SPACES

# Mapping nature-based solutions to societal challenges

**Technical review**
June 2023

## About SPACES

**SPACES is an emerging coalition that aims to mobilise financial and technical support for high-ambition countries to design and implement spatially-explicit strategies for delivering on the Kunming-Montreal Global Biodiversity Framework and related nature and climate objectives.** SPACES had a scoping phase in 2022, coordinated by the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) and Systemiq, working with UNDP, IIASA and IIS, among other partners.

SPACES invites interested countries and national technical partners to explore participation in the coalition. Potential benefits include: (i) technical support and capacity building, including the development of national datasets, tools and databases, working with government departments and national institutions (ii) sharing of experiences between countries (iii) a route to short and medium-term financial support for the development of spatial plans, including stakeholder engagement across sectors.

For more information, please visit www.spacescoalition.org, or contact info@spacescoalition.org

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## About this report

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# Executive summary

## Background

Decision-makers need solutions to simultaneously tackle different societal challenges. There is growing evidence that effectively placed nature-based solutions can deliver multiple benefits. These include safeguarding biodiversity, improving climate regulation and promoting sustainable development. It is therefore crucial to understand where to implement specific solutions and how their varying locations can grant different benefits.

Nature-based solutions are actions to protect, conserve, restore, sustainably use and manage nature in order to address social, economic and environmental challenges. Their location matters and decision-makers must work to identify locations where these solutions can best be implemented. Fortunately, technical advisers have a range of spatial analysis approaches available to support this process. There is no best overall approach. However, tailoring the approach used to map nature-based solutions greatly increases the chances of success.

## Aim and structure

This review is a product of SPACES, an emerging coalition that aims to mobilise financial and technical support for high-ambition countries to design and implement spatially-explicit strategies for delivering on the Kunming-Montreal Global Biodiversity Framework and related nature and climate objectives. The overarching aim of this review is to provide technical advisers with a summary of the different spatial analysis approaches available to map potential locations for nature-based solutions that provide the greatest benefits. Although the approaches explained in this review could be used to identify locations for all types of nature-based solutions, the case studies documented here are examples of nature-based solutions for climate change mitigation and/or adaptation.

Section 1 defines nature-based solutions and their role in climate change mitigation and adaptation. Section 2 describes a generic spatial planning process and how each step of this process can benefit from spatial analysis. Section 3 presents four spatial analysis approaches. These include suitability-first, systematic conservation planning, participatory mapping and mixed. The first two approaches are based on different computing techniques. While suitability-first provides answers by overlaying spatial layers, systematic conservation planning uses computer algorithms within a prioritization modelling. Involving stakeholders is not at the core of these approaches but these methods do provide higher chances of success. On the other hand, participatory mapping requires that local stakeholders, such as Indigenous Peoples and local communities (IP and LCs), have active roles throughout the analysis. And between these two extremes of stakeholder engagement, mixed approaches combine strong stakeholder participation with the use of either or both computing techniques. The requirements, advantages, challenges, and limitations of these approaches are described and illustrated through case studies. A final summary compares them.

# 1

# Introduction

The emerging SPACES coalition believes in the central role of spatial intelligence in decision processes that aim to integrate objectives on nature, climate and sustainable development. Spatial intelligence, the use of spatial data, tools, analyses and visualization, can strengthen spatial planning. However, it is not sufficient. We believe that spatial planning should be a participatory and inclusive process that recognizes, respects, and supports Indigenous Peoples' and Local Communities' (IP and LCs) rights, knowledge, and cultures and encourages the appropriate representation of minorities. This process should promote the synergies between social, economic, environmental and governance objectives. It also should explore alternatives that offer transparent and value-based assessments of potential benefits and trade-offs (SPACES n.d. -a).

Nature-based solutions involve better protecting, restoring or managing ecosystems in ways that tackle societal challenges. Alongside the rapid decarbonization of the economy, nature-based solutions can play a key role in climate change mitigation. In addition, these solutions can support climate change adaptation efforts aimed at benefiting people and the natural ecosystems they rely upon. Decision-makers wishing to realize the potential of nature-based solutions will need to know where different solutions can be applied, what benefits and trade-offs arise from selecting different locations for nature-based solutions and how to implement the solutions to ensure these benefits.

A range of spatial analysis approaches can be used to identify locations with the potential to deliver nature-based solutions. The results serve as an input for the inclusive planning process described above, or the analysis may be fully integrated into the process.  This review aims to provide decision-makers and technical advisers with a summary of the different approaches available to map potential locations for nature-based solutions, with a particular focus on integrating climate change and biodiversity objectives.

## 1.1 Nature-based solutions

### 1.1.1 What are nature-based solutions?

During the 5th Assembly of the United Nations Environment Programme (UNEA), its 193 Member States decided that:

> *"Nature-based solutions are actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits"*
>
> (United Nations Environment Programme 2022a).

The UNEA resolution also states that nature-based solutions:

> *"(a) Respect social and environmental safeguards, (...) including such safeguards for local communities and indigenous peoples; (b) Can be implemented in accordance with local, national and regional circumstances, consistent with the 2030 Agenda for Sustainable Development, and can be managed adaptively; (c) Are among the actions that play an essential role in the overall global effort to achieve the Sustainable Development Goals (...); d) Can help to stimulate sustainable innovation and scientific research."*

Not all actions that involve nature and are aimed at solving society's problems are considered to be nature-based solutions. This definition highlights that "nature-based solutions are actions to protect, conserve, restore, sustainably use and manage" nature, in order to address common global challenges in biodiversity, climate action, and sustainable development. These actions can occur in natural or modified ecosystems of all realms and at different scales but must provide benefits simultaneously to people and nature, and respect social and environmental safeguards, thus supporting the achievement of the UN Sustainable Development Goals. Nature-based solutions could support climate change mitigation and adaptation if actions are aimed at, for example, reducing greenhouse gas emissions or protecting communities from projected sea level rise.

### 1.1.2 Nature-based solutions for climate change

Nature's potential to support in tackling the current climate crisis is recognized under current and emerging multilateral agreements and targets. Under the United Nations Framework Convention on Climate Change (UNFCCC), the 2015 Paris Agreement (UNFCCC 2015) encourages Parties to conserve and sustainably manage forests. Building on this, the 2022 Sharm el Sheik Implementation Plan (UNFCCC 2022) emphasizes the role of all ecosystems in climate action, especially for mitigation. Target 11 of the new post-2020 global biodiversity framework (CBD 2022) under the Convention on Biological Diversity (CBD) urges that nature-based solutions and/or ecosystem-based approaches are used to restore, maintain and enhance nature's contributions to people including regulation of the climate, and protection from natural hazards and disasters. Target 8 commits Parties to minimizing the impact of climate change and ocean acidification on biodiversity itself and increasing its resilience, including through these approaches.

