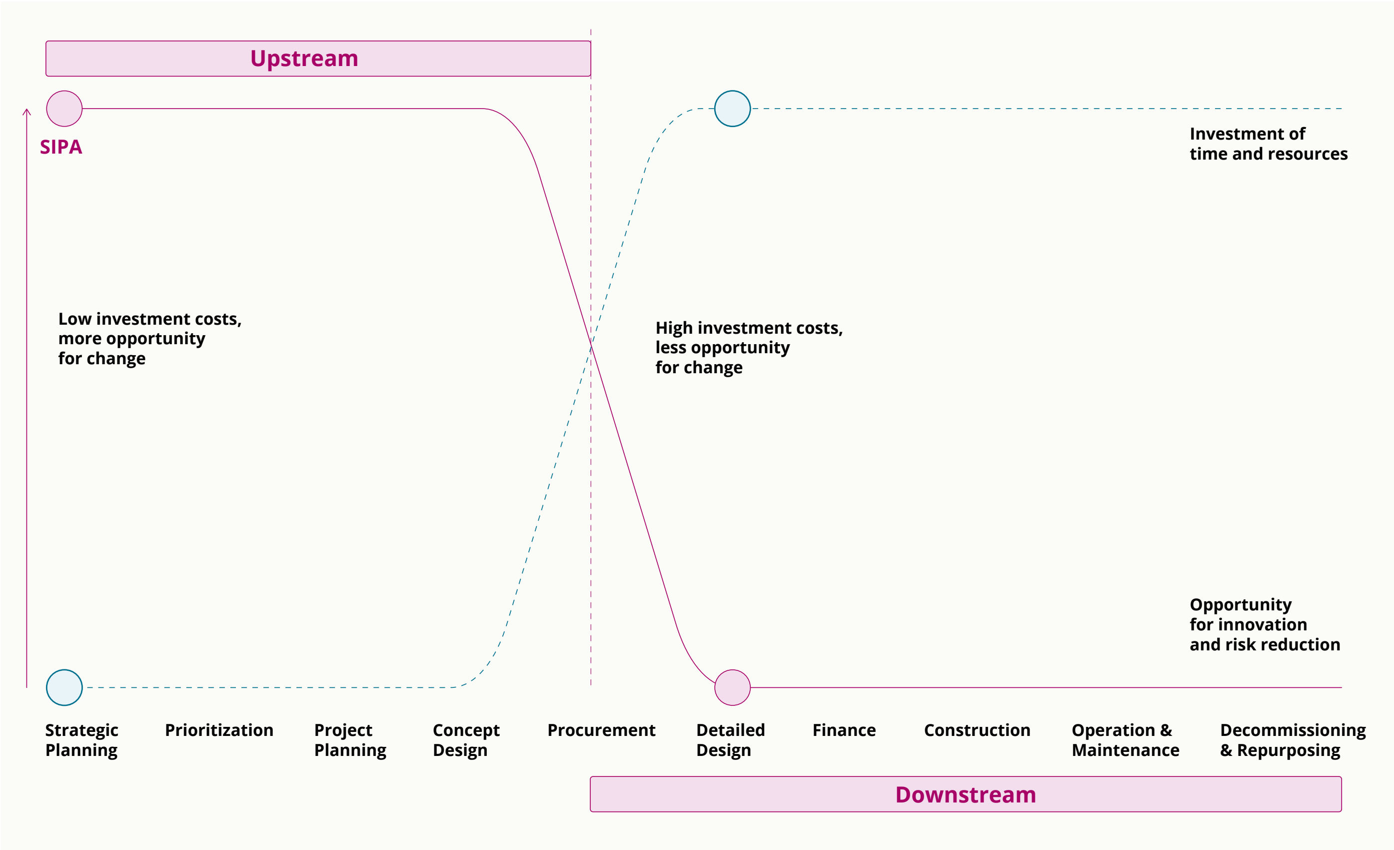


Figure 6 & 7. The benefits of considering nature-based solutions opportunities in the earliest stages of infrastructure planning.

This report aims to support these planning decisions by relevant actors in planning departments across ministries by spatially identifying areas that provide the most benefits for climate resilience for people and transportation infrastructure (roads) downstream. For example, planners at DEPDev and DPWH at the national level, in coordination with colleagues in the relevant targeted regions, could use the mapping analysis provided here (and through the interactive mapping portal, sipanbsmapper.org), to determine which areas to either avoid or identify for restoration in routing new national roads because they provide multiple climate resilience benefits both to individual projects but also populations downstream, reducing flooding or landslides, supporting water supplies, or protecting coastal communities and other critical infrastructure. Section 4 below, Applying this Information in Practice, provides additional examples and use cases for the mapping results in the next section, including use for cost-benefit analysis for individual projects.

MODELING APPROACH

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02 MODELING APPROACH

HERE WE IDENTIFY PRIORITY LOCATIONS FOR NATURE-BASED SOLUTIONS BY MODELING CLIMATE ADAPTATION ECOSYSTEM SERVICES

Nature provides a diversity of benefits to people, including regulating services that can protect people from hazards like flooding and coastal storms, reduce erosion and the resulting impacts on water quality, and recharge groundwater for a more reliable supply. These regulating services can help buffer people and infrastructure from the impacts of climate change and losing them could make us even more vulnerable to these impacts. Nature-based solutions, including conservation of existing ecosystems where they are threatened and restoration of degraded or converted ecosystems, are becoming an increasingly important strategy for climate change adaptation. But to implement such strategies most effectively, it's important to identify where these actions will have the greatest value for different services and for different beneficiaries.

Here we identify priority locations for nature-based solutions by modeling climate adaptation ecosystem services for plausible scenarios of conservation and restoration, targeting the areas with the greatest change in ecosystem service provision resulting from the scenarios.

Using the ecosystem service models from Integrated Valuation of Ecosystem Services and Trade-offs (InVEST[b]) in a broader modeling framework, we consider the supply of an ecosystem service (from biophysical models), the demand for that service (based on the location of potential beneficiaries of the service), and the flow of the supply of that service to where it is demanded. We quantify the supply of the service through a scenario approach where a change in the ecosystem--for example, a shift from forest to grassland, or forest to impervious surface--results in a change in (the supply of) the ecosystem service.

Measuring the supply in terms of change is important because while for some services, like water recharge, the supply is directly represented by the biophysical model, for services that mitigate a risk or undesired impact, like sediment retention, flood mitigation, or coastal risk reduction, the model outputs risks or impacts rather than service. **The service is the reduction in risk or impact on people or infrastructure downstream or protected from coastal storms from the addition or avoided loss of an ecosystem**.

Constructing scenarios for conservation requires a counterfactual of what would be likely to occur or could potentially occur in the absence of conservation. This can be represented through land-use conversion risk mapping, but a variety of assumptions must be made to assess that risk. We modeled two conservation scenarios for the Philippines to best capture both the impacts to ecosystems from roads and road-driven development and also the benefits that ecosystems provide to road infrastructure and people, both within the area of impact of roads and across watersheds and along coastlines.

[b] https://naturalcapitalproject.stanford.edu/software/invest

THE SERVICE IS THE REDUCTION IN RISK OR IMPACT ON PEOPLE OR INFRASTRUCTURE FROM THE ADDITION OR AVOIDED LOSS OF AN ECOSYSTEM.

The first scenario (unconstrained conservation: all potential areas supporting NbS) considers all relatively intact forest ecosystems, while the second (infrastructure impact conservation: avoiding the loss of NbS in areas impacted by infrastructure) focuses on forests within 25 km of roads near urban areas and within 15 km of roads in more rural areas. We considered the National strategic roads (JSN) and toll roads for identifying conservation areas within the designated buffer.

The first scenario, unconstrained conservation, helps us understand the value of conservation occurring anywhere (to provide value to roads and people). This scenario uses a counterfactual of any relatively intact forest areas potentially being converted to agriculture. By evaluating the loss of ecosystem services from this deforestation, we estimate the marginal value of the service on each pixel, which identifies the most critical areas for conservation. Specifically, the "service" is a combination of biophysical value (e.g., tons of sediment retained, cubic meters of water filtered) and the number of people or kilometers of road benefiting from these services. In this scenario, the highest biophysical service value might be higher in less populated areas, but this would be counterbalanced by the number of people or area of roads that could benefit being higher in more developed areas, so the overall highest areas could be expected to be still relatively intact areas that are not too distant from population centers.

In the second conservation scenario, infrastructure impact conservation, we instead created a degradation function to estimate how roads can impact forests over space and time. The function creates the greatest degradation in biophysical service value closest to roads and then dissipates to lesser impacts laterally out to a maximum distance of 25km for roads near settlements and 15km for rural roads (based on peer reviewed literature). This scenario helps identify the areas around current infrastructure that are highest value to roads and people, and therefore where managers should be most concerned about avoiding any potential impacts that could branch out from that existing road network. Roads are well documented to lead to cascading impacts from other uses (e.g., higher rates of timber and fuelwood harvesting, more illegal clearing for agriculture), but it would be difficult to prevent those impacts everywhere at once along roads. This scenario highlights where prevention activities through conservation interventions would be most important for NbS that support climate resilience.

Constructing a scenario for restoration is far simpler; we reclassified all agricultural and open/barren land classes to “secondary forest” (which is to say, forest but not as high quality as current primary/intact forest). The biophysical models are run on each scenario, and the difference between the scenario and the baseline (current) land cover is the marginal value of the biophysical supply of the service, which as with the other services, is combined with the number of people or km of roads benefiting to arrive at the full marginal value of the service for restoration.

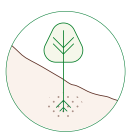
If the supply of an ecosystem service is high but there is nobody who needs it, the ecosystem does not truly provide a service to anyone. The biophysical supply of the service must be combined with socioeconomic information about beneficiaries that indicates the demand or need for the service, in order to

IF THE SUPPLY OF AN ECOSYSTEM SERVICE IS HIGH BUT THERE IS NOBODY WHO NEEDS IT, THE ECOSYSTEM IS NOT PROVIDING A SERVICE TO ANYONE.

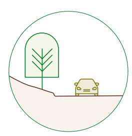
understand where the ecosystem service provides the most value.[c] Specifically, we attribute the number or amount of beneficiaries to the pixel of habitat (30m x 30m) benefiting them, based on the flow algorithm of how the service is delivered to them (hydrologic routing for the water-related services, spatial proximity for coastal risk reduction), and then multiply the number of beneficiaries by the benefits provided by that pixel, such as sediment retention, flood mitigation, coastal risk reduction, or water recharge.

Ideally, the model would also include information about vulnerability or adaptive capacity (e.g., based on income or other demographics). However, SIPA's scope is broader than just identifying vulnerable subsets of the population. Therefore, we evaluate changes in biophysical supplies of ecosystem services for conservation and restoration scenarios by considering the number of people or the amount of infrastructure benefiting from these services.

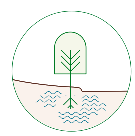
The result is the realized service that we include in spatial prioritization analyses to identify the areas for conservation and restoration that provide the most value to the most people and greatest area of infrastructure: nature-based solutions for climate resilience. We prioritized the top 10% of ecosystem service-providing areas for restoration and conservation for each of 7 service-beneficiary combinations:



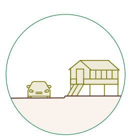
Sediment retention for downstream populations



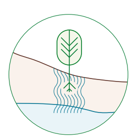
Downstream roads



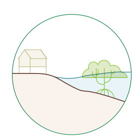
Flood mitigation for downstream populations in floodplains



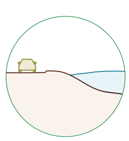
Downstream roads in floodplains



Water recharge for downstream population



Coastal protection for coastal populations



Coastal roads

[c] This is why many "intact" ecosystems in protected areas, for example, may not be showing up as important: because they are either beyond the 15-25km extent of estimated degradation under the infrastructure impact conservation scenario, or there are relatively lower population numbers or kilometers of roads benefit-ting downstream.