Estimates of the potential contribution from nature-based solutions to climate change mitigation range from 5 to 11.7 $GtCO_2e$/year by 2030 (UNEP and IUCN 2021), depending on speed of implementation, and other factors including the cost/price per tonne of emissions reductions and removals. Examples of nature-based solutions (United Nations Environment Programme 2022b) for climate change mitigation include restoration of natural forests under community management; promotion of agroforestry for carbon storage and diversified local livelihoods (UNDP n.d. -a); blocking drains and rewetting peatlands to re-establish their hydrology, and where appropriate, developing flooded agriculture and agroforestry on peatlands to continue to support livelihoods (Tanneberger *et al.* 2021; Strack *et al.* 2022).

It is more difficult to quantify the overall potential for nature-based solutions to support climate change adaptation efforts. Communities and business will need to adapt to or avoid a wide range of possible negative impacts of climate change (Chausson *et al*. 2020). These impacts range from increases in the frequency or intensity of droughts, floods, pest and disease outbreaks, and wildfires, to decreases in water and air quality. Here, nature-based solutions typically involve increasing the availability and resilience of ecosystem services that people depend upon in their daily lives or in times of crisis. Even in an urban environment, trees, green roofs and walls can help to keep city streets cool and to clean polluted air (Eggermont *et al*. 2015; European Comission 2015; Kapos *et al*. 2019)

### 1.1.3 Mapping nature-based solutions

To make the best of the limited resources available for implementing nature-based solutions, it is important to identify locations with the highest potential to provide benefits simultaneously for nature, climate and other sustainable development goals, such as food, water, or livelihoods security. Various spatial analysis approaches are available to explore the potential suitability of locations for nature-based solutions to be implemented across the landscape and seascape and understand the different benefits they could provide.

Each spatial analysis needs to be tailored to the specific context to make sure that the results are as useful as possible for the planning process that is underway. Design considerations include the specific objectives, nature-based solutions of interest, stakeholder engagement needs, technical capacity, culture, geographic characteristics, laws, commitments, and targets.

Spatial analysis can be performed for different purposes and may be a stand-alone task or embedded throughout a spatial planning process. Useful spatial analyses are not restricted to identifying areas for nature-based solutions implementation, but that is the focus of this review.

## 2

# Spatial planning

Spatial planning is “the process of identifying how management zones can be organized spatially to achieve a series of objectives” (Systemiq 2022). Integrated spatial planning explores problems and alternative actions for different sectors, including how to achieve multiple goals around nature, climate, and sustainable development. There are a multitude of ways to develop a spatial plan: from top-down decision-making on zones for different land-uses, to highly decentralized planning led by communities and other local stakeholders. Between these two extremes, the level of engagement and the representation of different stakeholder groups vary from case to case.

## 2.1 Spatial planning can help decision-makers to address complex challenges

Decision-makers often face the challenge of determining where multiple, sometimes conflicting activities can best take place across landscapes and seascapes. Decisions on when and where efforts and funds should be allocated, and how progress and success can be measured (Groves and Game 2016; Rittenhouse 2017), are often made independently for different land uses, for example with different authorities responsible for assigning concessions for forestry, agricultural plantations or mineral exploration, or for designating protected areas. An integrated spatial planning process allows decision-makers to assess alternative actions and scenarios that provide synergistic solutions for nature, climate and people, and their potential trade-offs.

Specific elements during the planning process can be particularly important for successful implementation in different contexts. For example, in some recent case studies (SPACES n.d. -b) success depended on the involvement of key national and community stakeholders in an inclusive and participatory process that agreed upon a clear, unified goal supported at the most senior decision-making levels. Other examples needed to integrate multiple objectives, such as nature conservation, climate action and agricultural production, as well as financial constraints, to enable the identification of feasible nature-based solutions.

## 2.2 Six steps of a spatial planning process

A clear and robust planning process is more likely to yield decisions that are inclusive, defensible and transparent than an opaque one. A key recommendation emerging from the field of decision science is to break the process of taking such complex decisions up into several distinct steps. This helps to ensure that important elements are addressed in sufficient detail (Gregory *et al.* 2012). A spatial planning process will usually include the following steps:

1. deciding on the scope of the planning exercise (reason to act, stakeholders to involve, initial scoping of possible objectives, metrics, actions and trade-offs)
2. defining/refining specific objectives (what should be achieved) and performance measures (how progress toward objectives through implemented actions will be measured)

3. developing/refining alternative actions (how objectives could be achieved), and sometimes scenarios (to explore key sources of uncertainty)
4. estimating consequences of the alternative actions
5. assessing likely trade-offs to select the most promising solution(s)
6. implementing, monitoring and evaluating the solution(s) (with potential to update the plan, if needed)

These steps provide an evaluation structure that helps decision-makers to clearly define relevant objectives and performance measures and find solutions to a problem. Following this structure can foster learning and a shared understanding of the process underway. Maps can provide insight along the way and most often provide the basis for a final informed and defensible decision between different alternative actions by visualizing relevant information.

Most steps will involve discussion about specific elements of the planning process, which need to be chosen from multiple options (Table 1.1). Involving a diverse group of stakeholders throughout the planning process facilitates better deliberation and assessment of all elements of the planning process and the potential solutions from multiple angles. Stakeholders can be actively involved in one, several or all steps, or might only be informed or consulted. Ideally, stakeholders who are potentially impacted by the decision should be involved throughout the process, providing insights to clarify the context of the decision and support the decision-making. Technical or legal experts might only be included at particular steps.

*Table 1: Example of a decision-making problem with different possible objectives, performance measures, alternative actions and trade-offs.*

| **Problem** | **Examples of objectives** | **Examples of performance measures** | **Examples of alternative actions** | **Examples of likely trade-offs** |
|---|---|---|---|---|
| Species decline caused by current land management. | Halt/reverse loss of<br>• species<br>• habitats<br>• ecosystem services | Population size of all/some species.<br>Area of habitat of all/some species.<br>Visitation rate of pollinators to flowers. | Create / expand the network of PAs and OECMs, including lands managed by IP and LCs.<br>Restore degraded / converted habitat.<br>Create land-use zoning.<br>Replace ecosystem service loss with managed species. | Action can benefit one species but harm another.<br>Action can achieve biodiversity objectives to the detriment of other objectives (e.g., financial costs or agriculture expansion). |

PA = Protected Area, OECM = other effective area-based conservation measures, IP and LCs = Indigenous Peoples and local communities

When deciding which action to implement, diverse values and local contexts are often critical in understanding the implications of choices between different alternative actions. Incorporating the views of a representative and inclusive group of stakeholders is key to making a decision that is widely understood, supported and accepted. Stakeholder engagement needs to be designed according to the scope of the planning exercise – every interested person may be able to engage with a plan for the lands of a particular village, while a national planning exercise is more likely to involve representatives of different stakeholder groups. Throughout, empowering all relevant stakeholders to participate equally and taking into account views of women, youth, elderly, ethnic minorities and traditionally marginalized or underrepresented groups ensures an inclusive and transparent planning process. Clear and transparent communication between all actors involved in the planning process will build trust and avoid information asymmetry. That could mean communicating technical and other expert knowledge in clear and plain language so that all stakeholders can understand and fully participate in the process.

### 2.2.1 Scope: clarifying the decision context

The first step of a spatial planning process is to develop a clear overview of its scope, including the problem(s) to be addressed, the people to involve and the desired output of the process. This may involve deciding upon:

- problems to be addressed: values (such as nature’s contributions to people, or economic value from resource use) and current or future threats to these
- lifetime of planning decision (time scales, iterative or once-off)
- key stakeholders (authorities, experts, organized civil society, interested and impacted communities) and their level of engagement in each step of the planning process
- alternative actions and scenarios, and how they address the identified problem(s)
- constraints (budgets, timelines, existing zoning, other competing objectives)
- key uncertainties
- key trade-offs
- desired output of planning process (e.g., priority ranking, optimal solutions, zoning or allocation of specific sites)

Spatial planning can help decision makers to agree upon one “optimal solution”, usually in the form of a map, that could be directly implemented. This final output, informed by spatial analysis and stakeholder inputs, would be intended to guide or regulate land-use decisions across the area mapped, depending on context. In contrast, when decisions are made opportunistically or incrementally over longer time periods, for example under a policy framework that incentivizes rather than mandates specific actions, maps that rank different locations within an area of interest or provide broader zones for potential action can be more useful.

### 2.2.2 Defining useful objectives and performance measures

The objectives of a spatial planning process have wide implications for the choice of methods and results, so must be co-developed with stakeholders as early as possible.

**Objectives** set out a challenge (e.g., number of species threatened with extinction) accompanied by a desired direction of change (e.g., decrease) that should be achieved as an outcome of spatial planning. Targets add quantitative aims to objectives, such as thresholds that indicate whether the objective has been achieved (e.g., decrease the number of threatened species by 50%). Whether to set these hard targets early on is an important decision in itself. Setting such thresholds early on may rule out efficient solutions that fall short of a given target but have more balanced outcomes against multiple targets.

A “good” set of objectives is *complete* (capturing everything that matters within the scope of the analysis), *concise* (nothing is unnecessary or ambiguous), *sensitive* (to the choice of alternative actions such as reforestation v crop production), *understandable* (avoids technical jargon) and *independent* (of outcomes of other objectives).

**Performance measures** quantify the progress made towards achieving the objectives and highlight differences between the consequences of alternative actions.

Performance measures can be 1). direct measures (e.g., number of animals), 2). proxies (e.g., area of suitable habitat as an indicator of population size), or 3). constructed (e.g., scales from 1 to 10). Some challenges can arise when performance measures are too subjective, such as good/moderate/poor categories (Game *et al.* 2013).

Using multiple performance measures for one objective can enhance the understanding of complex problems, such as forecasting how different actions impact the achievement of objectives under different scenarios. For example, to achieve the objective of protecting biodiversity, it would be more effective to measure not only the area of land under protection, but also indicators that inform about the ecological or environmental characteristics of the land, such as species richness or ecosystems extent (Visconti *et al.* 2019; Adams *et al.* 2021).

Performance measures should be *complete* and *concise* (providing measures for all objectives, without being redundant), *unambiguous* (everyone should interpret the metric in the same way), *understandable* (meaningful and intuitive for decision-makers), *valid* (the relationship between the metric and the objective is well understood), and *operational* (it is feasible to collect the necessary data).

### 2.2.3 Developing alternative actions and scenarios

Often multiple potential actions could be taken to address a given problem. These may involve different nature-based solutions: for example, to conserve a given species, actions could include designating a protected area or changing agricultural practices to better accommodate its needs. Working with stakeholders to identify these alternative actions is a key step in the spatial planning process.

Some common pitfalls in identifying options for action include assuming too early what actions stakeholders might prefer, settling for the first few ideas, or choosing actions that have been used before without much thought. Opting for actions that don’t work only because they justify past decisions or expenditure (the “sunk cost trap”) will lead to suboptimal results. Constraints that should be considered during the development of alternative actions may include legal regulations, allocated time, budget or jurisdictional power.

Developing different scenarios for implementation of the actions can help to highlight their relative advantages, trade-offs and any uncertainties involved. Scenarios are plausible futures that illustrate how effective alternative actions are at achieving the objectives under different conditions. For instance, a new protected area might be effective for conserving the species under the current climate but be situated in the wrong place if the species’ range shifts due to future climate change. While scenarios can be a useful decision-support tool, it is easy to present so many options that stakeholders are overwhelmed. Involving stakeholders in conceptualizing the possible different scenarios can help, and local knowledge and expertise will lead to more plausible scenarios.

### 2.2.4 Estimating impacts

Spatial analysis is often at the core of estimating the impacts or the consequences of alternative actions. Section 3 of this paper explores different approaches to doing so, from working with traditional and local knowledge through to feeding spatial data into mathematical or logical algorithms. The same approach should be applied across all alternative actions, to allow advantages and disadvantages to be compared.

As maps resulting from a spatial analysis can be complex, other ways of communicating the consequences of the alternative actions might be needed. Charts or stories can support the description or contextualization of the results. A consequence table can be used in addition to maps (Gregory *et al.* 2012) to summarize the different potential actions and consequences for each objective. A useful consequence table should expose key trade-offs and uncertainties. If it does not, it may be necessary to go back and refine objectives and metrics as part of an iterative process.

### 2.2.5 Assessing trade-offs and deciding

Most alternative action evaluations require trade-offs between the different objectives to be assessed. In every spatial planning process, its decision-makers have to balance the benefits of achieving one objective against the losses of falling short of another. An important challenge for the facilitator of this process is being aware of and actively mitigating peoples' natural cognitive biases, which can lead to important details being overlooked (Kahneman 2011; Cinner 2018).

A well-designed spatial plan should *inform* decision-makers about trade-offs, be *context-specific* to stakeholder values, *consistent* in ranking alternative actions, and *transparent*, with rationale behind the decision openly communicated.

### 2.2.6 Monitoring the results of implementation

Once a decision has been made, the chosen action(s) can be implemented. Progress towards achieving the planned objectives should be measured periodically, along with any undesirable consequences. These monitoring results represent new spatial intelligence, which can be compared to the plan to assess the effectiveness of the action, feed into adaptive management and inform future planning processes.

3

# Common spatial analysis approaches

## 3.1 The role of spatial analysis within spatial planning

Spatial analysis is the process of assessing problems and possible solutions geographically (usually using computer processing), deriving results, and exploring and examining those results. It is extremely efficient in assessing whether particular locations are suitable for specific purposes (such as forest restoration), estimating and predicting the impacts of actions, interpreting, and understanding changes (for example, in land use and in biodiversity), detecting patterns, and much more (ESRI 2018; SPACES n.d. -a).

Within a planning process, spatial analysis can help in deciding the scope, estimating the impacts of alternative actions under different scenarios, understanding potential trade-offs, and monitoring progress and impacts after implementation. The results of spatial analysis can only be as robust as the input data and rationale. Limitations resulting from lack of data or of capacity to process or interpret data must be clearly communicated to inform a robust decision-making process.