To at least partially estimate relative climate-resilience of the services themselves, each service was modeled under current and future (SSP 2 RCP 4.5) climate conditions, and only areas falling in the top 10% of service provision for both were selected as the "climate-robust" priorities for conservation and restoration. We then overlapped these top 10% areas of provision to identify hotspots of service provision.

We developed three overarching questions to analyze our results which would help national level planners better understand the findings in the context of national priority projects, programs, and provinces:

01 Where are the highest priority areas for different services?

02 What percentage of these priority areas are already protected or otherwise prioritized for conservation or restoration?

03 How many people and how much road infrastructure are benefiting from these areas?

RESULTS

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03 RESULTS

Our analysis identifies both where and how much—in terms of total kilometers of roads and millions of people—conservation and restoration efforts through NbS should be prioritized to maintain and enhance climate resilience through sediment retention, flood risk reduction, water recharge, and coastal protection services. This section is broken down into three areas

01 Where these priority areas are located;

02 How much they are already protected;

03 How many people and how much infrastructure benefit.

Overall, in areas most impacted by road and settlements, results show that conserving the priority top 10% of areas that support the most NbS benefits, representing just 19% of the country's land area, is critical to maintain resilience for millions of people and tens of thousands of kilometers of roads. A similarly small land area is disproportionately important if we broaden the analysis to all areas beyond this impact zone: conserving just 16% of these priority areas is important for resilience. We similarly find that restoring degraded forests on just 13% of the country's land area would benefit millions of people and thousands of kilometers of roads (Table 1, Table 3).[d]

Table 1. Total Area of Identified Conservation or Restoration Top 10% NbS Priorities

Scenario	Area (Ha)	Percent of total country area
Unconstrained Conservation	**4,642,975**	**16%**
Infrastructure Impact Conservation	**5,637,102**	**19%**
Restoration	**3,809,010**	**13%**

3.1 WHERE ARE THE HIGHEST PRIORITY AREAS FOR DIFFERENT SERVICES?

Different provinces and the services they provide show varying spatial patterns for conservation and restoration. For both conservation scenarios, regions II, III, VI, X, and Cordillera Administrative Region (CAR) are the top five regions disproportionately home to priority areas. For restoration, the top regions are I, II, III, IV-A, and X (Figure 8).

Roughly 25-28% of these areas provide multiple services depending on the scenario; i.e. sediment retention and water recharge are both supported by the same forests (Table 2).[e] These overlapping areas under each scenario occupy 3-5% of the total area of the Philippines, arguably representing even more critical priorities for conservation and restoration given their scarcity and provision of multiple benefits. Sediment retention overlaps with other services the most across both

[d] To download and further explore all relevant data and mapping layers, please visit our interactive mapping portal at www.sipanbsmapper.org.

the conservation scenarios whereas water recharge overlaps the most with other services in the restoration scenario. Coastal protection overlaps the least, with less than 1% for both conservation and restoration, due to its limited geography, being confined to within 2 km of the coast.

Table 2. Proportion of priority areas with overlapping services across the country

Scenario	A-Total country area (Ha)	B-Total prioritized area for each scenario(Ha)	Portion of prioritized area with more than one service provision		
			C -Total Area (Ha)	Percentage of the prioritized area that has more than one service. (C/B)	Percentage of the total country area that is prioritized and has more than one service (C/A)
Unconstrained conservation	187,982,622	34,654,501	8,565,003	24.72%	4.56%
Infrastructure Impact Conservation	187,982,622	29,807,538	8,976,836	30.12%	4.78%
Restoration	187,982,622	19,855,550	5,878,018	29.60%	3.13%

The maps below show municipalities that provide the greatest contributions of services under conservation or restoration scenarios (Figure 8). The intensity of the color represents the total ecosystem service contribution, with darker colors indicating municipalities that have a higher number of services spread over a larger area. This map highlights areas where both the intensity of ecosystem services and the proportional area are significant, providing a comprehensive view of ecosystem service hotspots.

Maps 9-11 show these same results in greater detail at the pixel level (which can also be explored at our interactive mapping web portal here), with the darkest shades representing areas that provide the most services (sediment retention, water recharge, flood risk reduction, or coastal protection). The difference in the conservation scenarios here is most evident, showing areas much farther from current roads providing benefits in the unconstrained scenario compared to the limited 15-25km bands of the infrastructure impact scenario. The impact scenario maps show which areas are critical to invest in to maintain resilience supporting functions for roughly 45% of the population and nearly 40% of the road network (Figure 10).

As the next section details, many of these areas are found outside Protected Areas and Key Biodiversity Areas, showing both the critical importance of new interventions to maintain these resilience services in areas most likely to be degraded or deforested due to their proximity to the road network, but also new opportunities for investment in NbS beyond this buffer across watersheds and along coastlines. The restoration scenario shows the effectiveness of PAs and KBAs, with most priority areas found outside of them (Figure 11). There are, however, some evident priority areas within them that would present the easiest opportunity to create mutual benefits for both biodiversity and climate resilience for people and infrastructure.

[e] Spatial patterns for the biophysical supply of the different services—meaning where nature provides benefits regardless of how many people benefit downstream—are more distinct than for the realized services based on total beneficiaries because different climate, soil, topographical, and other geographic features determine the biophysical supply of each service. Sediment retention biophysical values tend to be greatest on steep slopes with highly erodible soils, while nature contributes the most to water recharge and flood mitigation on more moderate slopes with highly permeable soils. Coastal risk reduction is of course limited to ecosystems within a few kilometers of the coast, but there are some overlaps with areas with high magnitudes of flood mitigation and sediment retention, especially in coastal wetlands.

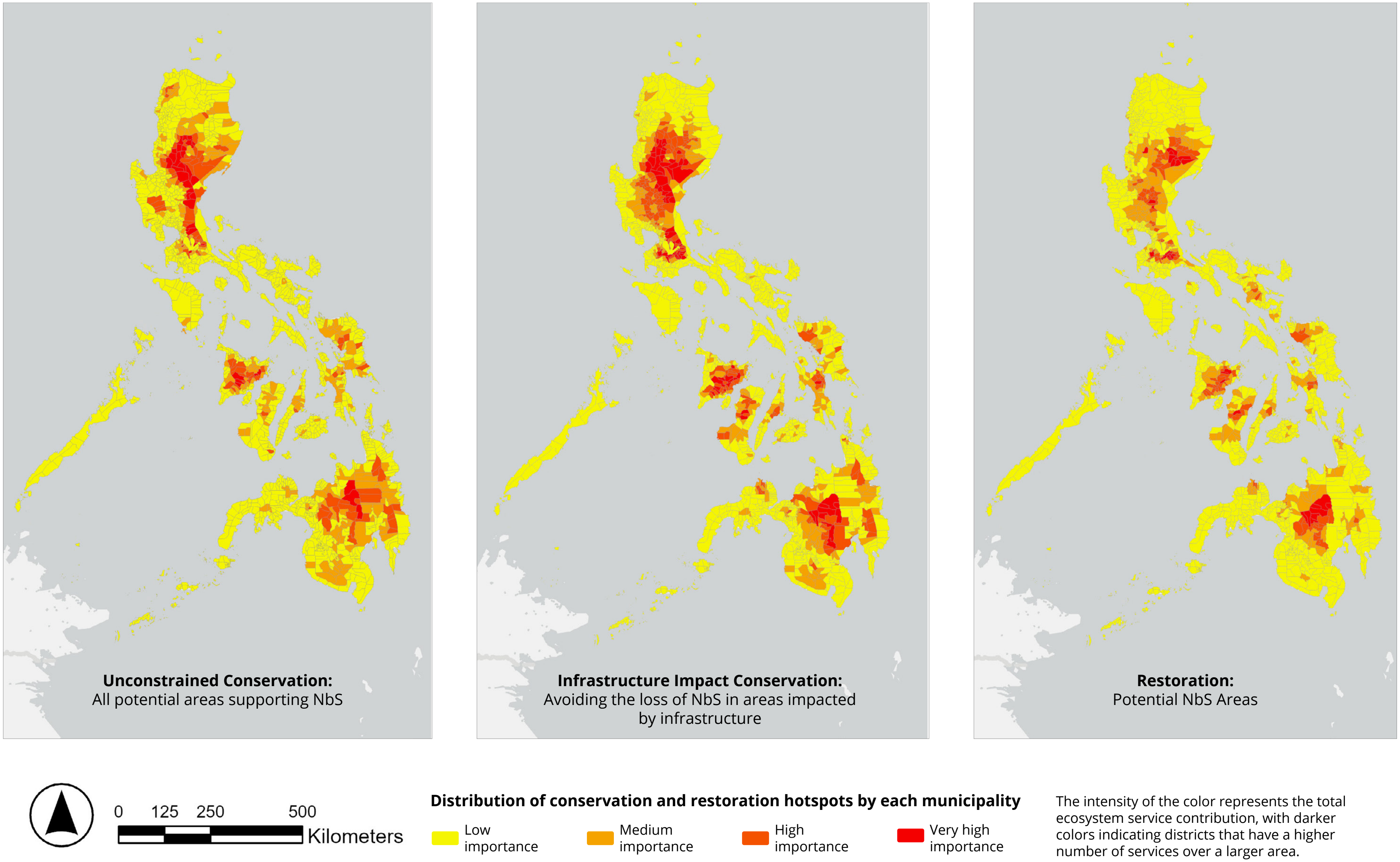


Figure 8. Conservation and restoration hotspot maps illustrating the total ecosystem service contribution per hectare for each municipality.

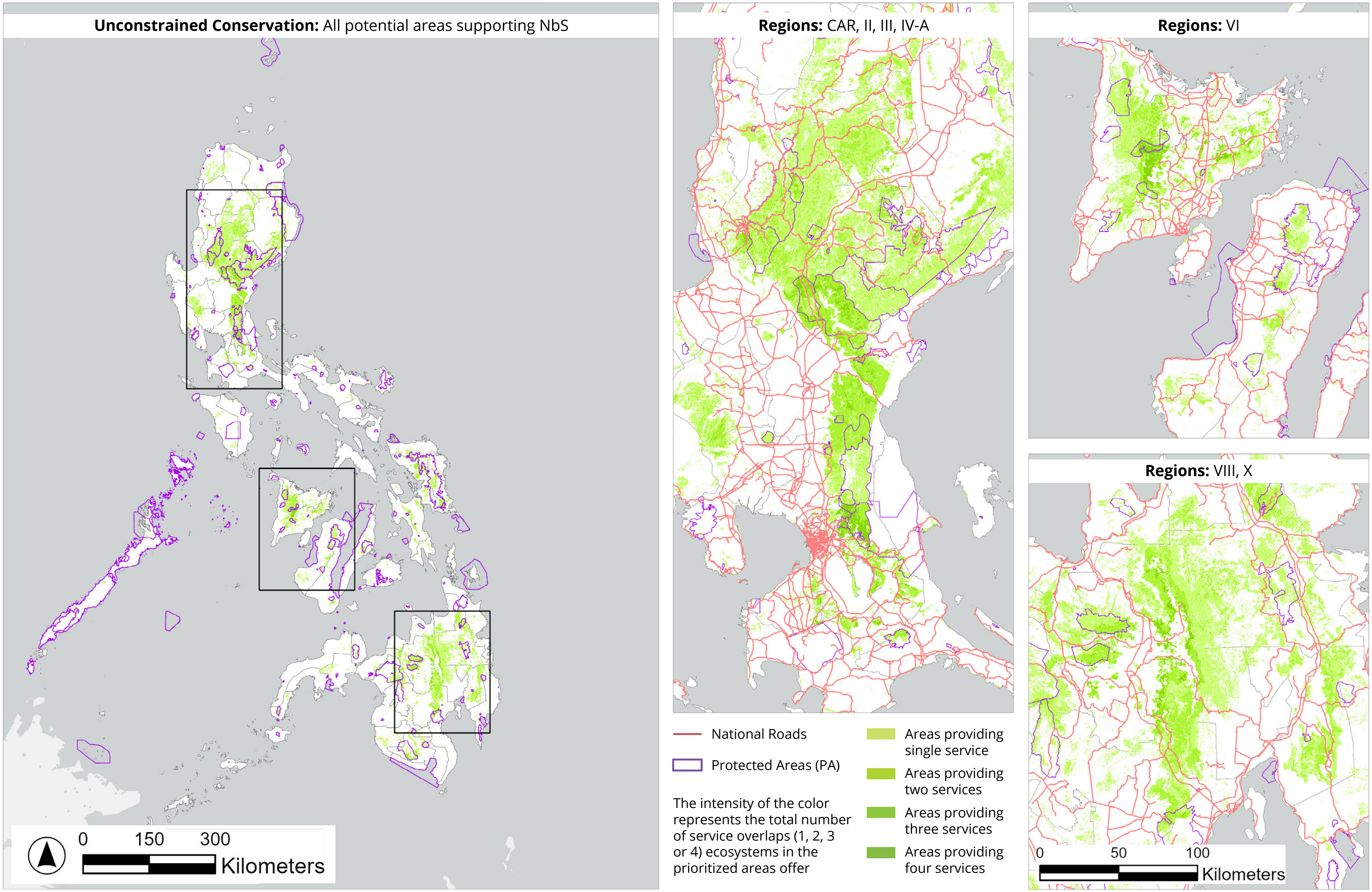


Figure 9. Unconstrained Conservation Scenario: Key provinces with one or more service overlaps