This review focuses on how spatial analysis can help to identify locations with the best potential to realize the promise of nature-based solutions – the places where these actions are feasible and deliver the most positive overall impacts. This may involve assessing the technical, regulatory, social or environmental feasibility of implementing specific nature-based solutions in different places and assessing the likely benefits and risks. Some analytical approaches involve comparing the combined impact of land-use choices, such as considering the biodiversity benefits of a network of protected areas rather than choosing areas individually.

Different contexts can require different types of spatial analysis. In this section, advantages and challenges of several common approaches to mapping the potential for nature-based solutions for societal challenges are described. Table 1 summarizes information on four such approaches: a). suitability-first, b). systematic conservation planning, c). participatory mapping and d). mixed. Section 3.1 presents aspects common to all approaches, explains the benefits of stakeholder engagement and highlights the need to address and respect environmental and social safeguards. Then, Sections 3.2 to 3.5 briefly describe the four approaches and present case studies for each one.

*Table 2: Characteristics of four spatial analysis approaches: suitability-first, spatial conservation prioritization, community-led and mixed.*

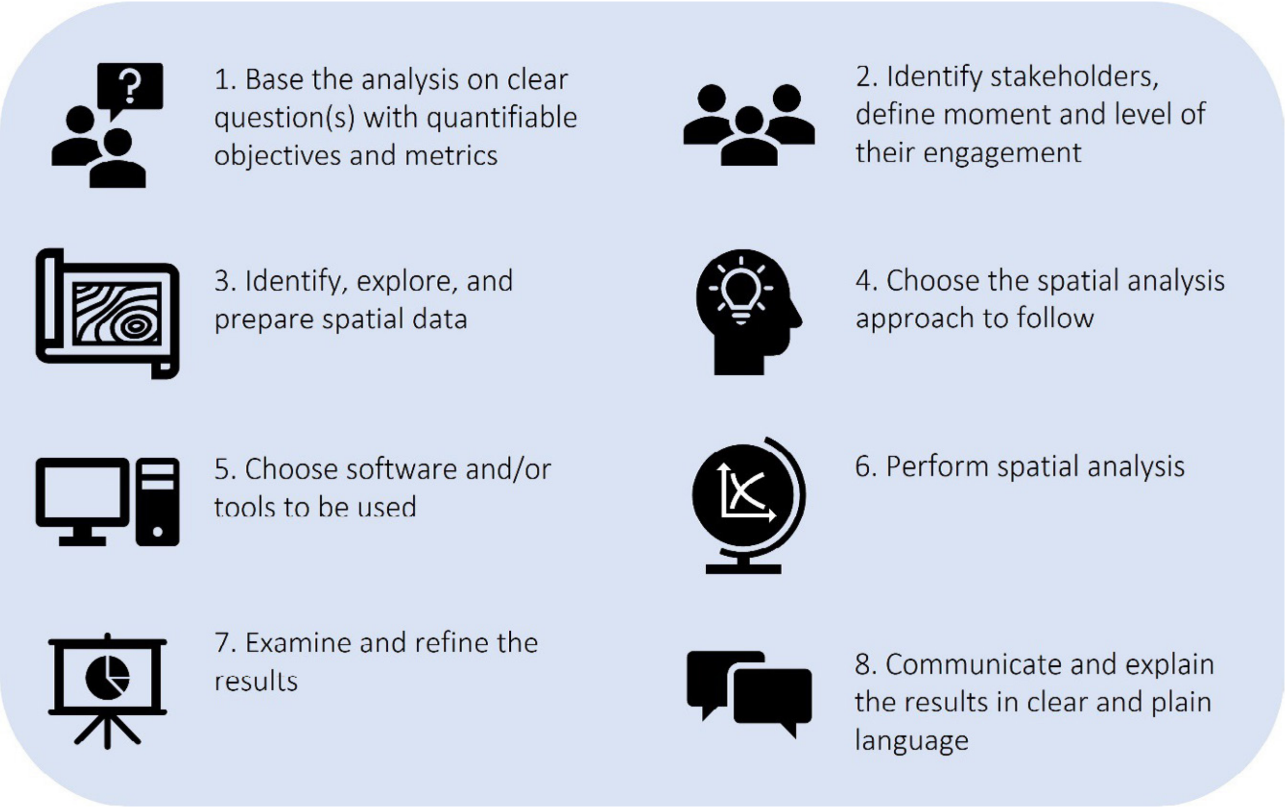
| Approach | Main characteristic | Geographic scale | Expertise required | Software or tool(s) used | Input data | Stakeholder participation | Main advantages | Main challenges |
|---|---|---|---|---|---|---|---|---|
| **Suitability-first** | Computer-dependent overlapping of spatial layers. | Local to global analyses. | GIS knowledge for preparation of spatial data and tables. Skills for processing different data formats. Knowledge on chosen software. | ArcGIS, QGIS or similar; R, Python or similar. | Species richness; Current protected areas; Current land use or land cover; Threats; Carbon content in biomass / soil Human population density. | Not essential but yields more useful and relevant results. | Can support the identification of locations for nature-based solutions that also address UN Sustainable Development Goals. | Results from different analyses may need to be presented in separate maps. |
| **Systematic Conservation Planning (SCP)** | Computer-dependent prioritization modelling. | Local to global analyses. | Same skills listed for suitability-first. Understanding of pareto frontiers or trade-off curves to interpret results. Mathematical knowledge to understand the meaning of objective functions. | Zonation, Marxan, Prioritizr (within R). | | Not essential but yields more useful and relevant results. | Identification of “optimal” solutions in extremely large solution spaces, which are too complex to understand without the aid of computer algorithms. | Requires thorough understanding of the selected algorithm and software settings to be able to interpret and communicate results. Can be perceived as ‘black box’. |
| **Participatory mapping** | Community-led spatial analysis. | Local to sub-national analyses. | Knowledge of safeguards, sensitivity to local customary norms and local language; facilitator with expertise in inclusive participatory approaches. | Computer software not required (though GIS may be used to develop input maps). | | Core to the approach. | Uses traditional and local knowledge as primary sources. Active role of communities leading to positive governance, empowerment and ownership. | Mapping methodology and outputs can be too context specific to be replicated or scaled up. |
| **Mixed** | Computer-dependent analysis with active participation of community. | Local to national analyses. | Same as participatory mapping and the selected computer-dependent approach (suitability-first or SCP). | Same as selected computer-dependent approach. | | Core to the approach. | Active role of communities leading to positive governance, empowerment and ownership. | Coordination of the wide group of actors and results from different approaches can be time-consuming. |

## 3.2 Planning a spatial analysis

Spatial analysis can only provide answers to clearly framed questions with defined objectives and metrics. Usually, it is embedded in a wider spatial planning process, in which these requirements have already been discussed. Additional questions that may arise during the planning of an analysis are the depth and timing of stakeholder engagement and the technical approach to follow (Figure 1).