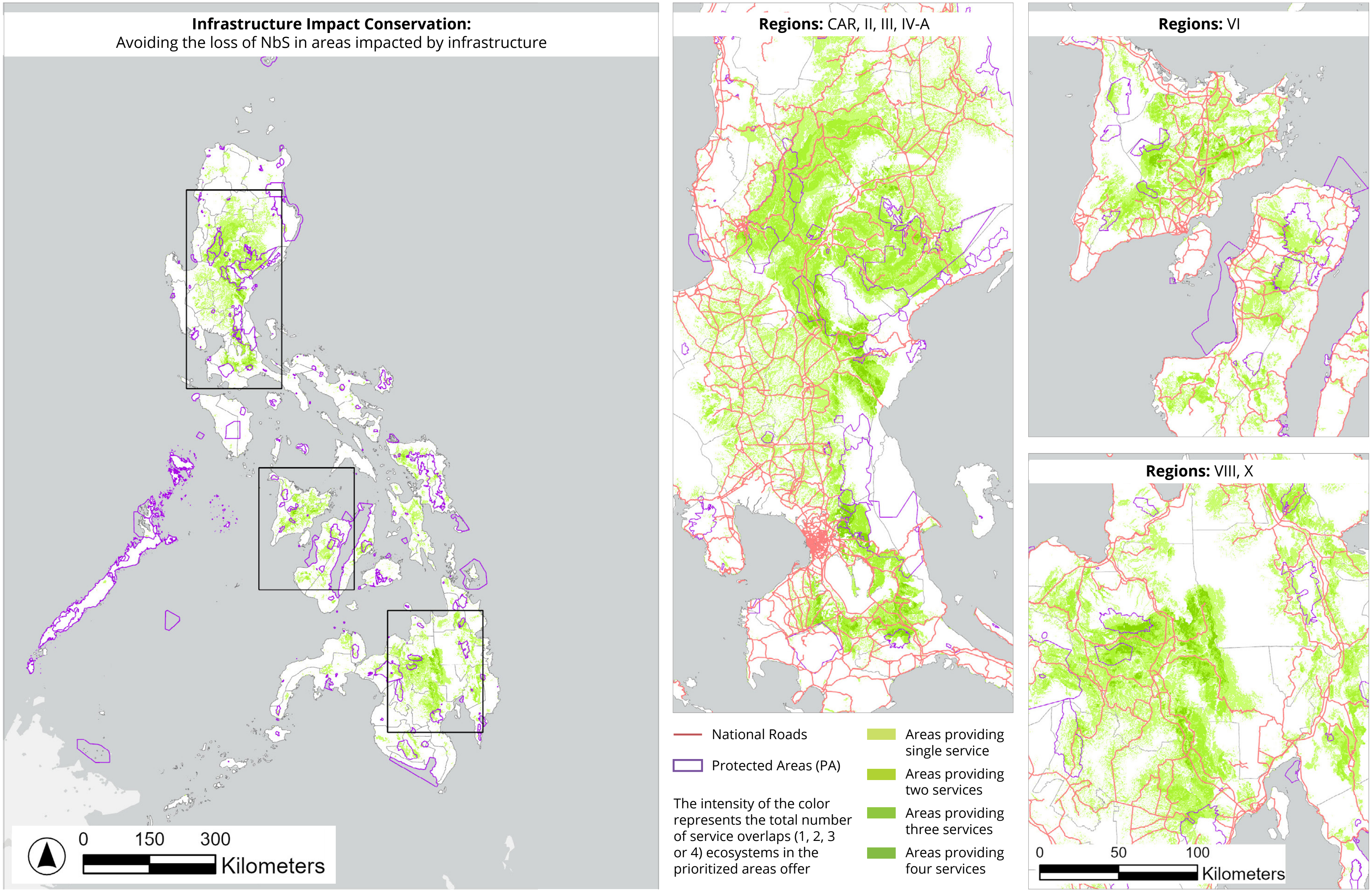


Figure 10. Infrastructure Impact Conservation Scenario: Key provinces with one or more service overlaps within 25km of human settlements and 15km of toll roads.

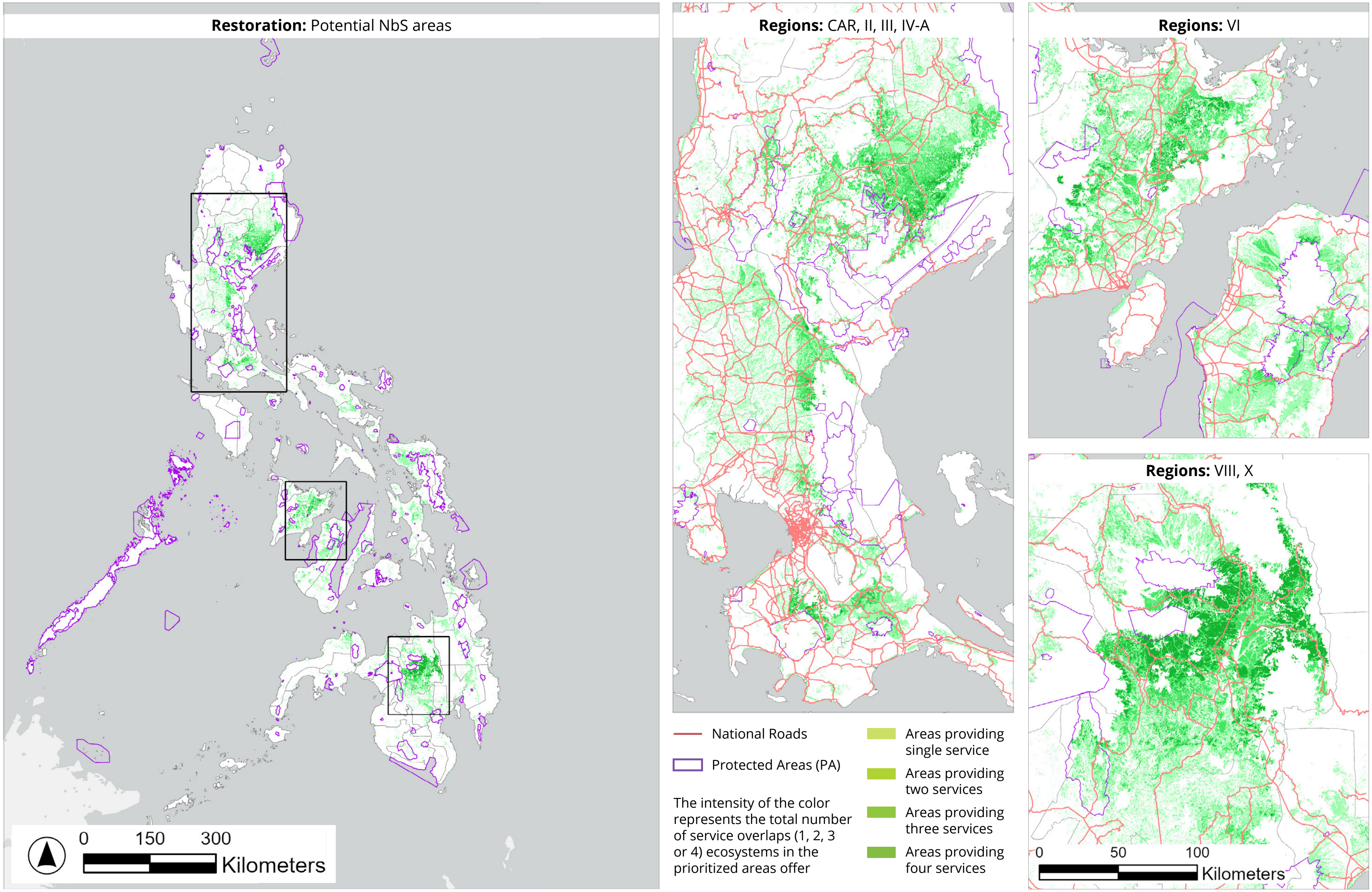


Figure 11. Restoration: Key provinces with one or more services.

3.2 WHAT PERCENTAGE OF THESE PRIORITY AREAS ARE ALREADY PROTECTED OR OTHERWISE PRIORITIZED FOR CONSERVATION OR RESTORATION?

A significant percentage of areas identified for conservation and restoration lie outside of protected areas (PA) and the Key Biodiversity Areas (KBAs). Under the unconstrained conservation scenario, about 75% of areas are unprotected, while within the road impact buffer, the number rises to 83% (as we would expect given that the scenario excludes some PAs farther from roads). Not surprisingly, given that we would expect to see more degradation outside protected areas, the total area prioritized for restoration currently lacking protection is even more at 93%

For all three scenarios, the area lying outside of KBAs is between 70-95%. A smaller percentage of areas within PAs also lie within KBAs—14% under the unconstrained conservation scenario, 9% for the infrastructure impact conservation scenario, and 3% for restoration. These results show that there is significant potential to invest in NbS to maintain and enhance climate resilience for people and infrastructure through conservation or restoration approaches, though the majority are found outside the PA network.

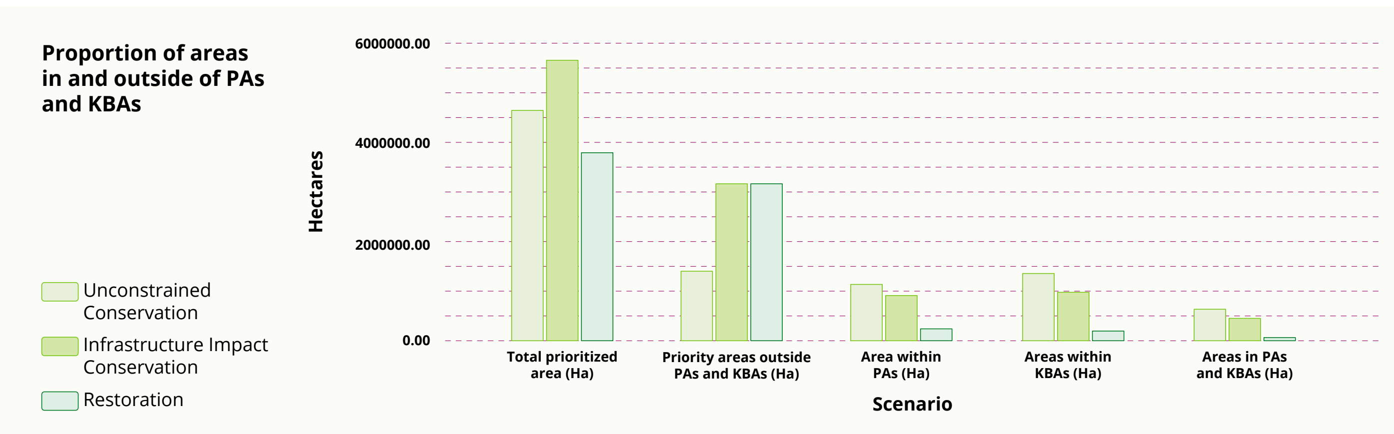


Figure 12. Proportion of identified conservation (both scenarios) and restoration areas within and outside of existing protected areas (PA) and key biodiversity areas (KBA).