### 3.2.1 Stakeholder engagement

It is possible to run a spatial analysis on a computer without any stakeholder involvement. However, engaging diverse stakeholders and considering their values and opinions will generate more robust and useful results, more likely to be accepted and owned by the communities implementing the nature-based solutions or experiencing their impacts. Engaging a wide range of stakeholders - especially groups frequently marginalized from the decision-making process such as ethnic minorities, women, and IP and LCs - can reduce unintentional negative impacts and provide more accurate context about perceived threats and values held by the community. For example, social norms mean that men and women often have specific roles and responsibilities in the use and management of natural resources, meaning that men and women also possess distinct and complimentary ecological knowledge that is critical to the analysis.



1. Base the analysis on clear question(s) with quantifiable objectives and metrics
2. Identify stakeholders, define moment and level of their engagement
3. Identify, explore, and prepare spatial data
4. Choose the spatial analysis approach to follow
5. Choose software and/or tools to be used
6. Perform spatial analysis
7. Examine and refine the results
8. Communicate and explain the results in clear and plain language

*Figure 1: Aspects to be considered while planning the details of a spatial analysis.*

To ensure the fair and effective participation of marginalized groups, it may be necessary to take special measures, such as holding separate consultations to avoid negative power dynamics, agreeing a suitable time and location, using facilitators with expertise in indigenous and local knowledge, and following principles of Free, Prior, and Informed Consent. Moreover, seeking local guidance from trusted and reputable sources can help to ensure participatory approaches are well suited to local customary norms and participatory approaches with diverse stakeholders can promote justice and equity.

Types of stakeholder engagement (Figure 2) can vary depending on preferences or on the chosen spatial analysis approach. For computer-dependent approaches, stakeholders can play a key role defining the question, objectives and metrics used to measure performance of the results. They can provide access to national or local data and traditional knowledge not recorded in datasets or databases. Stakeholders can analyze portfolios of solutions resulting from prioritizations or overlay exercises and define roadmaps for the implementation and evaluations of success of the chosen solution.

For the other two approaches included in this review, participatory mapping and mixed, stakeholder engagement and active participation is essential throughout the analysis. The key actors in both approaches are the local communities that live and/or depend on resources from the area under analysis.

Stakeholder engagement benefits from having experienced facilitators leading the interactions (Milz 2022) and from building stakeholders' capacity as part of the process. Facilitators can ensure that communication is clear, concise and transparent (e.g., without using jargon or ambiguous terms) avoiding misunderstandings. Facilitators also promote collaboration and minimize conflicts while supporting an effective and useful participation from each of these actors (Milz 2022).

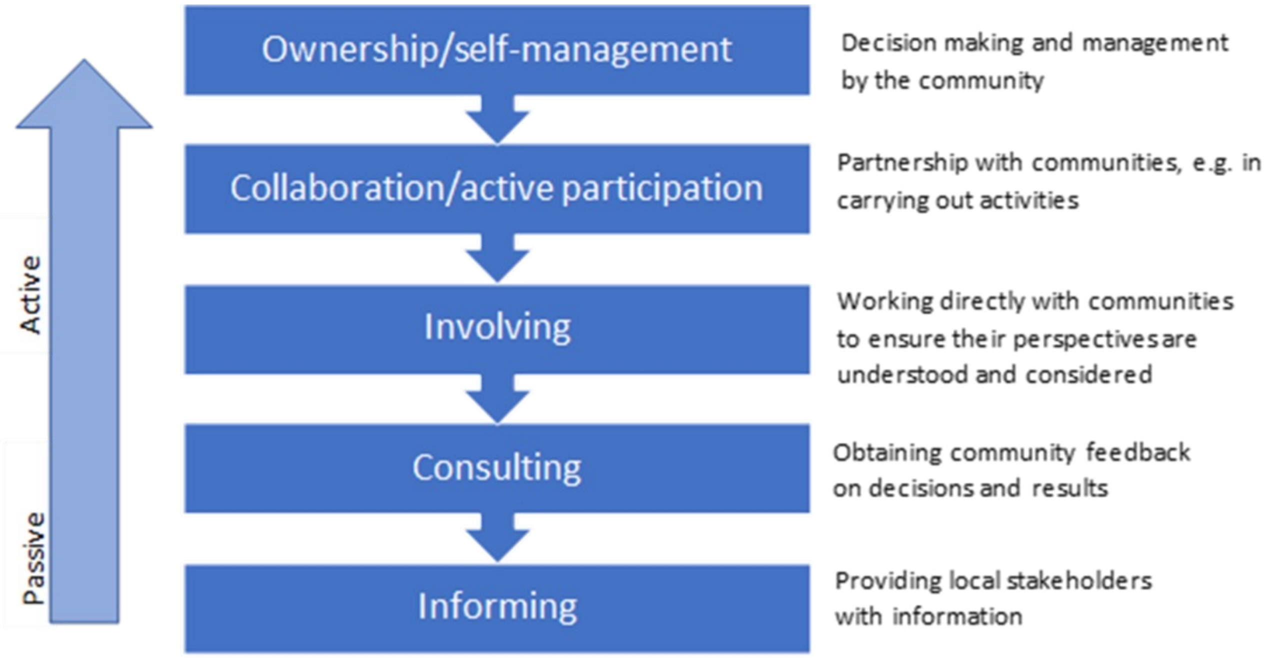


*Figure 2: Types of stakeholder engagement. Compiled from sources such as: (Chambers 2010; Roy et al. 2012)*

### 3.2.2 Social and environmental safeguards

All approaches aimed at identifying locations for nature-based solutions propose to implement an action in a specific location to bring benefits to nature and people. Although these actions are intended to lead to positive outcomes, there can be risks of negative impacts. According to UNEA, nature-based solutions must respect social and environmental safeguards. This entails putting in place measures to assess and minimize the risks of negative social and environmental impacts, while promoting the delivery of the expected benefits to nature and people. More information about safeguards and principles relevant to IP and LCs in spatial analysis and planning can be found in SPACES IP and LCs consultation paper (Systemiq 2023).

## 3.3 Suitability-first approaches

### 3.3.1 What are suitability-first approaches?

“Suitability-first” is a computer-dependent analysis that uses spatial logic to identify suitable locations to implement a desired action. This involves overlaying biophysical data with contextual data that can include socio-economic, environmental and other types of information such as existing land use designations or permitted uses. The analysis can result in a simple map of all feasible areas, or a ranking of these locations according to their potential to deliver benefits.

This type of analysis has been used to identify locations to implement REDD+ (activities in developing countries that reduce emissions from deforestation and forest degradation, conserve or enhance forest carbon stocks, and sustainably manage forests). Here, spatial analysis can help to assess areas of forest or potential future forest for their ability to provide multiple non-carbon benefits in addition to the expected climate change mitigation benefits.

In the context of nature-based solutions for climate change, suitability-first analysis can be used to combine spatial information about the following parameters:

- location of relevant ecosystems
- legal status (e.g., protected area, logging concession)
- conservation status (e.g., pristine, degraded or converted)
- potential to provide ecosystem services to people (e.g., water provisioning)
- potential to support climate regulation (e.g., removing and/or storing carbon from the atmosphere)

This type of analysis could highlight locations that have potential to provide more benefits (e.g., a higher number of desired features) or which pose fewer risks (e.g., no anticipated negative impacts on local communities).

### 3.3.2 Stakeholder involvement

Suitability-first approaches can be conducted without stakeholder involvement, as a pure theoretical exercise. However, if aimed at informing decision-making, this type of analysis greatly benefits from an active participation of a wide range of stakeholders from an early stage (see Section 3.1.1).

### 3.3.3 Technical requirements

Suitability-first approaches have some technical requirements:

- Access to GIS or another type of software (e.g., QGIS, ArcGIS, R, or others).
- Enough technical expertise, GIS knowledge and chosen software knowledge to create a workflow based on spatial logic that assesses the suitability of different locations for the selected nature-based solution. Beginners might be able to perform the analysis with step-by-step instructions.
- Data preparation can, however, require higher levels of technical expertise and GIS knowledge, especially if data was collected and collated using different methodologies and scales.

### 3.3.4 Advantages

- The resulting maps are usually easy to understand.
- Can support the identification of locations for nature-based solutions for climate change that address other UN Sustainable Development Goals (such as SDG1: no poverty) (Walcott *et al.* 2015).
- Can build capacity of communities for collective action, technical knowledge and land management, if local stakeholders are strongly engaged (Walcott *et al.* 2015).

### 3.3.5 Challenges

- The results from different analyses (e.g., potential benefits and risks) may need to be presented in separate maps.
- Data availability can restrict the scope of the analysis that can be undertaken.

### 3.3.6 Frequently used data

Some spatial data types are frequently used for suitability first approaches:

- Distribution of ecosystems of interest (e.g., forests) or current/historical land-use data.
- Distribution of threats to the ecosystems of interest (e.g., deforestation risk, projected land-use change, human pressures, proximity to roads).
- Current protected areas and other formal land-use designations.
- Biodiversity - species richness, threatened species richness, Key Biodiversity Areas or other biodiversity metrics.
- Ecosystem services - carbon in biomass, soil organic carbon stocks, water quality, water provisioning, water stress, pollination services, food provision, timber provision, etc.
- Population, population density, vulnerable populations, jurisdictional income per capita.

## **Case study 1:** Mapping Opportunities for Cocoa Agroforestry in Côte d'Ivoire (Critchley *et al.* 2021)

**Location:** Côte d'Ivoire, national scale

**Area analyzed (km²) and ecosystem type:** National analysis (~322.462 km²) focused on cocoa growing areas (plantations) and areas climatically suitable for cocoa.

**Objective of the spatial analysis:** Côte d'Ivoire's policies and strategies on forest conservation and restoration state that agroforestry can contribute to achieving the national forest restoration target (20% of land area by 2030) and other relevant targets. It is therefore imperative to identify areas suitable for implementing agroforestry and to assess potential benefits that this could bring.

The spatial analysis sought to identify priority areas within existing cocoa plantations where agroforestry could be implemented, increasing tree cover. It also aimed to identify areas with potential to deliver multiple benefits, such as carbon sequestration and biodiversity conservation.

**Methodology:** The methodology used for mapping priority areas and their potential to deliver co-benefits consisted of two main steps: the first aimed at identifying suitable areas for cocoa agroforestry and the second at assessing potential benefits that could be delivered. All analyses were carried out in Python Jupyter Notebook using the geemap package (Wu 2020).

The identification of suitable areas was completed by overlaying spatial data to find areas that represented a set of criteria and avoiding areas based on a set of constraints. **The criteria** included:

- Areas where cocoa is currently grown (VividEconomics 2020) were targeted for conversion to agroforestry
- Areas in west Africa projected to be climatically suitable for cocoa both currently and in 2050 (Schroth *et al.* 2016) were used to refine the current cocoa growing data. With the absence of a soil suitability dataset, the analysis was based on the assumption that areas with current cocoa plantations meet any soil requirements.

**The constraints** were established based on national policies and included:

- All remaining primary and secondary forests should be protected, including classified forests (private forest domain of the state) with degradation levels lower than 75%.
- Intact non-forest natural ecosystems (e.g., natural grasslands and wetlands) should remain intact rather than converted into cocoa agroforestry.

- Cocoa agroforestry should be implemented only in current cocoa plantations and in classified forests that are more than 75% degraded.
- Areas where conversion to cocoa agroforestry could reduce carbon stocks in both biomass and soil should be avoided.

The first step was to identify current and potential cocoa growing areas, using these criteria and constraints. At the same time, the team assessed the current tree cover status of cocoa growing areas, options for increasing or restoring tree cover within cocoa plantations and the current and future climate suitability of these areas.

The spatial logic for identifying current and potential cocoa growing areas was applied differently in two land categories: (1) “the rural domain”, meaning areas outside protected areas and classified forests, and (2) areas within classified forests. Areas within protected areas were excluded from the analysis, even if they were also designated as classified forests.

In the rural domain, non-cocoa areas (VividEconomics 2020) were excluded from the analysis. Tree canopy cover (Sexton *et al*. 2013) and forest disturbance data (Vancutsem *et al*. 2021) were used to classify cocoa growing locations into full-sun (<30% canopy cover), partial shade (>=30% canopy cover and recent disturbance) or high shade plantations (>= 30% canopy cover and not disturbed). Data on climatic suitability for cocoa (Schroth *et al*. 2016) were used to exclude locations which were not suitable under a current or future climate. Within classified forests (UNEP-WCMC and IUCN 2021)[1], the assessment focused on existing cocoa growing areas and degraded non-cocoa land covers where <25% canopy cover was present (excluding settlements, closed forests and water). As in the rural domain, the same classification system (full-sun, partial shade and high shade) was applied to cocoa growing areas.

Once current and potential cocoa growing areas were identified, the analysis developed scenarios for increasing tree cover on plantations. Within classified forests it was assumed that high shade agroforestry would be implemented on all cocoa growing areas. In the rural domain, it was assumed that implementing high shade agroforestry would be unlikely. Here, all locations identified as full-sun plantations were assumed to transition to partial shade agroforests, with all other locations remaining the same (partial and high shade agroforests).

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[1] spatial data on classified forests received from Bureau National d’Études Techniques et de Developpement (BNETD) and the Permanent Executive Secretariat of REDD+ in Cote d’Ivoire in 2016

Following that, the second step entailed an assessment of the potential co-benefits from promoting cocoa agroforestry within the areas identified. Carbon stock values were estimated from a literature review and assigned to the cocoa plantation classes in each scenario to assess the potential change in carbon. Finally, carbon stock gain, proximity to forests and settlements were combined to create a national restoration prioritization map. It was assumed that increasing tree cover in areas close to forest cover would benefit biodiversity conservation through improved habitat quality and connectivity. Similarly, increasing tree cover in areas close to settlements could improve the provisioning of ecosystem services such as timber and non-timber forest products, and water quality.