3.3 HOW MANY PEOPLE AND HOW MUCH ROAD INFRASTRUCTURE ARE BENEFITING FROM THESE AREAS?

Table 3. Road and population benefiting by NbS upstream

Scenario	Total Population	Total km of toll roads	Number of people benefiting	% percent of people benefiting	Number of km of roads benefiting	% of roads benefiting
Unconstrained conservation	105,476,431	37,846	42,732,296	41%	15,799	42%
Infrastructure Impact Conservation	105,476,431	37,846	53,580,731	51%	21,142	56%
Restoration	105,476,431	37,846	50,557,934	48%	19,586	52%

The climate resilience of approximately 54 million people, about half the population, and roughly 56% of the nation's roads depends on conserving the priority areas most impacted by infrastructure and development (within the 15-25 km buffer; Figure 14, Table 3). Broadening the analysis to all ecosystems that might support climate resilience, the numbers decrease slightly to nonetheless still very significant numbers of 43 million people and 42% of the road network (Figure 13). This indicates that there are regions distant from existing settlements and current or planned roads that nonetheless provide valuable NbS for people and roads downstream and along coastlines. The lower beneficiaries are due to two reasons: more people inherently are closer to roads and settlements so they are more directly benefitting from those ecosystem services within the buffer; and the biophysical supply of NbS benefits is much larger in areas well beyond roads, reducing the proportional number of people and roads who might benefit from the top 10% prioritized areas.

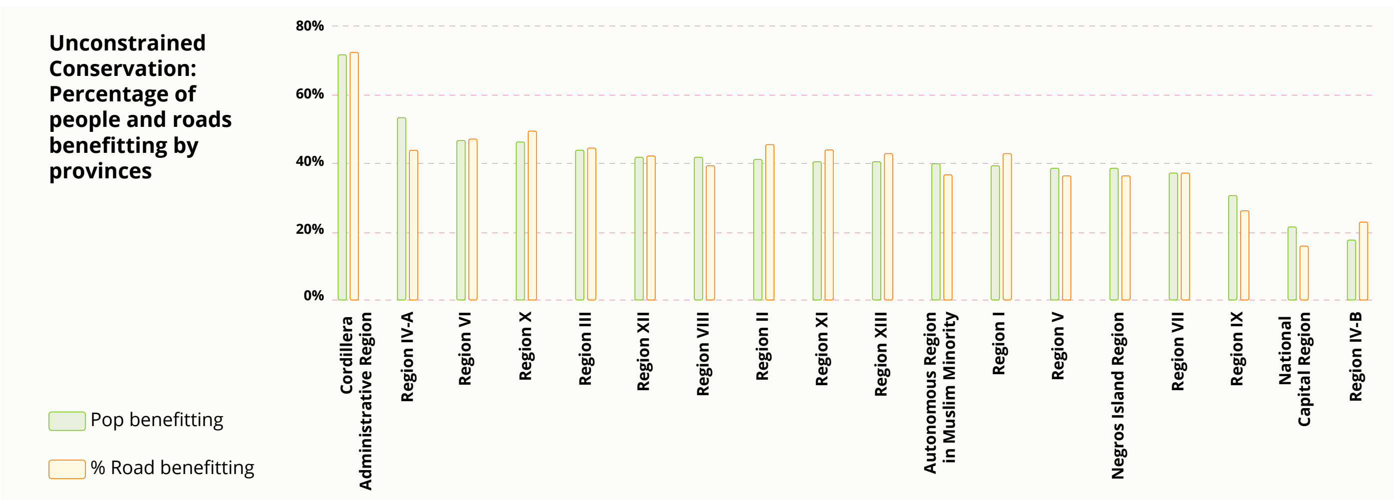


Figure 13. Proportion of total number of people and km of roads benefiting in each province under the identified unconstrained conservation scenario.

Cordillera Administrative Region (CAR) and Region IV-A have over 50% of their population benefiting from conserving all identified areas. Similarly, in 10 regions over 40% of the road network benefits from conserving areas identified under the unconstrained conservation scenario (Figure 13). Cordillera Administrative Region (CAR) and Region X are top provinces with the greatest number of people and roads simultaneously benefitting. Under the infrastructure impact conservation scenario, Cordillera Administrative Region (CAR), regions II, X, and II have over 50% of their population and roads simultaneously benefitting climate resilience services provided by the identified ecosystems.

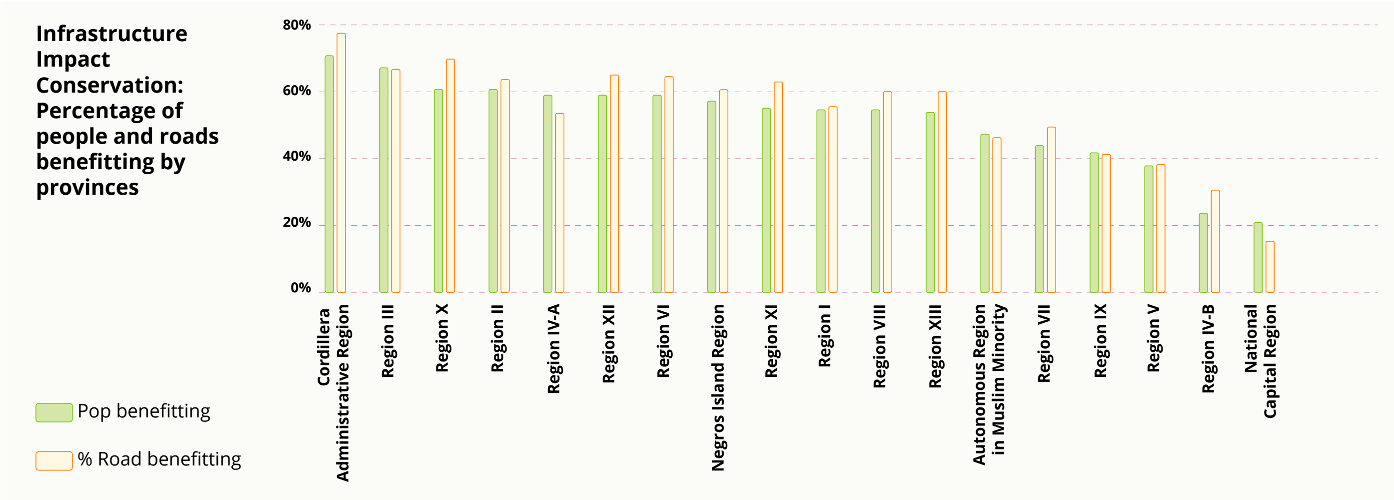


Figure 14. Proportion of total number of people and km of roads benefiting in each province under the identified infrastructure impact conservation scenario.

Our results show significant opportunities to enhance adaptive capacity for people and improve resilience for roads through restoration of identified areas. Roughly half the population and road network would benefit (Table 3). These beneficiaries include people downstream of and in low-lying areas along the coasts within the protective distance of ecosystems identified for conservation or restoration. Region X, III, II, and Negros Island region are some of the key regions with the need for large scale restoration strategies to be considered in the infrastructure planning and implementation cycles (Figure 15).

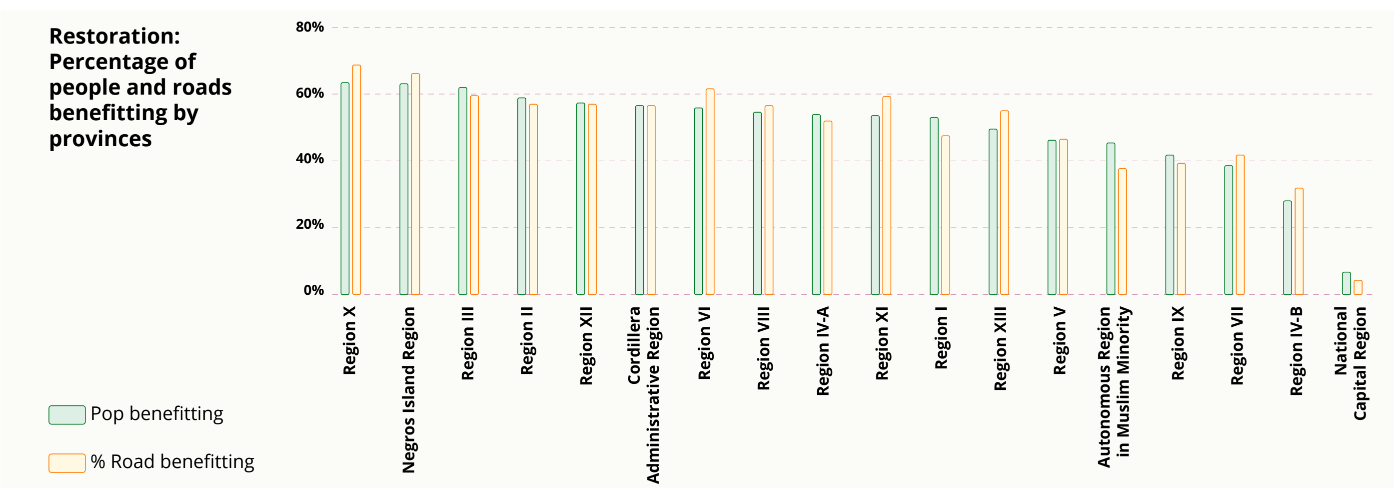
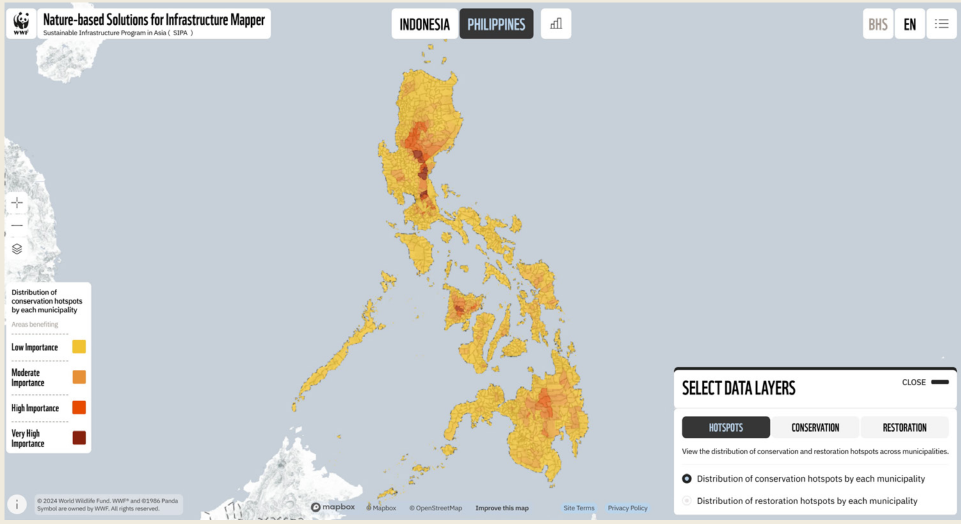


Figure 15. Proportion of total number of people and km of roads benefiting in each province under the identified restoration scenario.

BOX 3. NATURE-BASED SOLUTIONS FOR INFRASTRUCTURE MAPPER



To assist planners and decision-makers in exploring maps more thoroughly, WWF has developed an interactive mapping portal, www.sipanbsmapper.org, including additional relevant layers and maps only briefly summarized here. The portal identifies Nature-based Solutions (NbS) areas for investment opportunities under scenarios of habitat conservation and land restoration for four ecosystem services:

01 Sediment retention,

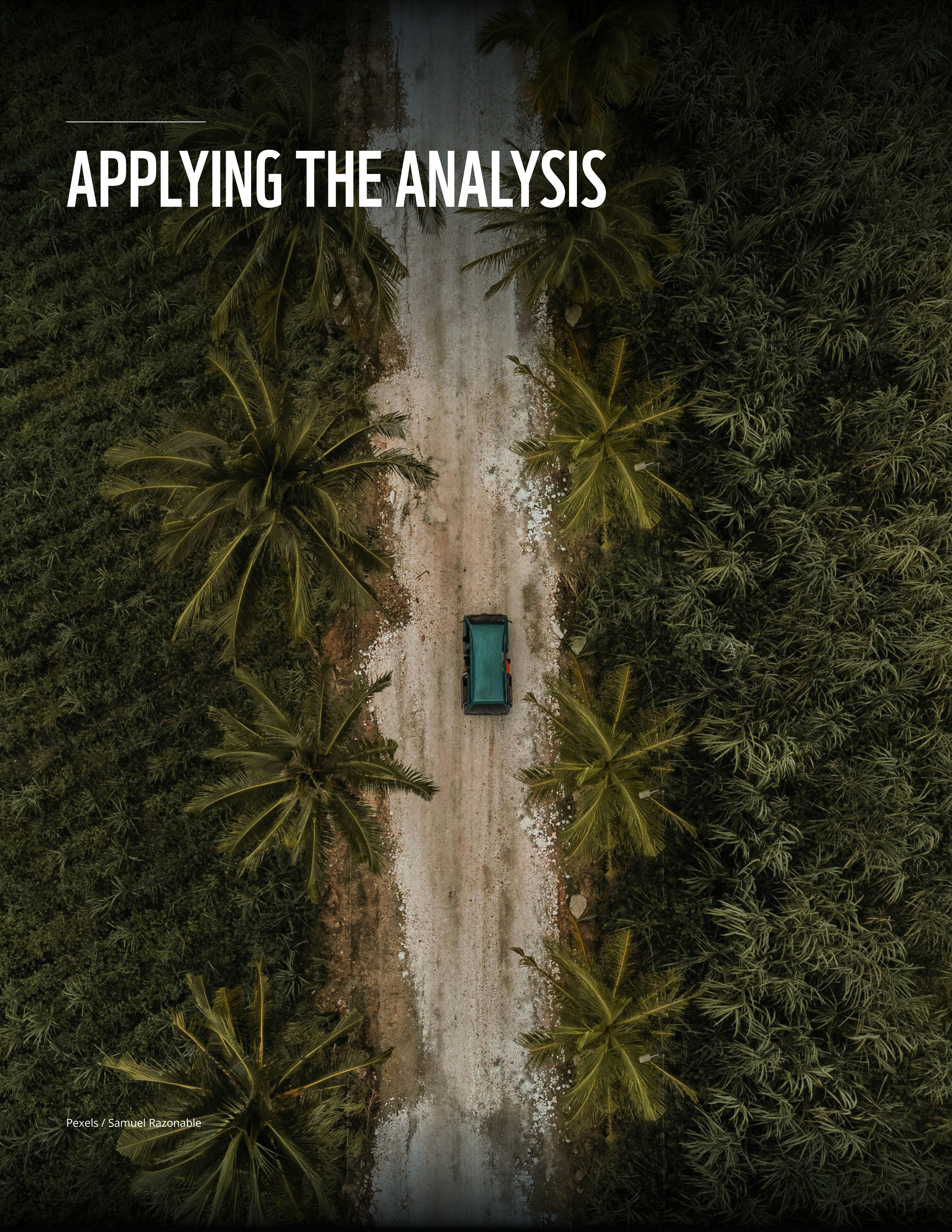
02 Flood mitigation,

03 Coastal risk reduction,

04 Water recharge.

The portal also allows users to toggle between baseline maps and identified priority areas and hotspot maps that highlight the most critical municipality providing the highest levels of ecosystem services over a larger area.

APPLYING THE ANALYSIS



Pexels / Samuel Razonable

04 APPLYING THE ANALYSIS

PLANNERS CAN USE THESE MAPS TO AVOID IDENTIFIED CONSERVATION AREAS OR TO IDENTIFY DEGRADED LANDS FOR RESTORATION WITHIN THE PROJECT AREA.

The maps and analysis presented in this report are most relevant in guiding Philippines' national and subnational strategies in infrastructure planning (targeting transportation and roads specifically), to improve climate resilience of communities and transportation (and other infrastructure that similarly benefits) through nature-based approaches. There are, however, also significant co-benefits for national strategies and goals in biodiversity conservation, restoration, and climate mitigation and adaptation plans.

4.1 MAINSTREAMING NbS IN KEY NATIONAL AND SUBNATIONAL PLANNING PROCESSES AND THEIR IMPLEMENTATION

DEPDev, DENR, DPWH at the national and sub-national levels can use these maps when planning new national roads, determining the status of protected areas, or advocating for increased investments in sustainable projects. DEPDev, for example, could leverage these maps and results in its flagship infrastructure prioritization process to ensure major infrastructure projects align with conservation and restoration priorities, or request changes in project designs to incorporate restoration or conservation. These maps would also be useful for various DENR programs, including the Enhanced National Greening Program, Intensified Forest Protection and Anti-illegal Logging, and the Operationalization of the National ENR Geospatial Database. They could help identify targets for enhanced conservation or restoration investments to maximize resilience benefits for transportation and other sectors, with significant co-benefits for biodiversity and tourism-based livelihoods.

Similarly, the results can be used to set new national targets or develop and update indicators in line with the Philippines' global and national commitments. For example, a new national target could be established for the total area of habitat conserved or restored for climate resilience benefits, directly supporting the 2025 budget, which has allocated the most funds to climate change in recent years. This target could be coordinated and cross-referenced with the National Biodiversity Strategy and Action Plan (NBSAP), National Adaptation Plan (NAP), and measured in terms of road infrastructure and/or the number of people benefiting. The analysis could guide strategic prioritization for any ministry or department investing in NbS or significant infrastructure assets by highlighting areas that disproportionately benefit the most people and/or road infrastructure.

4.2 INTEGRATING CLIMATE RESILIENCE AND SUSTAINABILITY IN NATIONAL TRANSPORTATION INFRASTRUCTURE STRATEGIES AND PROJECTS

With the strong commitment toward fighting climate change shown in the Philippines' 2025 budget, which earmarks PHP 1 trillion for climate initiatives, the maps could help in determining better planning decisions to avoid identified conservation areas that provide the most resilience benefits and biodiversity co-benefits. During the siting and design phases of toll roads, planners could use these maps to route roads away from areas providing multiple ecosystem services that support climate resilience and biodiversity.

Additionally, planners could overlay socio-economic layers, such as indigenous lands or key biodiversity hotspots (KBAs), to prioritize areas for conservation or restoration. This can be done based on updated cost-benefit analysis tools that incorporate fuller suites of environmental impacts and benefits (see 4.3).

Alternatively, if a road passes through a degraded forest, project developers could consider actions to restore specific areas, reducing operations and maintenance costs under worsening climate extremes while creating significant biodiversity co-benefits. This exemplifies "nature-positive" infrastructure development. Although the up-front costs may be higher, integrating NbS ultimately creates far greater value across multiple beneficiaries over the long run than purely engineered solutions. Incorporating NbS can enhance project viability, particularly for external funders aiming to meet sustainability targets or developers with sustainability priorities.

4.3 ANALYZING COSTS AND BENEFITS FOR EXISTING AND FUTURE ROADS

Under the SIPA program for Indonesia, IISD applied its Sustainable Asset Valuation (SAVi) tool to develop cost-benefit analysis for sections of road in Sumatra and Borneo under the conservation and restoration scenarios identified in Section 2.[36] WWF identified a 50 km stretch of road that was found to be at high risk of flooding based on national flood frequency maps (Figure 22). The area upstream of this entire stretch of road can be delineated and each of the scenario maps for conservation and restoration clipped to that extent to highlight the areas of highest value to that stretch of road. In this case, small areas immediately uphill of the road are found to be important, but much larger extents with high value have been identified further up in the watershed. Although this case study focuses on Indonesia, planners at various national-level agencies, such as DEPDev, can leverage this approach to replicate the analysis for future projects under the Infrastructure flagship program.

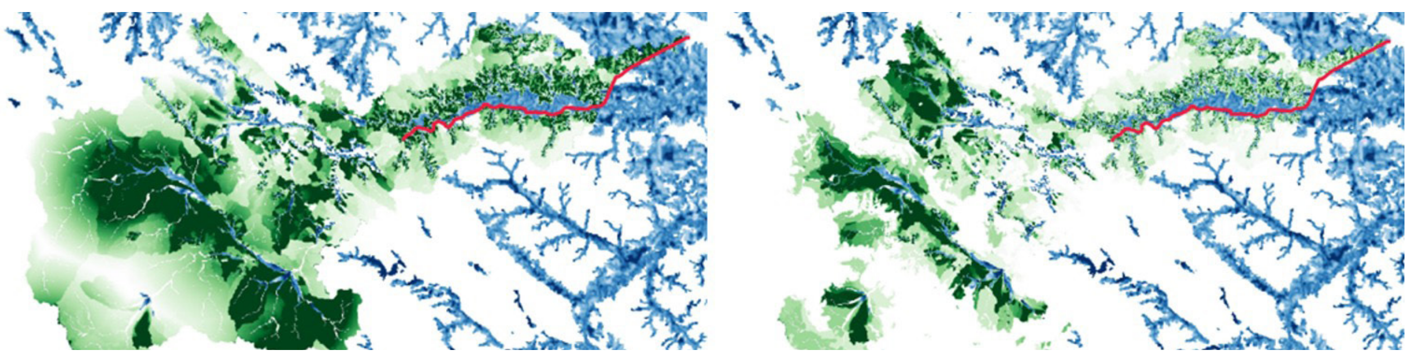


Figure 16. Flood mitigation service provided to a focal stretch of road in Central Sumatra by conservation (left) and restoration (right) activities. Flood risk (shown in blue, with darker shades corresponding to higher risk) is superimposed on flood mitigation potential (in green, again with darker shades for higher potential value) of natural habitat in each scenario. The stretch of road to which the natural areas provide a mitigation benefit is shown in red, selected based on its high exposure to flood risk.

IISD's analysis shows that the overall economic benefits to each case study are significantly higher when avoided damages and losses due to climate hazards are achieved through either conservation or restoration, accounted for through a more holistic cost-benefit analysis that internalizes and values environmental costs and benefits (Table 4).

In sum, this analysis clearly shows the overall benefits (in terms of avoided damage impacts) to be greater for existing roads when NbS are used. Specifically, two applications of the SAVi model were tested and analyzed. The first is the urban area surrounding Pekanbaru in Sumatra; the second is a rural area characterized by palm oil production in West Kalimantan. A total of 15 indicators depicting different non-road benefits are included in the SAVi model. On the other hand, different indicators are of relevance to each location (e.g. access to services is more relevant to urban areas, while access to markets is more critical in rural areas).

The results of the analysis, as presented in Table 4, highlight the enabling role of nature in creating social and economic value. By preventing damage to roads, nature allows us to maintain access to markets and services, and prevents costs related to energy use, environmental pollution, and human health. It results that while direct, monetized benefits result in a Benefit to Cost Ratio (BCR) of 0.35 and negative Internal Return on Investment (IRR), the inclusion of intangible, non-road benefits increases the BCR to 6.05 and offers an IRR of 69.5% in the case of West Kalimantan, base case simulation. This indicates that for each dollar invested, when taking an economic, societal perspective, 6.05 dollars of avoided costs and added benefit will emerge over time, across a variety of economic actors.

Planners in the Philippines' national agencies could apply a similar approach to any spatial location of a beneficiary (whether community or infrastructure location) to help identify the areas where conservation or restoration activities would make the greatest contribution to mitigating flood risk, using a tool like SAVi that more fully accounts for all costs and benefits.