**Main findings:** The analysis provided a spatially explicit assessment of priority areas for increasing tree cover within cocoa growing areas (Figure 2).

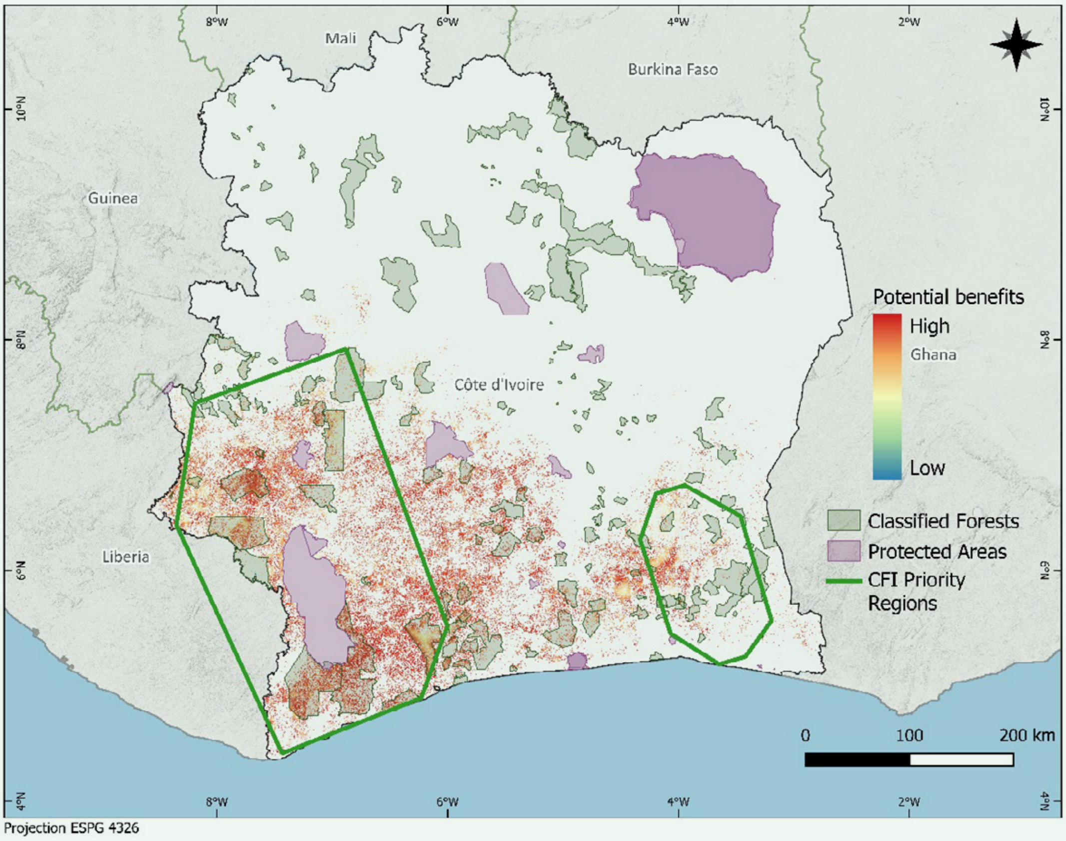

*Figure 3: "Combined priorities for increasing carbon stock, proximity to forest and proximity to settlements within cocoa growing areas identified as full-sun or partial-agroforestry. Current cocoa growing areas are restricted to those suitable under the current climate. Green circles indicate priority regions for the Cocoa and Forests Initiative start-up phase" (Source: Critchley et al. 2021).*

*Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.*

**Advantages:** The approach used several datasets within a robust methodology. The analysis considered aspects relevant to Côte d'Ivoire's political, social and environmental context.

Using proxies for potential biodiversity and ecosystem service benefits made it possible to generate information on parameters that sometimes lack specific data. Proximity data (distance to forests and settlements) was used as a proxy for potential biodiversity and ecosystem service benefits.

**Challenges:** This analysis had to use multiple datasets with different temporal timescales and spatial resolutions. To reduce this limitation, data from a time period as close as possible to the land-cover dataset were selected, and all data were resampled to a 30m resolution.

The land-cover dataset only identified a 'cocoa' class but did not stratify by cocoa management (e.g., monoculture or agroforest), therefore additional datasets had to be used to estimate this (VividEconomics 2020).

Detecting cocoa remotely and over large scales through satellite images is challenging. This is due to cocoa often being established under existing tree canopy, and commonly grown with at least a low level of shade, making it difficult to distinguish from surrounding natural forest. Relative to other datasets, the chosen land-cover dataset had a smaller estimate for cocoa area in Côte d'Ivoire, hence analysis may have underestimated the land area with cocoa plantation available for restoration.

**Key stakeholders involved:** A consultation workshop took place at the beginning of the analysis. This workshop aimed to inform stakeholders of the analysis, collect their feedback on what was proposed, clarify the national context of the work, and identify data sources. Participants were stakeholders from the public and private sectors as well as representatives of civil society. A quarter of the participants were women.

## 3.4 Systematic Conservation Planning

### 3.4.1 What is Systematic Conservation Planning?

Systematic conservation planning (SCP) focuses on **complementarity and efficiency** (Margules and Pressey 2000; Sarkar *et al.* 2006). It is an iterative process which uses algorithms to solve mathematical problems. Depending on the aim of the analysis, these problems can include setting targets for multiple features at the same time, e.g., a target of 20% for one species' distribution to be included in the chosen "solution", along with 50% of the country's biomass carbon stock, etc. The use of explicit objectives/goals in this way are the basis for SCP's transparency, robustness and evidence-based results.

The systematic conservation planning framework operates under the CARE principles of complementarity, adequacy, representativeness, and efficiency. These four principles help identify solutions that enable the long-term persistence of biodiversity and ecosystem services and ensure that objectives can be met at the least possible cost (Kukkala and Moilanen 2013).

- **Complementarity:** SCP aims to identify planning options where conservation areas complement one another to collectively achieve objectives.
- **Adequacy:** represents the quality of protected area networks to enable the long-term persistence of the biodiversity that it aims to protect. Adequacy may be achieved when a sufficient sample of biodiversity is secured.
- **Representativeness:** refers to the ability of conserved networks to contain representative samples of all features of biodiversity or ecosystems services that we aim to protect.
- **Efficiency:** the principle of efficiency reflects the goal to achieve conservation objectives for the least possible cost. Cost-efficient solutions are more likely to be feasible and implemented.

The mathematical problems posed during the prioritization stage can include the consideration of cost to maximize the conservation intervention's 'return on investment'. Output maps from the prioritization stage usually highlight candidate areas for conservation action (i.e., a solution to the mathematical problem), or rank areas from high to low importance. Some of the most commonly used tools or algorithms are Marxan (Ball *et al.* 2009), Zonation (Moilanen *et al.* 2011), and Prioritzr (Hanson *et al.* 2022) (see their main features in Table 3).