Table 4. Comparative benefits and costs of alternative road development scenarios in Indonesia

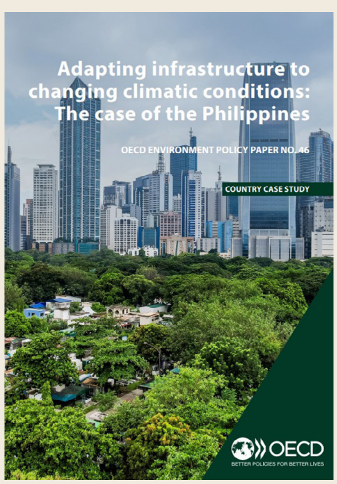
	BCR		IRR		NPV	
	excl. non-road benefits	incl. non-road benefits	excl. non-road benefits	incl. non-road benefits	excl. non-road benefits (IDR)	incl. non-road benefits (IDR)
Case 1: Base Case	0.35	6.05	Negative	69.5%	(239,168,041,921)	947,559,621,507
Case 2: Downside sensitivity	0.35	4.23	Negative	36.2%	(239,168,041,921)	568,862,840,509
Case 3: Upside sensitivity	0.35	8.23	Negative	131.1%	(239,168,041,921)	1,401,520,903,994
Case 4: Different crop and livestock	0.35	6.53	Negative	80.9%	(239,168,041,921)	1,048,388,735,059
Case 5: Tangible impacts only	0.35	2.41	Negative	13.9%	(239,168,041,921)	189,751,720,274

4.4 NEW INVESTMENTS IN NBS CONSERVATION AND RESTORATION PROJECTS FOR NATURE POSITIVE DEVELOPMENT

As noted in the results section, less than half of the areas prioritized for conservation of ecosystem services are protected within the current Protected Area (PA) network, even under the broader unconstrained conservation scenario. Given the clear win-wins for both the resilience of the road network and biodiversity, this presents an opportunity for coordination between key ministry departments—such as the Department of Environment and Natural Resources (DENR), Department of Economy, Planning, and Development (DEPDev), and Department of Public Works and Highways (DPWH)—to invest in Nature-based Solutions (NbS) for larger benefits. With most priority areas identified outside the Protected Area system or Key Biodiversity Areas (KBAs)—approximately 70-95% depending on the scenario—additional policy and collaboration mechanisms with private landowners are critical to ensure these areas remain functional ecosystems that continue to provide water recharge, flood risk reduction, sediment retention, and coastal protection benefits.

Similarly, there are shared benefits for restoration opportunities within Protected Areas, which account for 7% of the priority areas for restoration. These present direct opportunities for developers to create "nature-positive" projects that simultaneously invest in significant restoration efforts. For example, DENR could collaborate with DPWH to invest in these areas, given their role in supporting the resilience of the road network while strengthening the existing protected area system through restoration. They could collaborate with local stakeholders to assess the feasibility of conservation or restoration strategies for specific projects and identify the best ways to incorporate NbS strategies to achieve maximum benefits.

BOX 4. OECD'S POLICY PAPER ON ADAPTING INFRASTRUCTURE TO CHANGING CLIMATIC CONDITIONS: THE CASE OF THE PHILIPPINES



This policy paper examines the vital need for climate resilience in the Philippines' infrastructure due to its exposure to significant climate risks. It outlines how the Philippine Development Plan aims to integrate climate resilience into infrastructure development, recognizing its importance for economic growth and stability. The document highlights current efforts, such as risk assessments and policy frameworks, while also identifying challenges, including a lack of standardized approaches, limited capacity, and difficulties in financing. Ultimately, the paper proposes an action plan with concrete steps and priorities to strengthen the country's infrastructure against changing climatic conditions across various sectors like water, energy, transport, and social infrastructure.

RECOMMENDATIONS

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05 RECOMMENDATIONS

These analyses can support maintaining and enhancing climate resilience in the Philippines through nature-based solutions in relevant conservation, infrastructure development, and climate change adaptation policies, planning, and projects at both the national and subnational levels. However, they are most valuable in the "upstream" phases of infrastructure spatial and strategic planning that present optimal opportunities to proactively address climate and biodiversity risks through NbS. Given their comprehensive national coverage, these results can also effectively complement similar mapping analyses utilized in ongoing planning processes at national to subnational scales, including strategic environmental assessments (SEAs) and environmental impact assessments (EIAs) at the project level. In this context, we recommend the following to enhance climate resilience through NbS in Philippine infrastructure planning:

01 **Integrate these maps and analysis into existing risk assessment web portals and associated planning tools within and across agencies, including GeoRisk and DENR's Climate Risk Diagnostic Tools.**
As the primary centralized web portal for assessing climate risks nationwide, GeoRisk and its associated tools, including the forthcoming Plan Smart climate adaptation planning tool for cities, and DENR's new diagnostic tool, should be updated to include layers on priority areas for conservation and restoration for NbS for adaptation (e.g. the data layers and final maps for these analyses). Internal mapping databases and tools within agencies like DPWH to evaluate routes, connectivity, land use, and other critical inputs as part of transportation master planning could also be updated to integrate the full data and results of these analyses.

02 **Enhance inter-agency collaboration to support implementation of NbS in identified priority areas to meet climate and biodiversity plans and goals.**
DEPDev, DPWH, the Climate Change Commission (CCC), and DENR should collaborate to capitalize on existing mechanisms, such as the National Asset Management Plan (NAMP), Philippine Biodiversity Strategy and Action Plan (PBSAP), National Adaptation Plan (NAP), and forthcoming updated National Climate Change Action Plan (NCCAP), targeting priority areas. Such a joint effort would align with NAMP's overarching goal of enhancing the cost-effectiveness of public expenditures for national assets and provide co-benefits for biodiversity. For instance, conserving or restoring areas in Bukidnon province could provide crucial flood and landslide protection for downstream roads. Additionally, leveraging the People's Survival Fund (PSF) could provide financing for local adaptation projects focused on conserving intact ecosystems and restoring degraded areas which would not only reduce maintenance costs but also bolster resilience.

03 Leverage the Build Better More (BBM) programme budget to strategically invest in priority nature-based solutions identified in this analysis as "natural infrastructure".

The BBM programme, allocating PHP 148B for the development of over 700 km of new roads and an additional PHP 4.7B for environmental conservation, provides a unique opportunity to fund significant conservation and restoration efforts that would directly enhance climate resilience for not just infrastructure but communities downstream, while simultaneously creating significant co-benefits for ecosystems and wildlife. conservation and restoration areas and approaches and standards for implementation.

04 Consider expansion of the National Integrated Protected Areas System (NIPAS) or other mechanisms to reduce land use change in the priority areas identified in the analysis outside PAs, particularly "conservation" areas delivering maximum benefits.

Given that large areas that deliver multiple benefits are currently outside the PA system, there are significant opportunities for investment that would enhance climate resilience for downstream infrastructure and communities through new designations and management schemes to limit land use change. In collaboration with DEPDev, DPWH, and the National Commission on Indigenous Peoples (NCIP) where conservation overlap with ancestral domains, the DENR should ensure that infrastructure projects steer clear of these designated areas during the planning and siting phases. These crucial measures should be integrated into the Philippine Biodiversity Strategy and Action Plan (PBSAP) as well as in the next update of the Philippine Development Plan (PDP).

05 Enhance DEPDev's Infrastructure Flagship Project (IFP) Selection Process to incorporate NbS as a key project selection criterion.

For the team of technical experts engaged in the selection and prioritization of DEPDev's Infrastructure Flagship Projects (IFPs), there are multiple opportunities for integration:

A Incorporate ecosystem and biodiversity criteria in siting decisions as a requirement in the 'Revised Guidelines for the Formulation, Prioritization and Monitoring of the Government's Infrastructure Flagship Projects (IFPs).' During project submissions for the IFP process, project teams should explicitly demonstrate how NbS options are spatially integrated in proposed siting and design decisions to maximize the avoidance of priority conservation areas and restoration opportunities.

B The IFP's INFRACOM team responsible for technical evaluation could utilize the maps in their technical assessment of infrastructure proposals before presenting them to the Investment Coordination Committee (ICC) for approval. Through this process, for example, collaboration with DENR's Multi-Stakeholder Monitoring Team (MMT) could help integrate priority areas for Nature-based Solutions (NbS), as identified in this analysis, into the requirements for Environmental Compliance Certificates (ECCs) issuance.

06 Revise the Public Investment Program's (PIP) Online System (PIPOL) to require project developers to submit:

A Articulation of considerations and rationale guiding routing choices, including surrounding conservation areas and potential restoration opportunities;

B Specification of the land area (in sq. km) with substantial ecosystem service provision that may be impacted by the project, accompanied by proposed conservation and/or restoration strategies aimed at preventing or mitigating harm.

C Provide detailed plans illustrating collaborative efforts among key agencies within the project team for developing protection/restoration measures over the entire project lifespan.

07 Include NbS as a procurement requirement for Public-Private-Partnerships (PPPs) for major infrastructure projects.
As the Public-Private-Partnership Center (PPC) develops additional tools to mainstream sustainability and climate resilience to meet safeguards with technical support from the Asian Development Bank (ADB), these mapping layers and identified priority areas for conservation and restoration could provide valuable additional inputs at multiple scales. They will only be useful, however, if considerations of nature-based solutions at scale that support climate resilience are a mandated key project selection criteria.

08 Invest in training and capacity building programs at the national and subnational levels to train planners and key technical staff across agencies and departments in NbS.
WWF and the University of the Philippines Los Banos Foundation (UPLBFI) have worked with partners in the Caraga Region and Agusan Del Norte Province, including Butuan City and other LGUs to create similar analyses and training materials in at the subnational level. These could be used to train experts around the country to evaluate and integrate relevant NbS in planning analyses and decision making moving forward to maximize climate resilience, sustainability, and biodiversity co-benefits.

ANNEX

Pexels / Juan Laurio

ANNEX 1. DETAILED METHODS

We assessed the following ecosystem services providing climate resilience or adaptation-related benefits: sediment retention, coastal protection, seasonal water yield and flood mitigation. Below we describe

01 the biophysical models used, their assumptions, and inputs;

02 the beneficiaries mapping approach used;

03 the scenarios explored and methods used to generate them;

04 evaluation of scenarios and prioritization; and

05 post-processing analyses to assess the ecosystem service priority areas.

01 BIOPHYSICAL MODELS

1.1 SEDIMENT RETENTION FOR EROSION CONTROL AND DOWNSTREAM WATER QUALITY

Erosion causes issues for land degradation and for water quality, with sediments clogging waterways and often carrying diseases that can lead to water-borne illness. Here we model sediment retention provided by vegetation by adapting the InVEST Sediment Delivery Ratio (SDR) model, as described in Chaplin-Kramer et al. 2021.[37] The SDR model maps overland sediment generation and delivery to the stream, and can also be used to identify where sediment is being retained on the landscape due to land-use practices, which has benefits both on-pixel for erosion control and downstream for water quality. Ideally the downstream benefits would be delineated for reservoirs, irrigation canals, or other water delivery infrastructure that is most impacted by sedimentation, but often lacking datasets identifying all such infrastructure, we use the proxy of number of people downstream.

The potential for erosion is determined by climate (specifically rain intensity), soil properties, topography, and vegetation. Land use practices can impact the amount of erosion and the amount of sediment that can be retained by vegetation before it reaches a stream. The magnitude of this effect is primarily determined by: i) the main sediment sources (vegetation has a smaller effect in catchments where sediments are not primarily coming from overland flow); and ii) the spatial distribution of sediment sources and sinks (vegetation has a larger effect if positioned between sediment sources and the stream).

The InVEST SDR model is a spatially-explicit model working at the spatial resolution of the DEM raster (in this case, 30 m). For each pixel, the model first computes the amount of annual soil loss from that pixel, then computes the SDR, the proportion of soil loss actually reaching the stream. The amount of annual soil loss from a pixel (in tons·ha−1yr−1), is given by the revised universal soil loss equation (RUSLE1), as rainfall erosivity (R) multiplied by erodibility (K) by the length-slope factor (LS) by the land-use coefficients Cover factor (C), and Practice factor (P).

The C-factor represents the role that vegetation plays in preventing erosion or trapping sediment that has already been eroded, while the P-factor has more to do with the ways in which the slope of the hillside may be locally modified through different practices (e.g., terracing). This estimated soil loss on each pixel is then multiplied by the SDR for the pixel, derived from a conductivity index (a logged ratio of the upslope to downslope areas of that pixel), to calculate sediment export from each pixel to the stream. Outputs that may be of interest include soil loss (RKLSCP) as a measure of erosion and sediment export as a measure of water quality regulation, both calculated in terms of a difference between a baseline and an intervention scenario, in order to estimate the biophysical value of the intervention. See InVEST[38] and Hamel et al. (2017)[39] for more detail. In this implementation we have adjusted the model functionality to use a continuous rather than categorical C-factor (based on a raster of C-factor rather than a LULC map with a biophysical value assigned to each land cover class)[40], which enables exploration of an impact gradient (see section 4 on scenarios).

The model output is sediment export (in T/year), and a scenario output is subtracted from baseline output to calculate the change in export which is the ecosystem service of **sediment retention**.

1.2 COASTAL RISK REDUCTION

Coastal habitats such as coral reefs, mangroves, salt marsh, or seagrass, attenuate waves and protect the shorelines from the impacts of storms, such as floods and erosion. How much this attenuation matters depends on

01 the physical exposure of the shoreline to coastal hazards and

02 the people and infrastructure exposed

To map the coastal risk reduction provided by coastal habitats, we map coastal risk with and without the habitat, using methods based on the InVEST Coastal Vulnerability model, an index-based model assigning a relative rank (1-5, 5 being highest risk, 1 being lowest) based on wind, waves, surge potential, sea level rise, geomorphology, topography, and habitat. See InVEST[41], Chaplin-Kramer et al. 2019[42], and Chaplin-Kramer et al. 2021[43] for more detail on model structure.

Terrestrial habitats were taken from local land cover and clipped to within 2 km of the shoreline (the maximum protective distance of habitat; see Table 1, as parameterized in Chaplin-Kramer 2019 and 2021). Although much of this terrestrial habitat is located behind the coastline and the storm surge that would hit it, including this habitat is important to represent mitigation of potential flooding. Coastal habitat layers were taken from global datasets for coral reefs, mangroves, seagrass and salt marsh habitat[44]. We removed from these datasets the mangroves and salt marsh that spatially overlapped with terrestrial coastal habitat so they were not double-counted. The risk ranks and protective distances of each habitat type are shown in Table 1.

The physical forcing variables of coastal storms are wind, waves, and surge potential. We estimate risk due to wind exposure by calculating the relative exposure index as a function of average wind speed and duration multiplied by the distance of which the wind can blow uninterrupted over the water to the point on the shore.

Shoreline exposed to the open ocean can also be at additional risk for erosion when the wind blows over long uninterrupted distances and create powerful waves. Such areas are also more at risk for swells created by distant storms. Risk from both wave and wind power are derived from NOAA WAVEWATCH III data[45] Storm surge is a function of wind speed and direction but is strongly affected by the amount of time wind can blow over shallow areas before reaching the shore. Longer runs will create higher surges. We estimated surge potential by calculating the distance from a shore point p to the nearest edge of the continental shelf defined as where the bathymetry drops below 150m.

Table 1. Parameterizations for the InVEST Coastal Vulnerability model: risk rank (with 1 being the lowest) and maximum protective distances of the different habitat types.

Habitat	Risk rank	Protective distance (in meters)
Coastal forests / Mangroves	1	2000
Wetlands / Salt marsh	2	1000
Coastal scrub	2	2000
Cropland/sparse vegetation	4	500
Coral Reefs	1	2000
Sea grass	4	500

Other important variables in determining coastal risk are they physical characteristics of the shoreline itself: geomorphology or shoreline (substrate) type, as hard/rocky shorelines are less vulnerable than soft substrates; relief or elevation at the shoreline, because low-lying areas are more vulnerable than a cliff; and local sea level rise, which varies spatially at large scales and puts certain stretches of coastline at elevated risk in the future. We used an unpublished global dataset for geomorphology (Vafeidis et al. 2008), assigning all substrates a risk rank of 5 (the highest) except for the class defined as “unerodible,” which we assigned a rank of 1. Wherever the dataset was nodata, we calculated the geometric mean of the total coastal risk with one fewer variable. We accounted for the benefit of greater elevations above mean sea level by calculating the average elevation at each shore point p for all land above sea level within a 5km radius.[46] Past trends in sea level, measured by satellite altimetry[47] for 1993-2008, were used to establish spatially-explicit differences in relative risk from sea level rise.

The average rate of change from satellite altimetry (in mm/yr, converted to m/yr, multiplied by the 25-year period over which the data are based) yields an estimate of present-day rise).

This model is evaluated at regularly spaced intervals along shorelines (250 m, in this case). The model output is a unitless index of total coastal risk (Rt), which is a geometric mean of all associated risks ranked 1-5 described above, reported per point. While this result can be useful for inspecting the relative risk of shore points in an analysis, we also calculate the relative risk to shoreline without the benefit of protective habitat such as coral reef, mangrove, or coastal wetland (Rt_nohab). The ecosystem service that the protective habitat provides in terms of coastal risk reduction is then calculated as the difference between Rt_nohab and Rt.

Unlike the previous model which calculates the benefit of the habitat at the location of the habitat, the coastal risk model calculates the benefit where it is delivered, at the shore. Therefore, that benefit needs to be attributed back to the habitat that provides it in order to indicate what regions of offshore habitat are most valuable in terms of protection to the shoreline. We do this by taking the service value at each shore point and apply a weighted distribution with linear decay to a radius equal to the maximum protective distance of the habitat[f]. The result of this projection is then masked by the original habitat thus resulting in a map showing not only what areas of habitat provide the service, but what regions are most important.

1.3 SEASONAL WATER YIELD

The InVEST the Seasonal Water Yield (SWY) model represents the effect of land cover to slow run-off, which can increase groundwater recharge, and is therefore useful for capturing the effects of seasonality in streamflow. The contribution of a given parcel of land to seasonal streamflow depends on a number of environmental factors including climate, soil, vegetation, slope, and position along the flow path (determining if the pixel may receive water from upslope or if water recharged may later be evapotranspired). The InVEST Seasonal Water Yield (SWY) model provides a spatial estimate of monthly surface and subsurface runoff and recharge, based on two key features: sensitivity to vegetation (and hence land use), and explicit representation of routing (which allows for a spatially-explicit assignment of value to habitat within a watershed). The model relies on basic principles of

01 water partitioning, precipitation becoming runoff or evapotranspiration, and

02 routing, upgradient water becoming available to downgradient parcels.

The simplified routing processes mean that model outputs should be interpreted as indicators of change rather than predictions of absolute values (see InVEST[48] and Hamel et al. 2020[49] for more detail).

In this implementation we have made some adjustments to the InVEST model to allow for greater flexibility of use. First, we modify how the model handles curve numbers, which represent how vegetation can slow the flow of water as it runs over the surface of the ground and allow time for infiltration into the soil (which also depends on soil type).

We use continuous rather than categorical curve numbers (based on a raster of curve numbers rather than a LULC map with a biophysical value assigned to each land cover and soil class combination), which enables exploration of an impact gradient (see section 4 on scenarios). Similarly, the InVEST model takes numbers of rain events from a spatial lookup based on a shapefile of climate zones, which makes it difficult to run climate scenarios that vary continuously over a spatial area. We modified the model to take in a raster indicating the number of rain events per pixel[50].

The model has two main outputs that we use in the calculation of two different ecosystem services: the **baseflow index (B)** and **quickflow index (Qf)**, both unitless indices that represent relative spatial patterns in where water is allocated to different types of hydrologic flow. Baseflow measures how much water due to precipitation or upstream runoff is absorbed as groundwater. A high baseflow is beneficial for groundwater recharge and represents the ecosystem service of **seasonal water availability** (indicating water will continue to be released to streams during the dry season when water is more scarce). Quickflow is how much water is not absorbed by the current or downstream pixel and instead runs off during storm events. This result, multiplied by accumulated downstream flood risk is used to calculate the ecosystem service of flood mitigation (see next section).

1.3 FLOOD MITIGATION

Downstream flood risk can be mitigated by protecting or restoring habitats with high surface roughness and permeability (i.e., lower curve numbers) to minimize local quickflow and maximize slow moving water recharge. To capture the potential that a pixel on the landscape has to mediate flood risk, we consider the amount of influence the current pixel has on downstream risk to be inversely proportional to the upstream area flowing through it plus the sum of downstream flood risk. This scaling method captures the increased importance that a pixel would have on flood mitigation if it were on a short upstream flowpath versus a long one. A long path would have many opportunities to mitigate quickflow running through it, but a shorter path would make the current pixel (and those upstream) more important for mitigating that risk. Formally, the per-pixel distributed flood risk on each pixel calculated as:

$\text{distributed flood risk}_i = \text{flood risk}_i / \text{upstream area}_i + \text{distributed flood risk}_{ds}$

Where

01 distributed flood risk$_i$ is the calculated distributed flood risk at the current pixel and is a value that can be used to assess the effectiveness of interactions on the pixel for affecting flood risk in the current and downstream pixels (i.e. any pixels on the path of water flowing out from the current pixel)

02 flood risk$_i$ is the predetermined flood risk, perhaps taken from a published flood risk map

03 upstream area$_i$ the area upstream of the current pixel can be in area or number of pixels

04 distributed flood risk$_{ds}$ the downstream distributed flood risk calculated from a previous step

The resulting raster can then be multiplied by the quickflow index from the SWY model (previous section) to quantify the contribution of a pixel to downstream flood risk, or multiplied by the difference in quickflow between a scenario and the current baseline to represent the ecosystem service of mitigating the downstream flood risk. The model output is a unitless index of **downstream flood risk** or **mitigation of downstream flood risk**.

02 BENEFICIARIES MAPPING

We consider the following beneficiaries for each service: sediment retention for downstream roads (as a proxy for reduced erosion/landslide risk to roads) and for downstream populations (as a proxy for regulating drinking water quality for people); flood risk reduction for downstream roads (as a proxy for reduced flood damages to roads) and downstream populations (as a proxy for reduced flood damages to people/property); water recharge for downstream populations (as a proxy for regulating water availability for people); and coastal protection for coastal roads (as a proxy for reduced coastal storm damages to roads) and coastal populations defined as any human population <2 m above mean sea level within 1 km of the coast[g]; as a proxy for reduced coastal storm damages to people/property). We use population data from Worldpop 2020 to represent the number of people and we use current and planned roads to represent the infrastructure potentially benefiting. Note that it is possible, and fortuitous, that the same population benefits from multiple services. As discussed in the post-processing analysis later, we avoid double counting the population by making a single combined mask of the top 10% of all benefitting services to mask the population layer.

2.1 DOWNSTREAM BENEFICIARIES

Downstream beneficiaries are defined as the total number of people or amount of infrastructure (i.e., number of road pixels) downstream of a pixel of habitat on the way to the stream, that may benefit from an upstream hydrological flow into each land cover pixel. Starting at where the flowpath terminates (by hitting a body of water or the edge of the raster), we calculate the number of people to be added to a running total and proceed upstream. Mathematically, this is represented as a weighted flow length[51] using the beneficiary raster as the weight and based on the flow direction raster[52] calculated from the DEM. At each upstream step the running total is added to the current pixel and written to the Downstream beneficiary raster at the same time. This allows the calculation of the entire Downstream beneficiary raster in one pass but requires extra bookkeeping to calculate originating drains and track upstream flow branching.[53]

We multiply the downstream beneficiary raster by the respective service raster to produce a weighted index of beneficiaries service.

2.2 COASTAL BENEFICIARIES

Coastal beneficiaries are defined as the total number of people or amount of infrastructure within the protective distance (which varies by habitat, according to Table 1) of a pixel of habitat within low-lying areas (<2 m above mean sea level) along the shoreline.[54] To map these beneficiaries to the coastal habitat that protects them, first we generate a raster to show what points in space could benefit beneficiaries if they were protected. This is called the beneficiaries coverage raster (population counts or road presence) where any pixel value indicates the amount of beneficiary which is present at that point. This raster is used later to intersect with the service provided by a protective habitat and in turn calculate the protective value of that habitat. The beneficiaries coverage raster was created by first masking beneficiaries which were in low lying areas (<2m above sea level) with a 2D convolution,[55] using a circular linear decay kernel with a radius of the maximum distance a beneficiary could benefit from a shoreline being protected (1km for population, 15km for roads).

Next we generate a set of beneficiary protective service rasters which is an index indicating the value provided by a protective habitat to the beneficiaries that benefit from it. We calculate this mask by first rasterizing the CV habitat service risk values from the shore points which were created by taking the difference of coastal risk with the absence of habitat from the same risk calculated with the protection of that habitat multiplied by the beneficiaries coverage raster created in the first step. The result is a weighted index of beneficiaries*protective service. This mask is expanded to a coverage mask using 2D convolution with a circular linear decay kernel with a radius of the same distance as the protective distance of that habitat. The result is a set of rasters, one for each habitat type, where any pixel's value is an index indicating the protective service provided to that point from the given habitat. These rasters are then summed to create one final raster of ecosystem service value across all habitats.

03 SCENARIOS GENERATION

RESTORATION

To represent restoration, we change all agricultural and open/barren land classes back to "secondary forest" (which is to say, forest but not quite as high quality as current primary/intact forest). Specifically we use the following transition matrices: Transitions for restoration scenarios

CONSERVATION (AVOIDED IMPACTS FROM INFRASTRUCTURE)

Constructing scenarios for conservation requires a counterfactual of what would be likely to occur or could potentially occur in the absence of conservation. This can be represented through land-use conversion risk mapping, but a variety of assumptions must be made to assess that risk. We modeled two conservation scenarios for Indonesia and the Philippines. The first scenario (unconstrained conservation: all areas supporting NbS) considers all relatively intact forests, while the second (infrastructure impact conservation: areas supporting NbS impacted by infrastructure) focuses on areas within 25 km of roads near urban areas and within 15 km of roads in more remote regions. This approach allows planners and decision-makers to implement strategies that protect these areas during the construction of both existing and future toll roads.

In the first scenario, unconstrained conservation, we assume all relatively intact forest areas are converted to agriculture. By evaluating the loss of ecosystem services from this deforestation, we estimate the value of the services that would be lost. Specifically, the "service" is a combination of biophysical value (e.g., tons of sediment retained, cubic meters of water filtered) and the number of people benefiting from these services. In this scenario, the highest service value might come from areas farther from people, as the biophysical value could be higher in less populated areas.

In the second scenario, infrastructure impact conservation, we map the impact of toll roads on land conversion by modeling conservation efforts to avoid the potential impacts from current and planned roads. We create a "footprint" or "buffer" around roads, where conservation is prioritized. The footprint extends 25 km from roads near urban areas and 15 km from roads in more remote regions. This model reflects how infrastructure can influence land use and conservation efforts, with more people benefiting from the services provided by these areas.

Phase I: Probability Distribution Fields

To predict the future effects of infrastructure on the landscape we modeled the pressures from effects from roads and population centers to generate two dimensional "probability distribution fields" (PDF) (https://en.wikipedia.org/wiki/Multivariate_normal_distribution) that can be summed and used as a driver for simulated landscape change. We wanted to capture the effect that a single road line could have large distance effects, but population centers would have effects that could vary based on their overall size, not just distance from the edge. Thus we applied two different methods to calculate the probability distribution field emanating from infrastructure:

01 Roads: roads are first rasterized and modeled as a 0/1 mask. Then we apply a distance transform (https://en.wikipedia.org/wiki/Distance_transform) to create a raster whose values show the distance to the closest point to a road. From there we scaled the values so that values close to the road were "1" and decayed linearly to "0" as the impact distance faded at 15km.

02 Population centers: in order to differentiate the pressures from a city with a large land footprint compared to a village with a small footprint, we modeled the pressures from infrastructure using a 2D convolution (https://pro.arcgis.com/en/pro-app/latest/help/analysis/raster-functions/convolution-function.htm) with a linear decay kernel out to 25km. The effect of this result is that large population centers create high pressures (near "1") close to the city decaying to "0" at 25km. Small population centers due to their smaller footprint generate lower pressures close to the edge of the footprint but still decay to 0 at 25km.

The PDFs from the road and population centers are then summed, thresholded to 1.0, and used as a guidance of where landscape should change in the next phase of the algorithm.

Phase II: Land conversion

In this phase, landscape values are changed from existing values to “full impact” values for the c-factor and curve numbers used in the sediment retention model and seasonal water yield model.8 Resulting values are calculated as a linear interpolation between the original value on the landscape and the “full impact” value if under the full pressure (a value of “1” on the PDF). Formally, transformed landscape values are calculated as:

$$v_{transformed}(p) = v_{base}(p)*(1\text{-}PDF(p))+v_{full\ impact}*PDF(p)$$

Where p refers to the pixel location, $v_{base}(p)$ is the value of the landscape parameter at the pixel before the land change conversion, PDF(p) is the value of the PDF calculated in Phase I at the pixel location, $v_{full\ impact}$ is the value of the landscape parameter if under the full influence of the land change pressure (note this parameter does not depend on the pixel location, instead it is specified in the scenario), and $v_{transformed}(p)$ is the final landscape value at point p after the transform. As intuition, note that in the case of the PDF being “0”, meaning no infrastructure impact, the value of $v_{transformed}(p) = v_{base}(p)$ but if the PDF is “1” under the full influence of infrastructure we see $v_{transformed}(p) = v_{full\ impact}$.

Future climate

For each model we consider baseline and land use change under current and future climate scenarios (SSP2 RCP4.5). For each input we selected the top 10% most extreme scenarios from the ensemble models, with the most precipitation for sediment retention and flooding, and with the lowest precipitation for baseflow (water recharge). This was intended to explore the range of uncertainty for the future provision of each ecosystem service so that the pixels most robust to uncertainty could be selected for prioritization. However, due to the coarseness of these climate scenario data (30 km x 30 km), the spatial variability in priority pixels were limited to changes over fairly large regions.

For sediment retention, we calculate erosivity based on mean annual precipitation from current and future CMIP6[56] climate scenarios as E=1.2718*P^1.1801 from the model specified in (Yin et al. 2015)[57] where P is the mean of the annual precipitation over a 20 year future climate period. For flood risk reduction and water recharge (i.e., the Seasonal Water Yield model), we sampled CMIP6 data over 20 year periods (current and future) and calculated the monthly volume of precipitation and the number of rain events per month per pixel over each of the 20 year periods. These rasters were created by averaging these volumes and rain events over the 20 year periods per month to generate 12 precipitation and rain event rasters per scenario.

04 SCENARIOS EVALUATION AND PRIORITIZATION

In each case we look at the difference between the modeled outputs of the baseline and the two scenarios (restoration and conservation/avoided impacts). For sediment export and flood risk, since these are harms that ecosystems can mitigate or reduce, we use the difference between scenarios as the biophysical supply of the service of sediment retention or flood mitigation (and therefore the directionality of the differences are reversed, so that positive values indicate positive changes, less sediment export or less risk). For water recharge, the model output is the supply of the service directly (with positive values indicating more recharge). Likewise for coastal protection, the model output is already translated to the supply of an ecosystem service in order to map it back to the habitat that is providing the protection (with positive values indicating more protection). Specifically, we consider change in the following dimensions:

SEDIMENT RETENTION

01 Restoration = Sediment export for baseline - sediment export for restoration (Higher values indicate lower sediment export with restoration, which is higher retention)

02 Conservation = Sediment export for infrastructure impact - sediment export for baseline (Higher values indicate lower sediment export in the baseline than compared to infrastructure impact, which is higher retention for conservation or avoided impact)

FLOOD RISK REDUCTION

01 Restoration = Flood risk for baseline - flood risk for restoration (Higher values indicate lower flood risk with restoration, which is higher flood mitigation service)

02 Conservation = Flood risk for infrastructure impact - Flood risk for baseline (Higher values indicate lower flood risk in the baseline compared to infrastructure impact, by avoiding the risk due to that potential impact through conservation)

WATER RECHARGE

01 Restoration = Recharge for restoration - recharge for baseline (Higher values indicate higher baseflow with restoration, due to increased recharge)

02 Conservation = Recharge for baseline - recharge for infrastructure impact (Higher values indicate higher baseflow in the baseline compared to infrastructure impact, by avoiding losses due to that potential impact through conservation)

COASTAL PROTECTION

01 Restoration = Coastal protection for restoration - coastal protection for baseline (Higher values indicate higher protection with restoration, due to the reduction of coastal risk)

02 Conservation = Coastal protection for the baseline within 15 km of a road (Higher values indicate higher protection by avoiding the risk of potential impact through conservation)

> Note: this is handled differently because the model doesn't represent habitat degradation in a continuous way, only the removal of habitat. In this case we are taking the extreme of assuming the conservation value is the full value of the habitat within the impact zone of the road

IDENTIFYING CLIMATE-ROBUST PRIORITIES FOR CONSERVATION AND RESTORATION

We repeat the above analysis for the future climate scenarios described above. Then we select the areas in the top 10% of service provision for each beneficiary and each service in each scenario, across both current and future climate conditions (producing an "agreement map" for each, as an indication of a climate-robust set of priorities). We overlap all of the beneficiary-specific services (7 in total, listed above) for the top 10% highest value areas for conservation and for restoration. The areas with the highest values for overlap show where the greatest win-wins can be found for each activity, and the areas with any non-zero values show high value for at least one of the services to one of the beneficiaries.

We identified the top 10% of ecosystem service-providing areas for restoration (reforesting non-forested areas other than urban areas and settlements) and conservation (avoiding impacts from roads on adjacent areas). We overlapped the top 10% of areas of provision of the 7 service-beneficiary combinations:

01 sediment retention for

- **a** downstream populations and
- **b** downstream roads,

02 flood mitigation for

- **a** downstream populations in floodplains and
- **b** downstream roads in floodplains,

03 water recharge for

- **a** downstream populations, and

04 coastal protection for

- **a** coastal populations and
- **b** coastal roads.

Each service was modeled under current and future (SSP 2 RCP 4.5) climate conditions, and only areas falling in the top 10% of service provision for both were selected as the "climate-robust" priorities for conservation and restoration.

05 POST-PROCESSING ANALYSES

Several analyses were conducted after the main modeling results were generated, in order to answer relevant policy questions, including: how well are priority areas for ecosystem services represented by the current protected area network and by key biodiversity areas? Which municipalities contribute the most priority areas or the greatest number of overlapping priorities? And how many people benefit from these priority areas?

01 **Conservation priorities overlap analysis:** clip out the high value ES area (top 10% map) is outside of the current protected area (PAs) network, then overlap that outside area (areas of top 10% that doesn't intersect with PA) with key biodiversity areas (KBAs), calculate proportion of those areas outside of current protection that would be priorities for protection or restoration for ecosystem services.[58]

02 **Administrative summaries:** calculate the total area (sq km) and intensity (average services overlapping) of priorities within the island group, province, or each municipality that is a priority for conservation or restoration (in top 10% of ES values for that scenario). Combining the two of these results in a score that provides an overall score of how much and the relative importance of priority area in each administrative region.

03 **Number of people benefiting:** counting the people that overlap with at least one of the services in the top 10th percentile of all services calculated. First the service overlap count raster are masked to 0 wherever the raster intersects with a DEM pixel >2m above mean sea level. The result is a mask of top 10% services in low-lying areas. Then a downstream benefiting area raster is generated by calculating a weighted flow length[59] algorithm where the weight is the top 10th percentile service raster; the result is a mask that has a pixel value >0 wherever that point has a top 10th percentile service on or upstream from that pixel. Then the population raster is masked to wherever the low-lying service mask or upstream service mask is 1 resulting in a population map of people who are benefitting from a service in the flowpath or in low-lying areas. Finally, all pixels in the beneficiary raster that intersect the downstream coverage mask are summed and reported as the "total number of beneficiaries downstream of a given priority area".[60]

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Contact Us
World Wildlife Fund (WWF)
Climate Smart Planning and Design
Email / SIPA@wwfus.org
Website / https://www.worldwildlife.org/pages/climate-adaptation-and-resilience-program