Even though SCP emerged as the standard framework to identify optimal locations for establishing new conservation areas (e.g., protected areas), more recent applications can be more complex, such as identification of locations for other forms of area-based conservation action (Strassburg *et al.* 2020), representation of multiple dimensions of biodiversity in conserved areas (e.g., taxonomic, traits or phylogenetic diversities (Brum *et al.* 2017)), planning for the highest conservation impact (Brum *et al.* 2019; Monteiro *et al.* 2020), or for multiple management practices. An example of the last are Essential Life Support Areas (ELSA– see case study 3 for details) (UNDP 2022). ELSA are identified using a SCP approach involving multiple stakeholders as areas where nature-based actions can sustain key benefits to humanity. These benefits include sustainable livelihoods, food and water security, disaster risk reduction, or carbon sequestration.

SCP has been applied in terrestrial (Jung *et al.* 2021), freshwater (Lira-Noriega *et al.* 2015; Linke *et al.* 2019) and marine realms (Ruiz-Frau *et al.* 2015; Jones *et al.* 2020), as well as cross-realm planning (Álvarez-Romero *et al.* 2015) and at scales that range from local (Kirkman *et al.* 2019) to national (Fajardo *et al.* 2014; Lessmann *et al.* 2014; Cuesta *et al.* 2017) to global (Jung *et al.* 2021). In relation to nature-based solutions for climate change, SCP has been used to explore options to expand or modify protected area networks in response to species' climate-driven range shifts (Wan *et al.* 2017; Triviño *et al.* 2018), to protect climate refugia (Graham *et al.* 2019), or to understand how and where species and the protected areas network are most vulnerable to climate change (Belle *et al.* 2016). All these examples aimed to increase the protected areas' resilience and conservation benefits in the future.

### 3.4.2 Stakeholder involvement

Stakeholder involvement is not inherent to the prioritization exercise developed under SCP but brings great benefits to the analysis. Good SCP aiming at informing decision-making should include the participation from a wide range of stakeholders. That allows the analysis to reflect their opinions and values and to build a transparent and inclusive planning process (see Section 3.1.1).

### 3.4.3 Technical requirement

- Access to software/tools (Zonation, Marxan, Prioritizr) for running the analysis.
- Skills for preparation of spatial data and tables, processing different data formats.
- Understanding of concepts such as pareto frontiers or trade-off curves to interpret results.
- Mathematical knowledge to understand the meaning of objective functions.

### 3.4.4 Advantages

- Provides a quantitative/mathematical approach to problem solving.
- Enables the identification of optimal solutions in extremely large solution spaces, which are too complex to understand without the aid of algorithms and computers.
- Versatility for different contexts, data types and problem scope and scale.
- Resulting maps are usually easy to understand. For example, outputs often show colour gradients for ranking of planning units in the landscape, or outline extents of proposed new protected areas, including figures with cost-benefit curves or trade-offs between different objectives.

### 3.4.5 Challenges

- Typically requires working with large volumes of spatial data (e.g., hundreds or thousands of species distribution maps), demanding expertise in GIS and coding or command line interface.
- Data availability and data quality. Spatial data on the distributions of biodiversity or ecosystem services have historically been missing or poor in quality. This has prevented SCP from considering more diverse taxonomic classes, especially in data-poor regions such as the tropics, or marine and freshwater realms.
- Requires thorough understanding of the algorithm used and software settings to be able to interpret results correctly.
- Involves various assumptions which could cause the results to be misinterpreted, which can be crucial when explaining results to stakeholders and decision-makers.

### 3.4.6 Frequently used data

Spatial conservation prioritization is informed by different types of data, including spatial and non-spatial data. The ones most frequently used are spatial data on the conservation features (which can include various of nature’s contributions to people), information about the distribution of costs related to conservation, and spatial data on features that constrain the adequacy of sites for implementation of nature-based solutions (such as areas that are not available for various reasons, or sites with existing management interventions such as areas already conserved or under restoration). The following list describes the most frequently used data for those categories:

### Conservation features:

- Species distributions, species populations, abundances, or taxonomic classes other than species (e.g., subspecies, genera). Sometimes, proxies for species groups are used (e.g., umbrella, indicator, or surrogate species and species groups).
- Ecosystems, habitats.
- Ecosystem services (Villarreal-Rosas *et al.* 2020; Chaplin-Kramer *et al.* 2022)
  - Carbon stocks (biomass carbon, soil organic carbon)
  - Water stocks and water quality regulation (through nitrogen or sediment retention)
  - Crop pollination, fodder production for livestock, timber production, fuelwood production, riverine and marine fish catch
  - Flood regulation, coastal risk reduction
  - Access to nature, ecotourism

### Costs of implementing nature-based solutions in planning units. Because the cost of implementing action varies across space, spatial prioritization often considers:

- Financial costs, such as: cost of purchasing land, cost of land management, and opportunity costs of foregone economic activities.
- Biological integrity (Ardron *et al.* 2010) and anthropogenic impact: Because information on financial costs is often lacking, other information of ecological relevance such as the biological integrity or the human impact of the area are often used to favour the selection of some areas (i.e., sites with high biological integrity or low anthropogenic impact) over others (Ardron *et al.* 2013).
- Area: Spatial prioritization may also use the area of planning units as a proxy for cost.

### Constraints:

The term *constraint* in SCP is typically used for areas that are either “locked-in” (included) and “locked-out” (excluded) from the mathematical solution. This can include:

- Areas already under specific type of management such as existing protected areas, sites under restoration plans, conservation corridors etc.
- Areas that are considered incompatible with the implementation of the desired conservation action, which may include built-up areas or productive land.

Non-spatial data: non-spatial data is often used to inform different steps of the SCP framework. Examples include the use of population trends or species threat status to set species-specific representation targets or relative weights, or data relating to management of conserved areas.

*Table 3: Comparison of different decision support tools for SCP (UNDP 2022)*

| | **Zonation** | **Marxan** | **Prioritizr** |
|---|---|---|---|
| Aim of the tool | Continuous ranking of the planning area's conservation value. | Target-based planning. | |
| Algorithm | Priority ranking (maximal retention of weighted range-size normalized richness). | **Simulated annealing.** These algorithms find good solutions that are different in each run. This allows users to explore multiple solutions. | **Integer linear programming.** These algorithms can identify the best solution possible or estimate distance to the best solution as a measure of quality. |
| Support multiple zones with different objectives? | No. | Yes (Marxan with Zones). | Yes. |
| Outputs | A priority rank map produced by iteratively removing the planning unit that leads to the smallest aggregate loss of conservation value. | Solution maps – Creates portfolios of planning units that minimize the cost of the solution while ensuring that all targets are met. | Solution maps – In ELSA, it creates portfolios of planning units that cover as many features as possible within a given "cost". |
| Pros | Applicable to very large datasets. | The most frequently used conservation planning software. | Higher quality solutions in less processing time. Supports a broad range of objectives, constraints and other parameters. |
| Cons | Primarily operates on binary conservation planning problems. | Simulated annealing provides no guarantee of solution quality. Can be relatively slow in solving large problems. | Not suitable for solving very large problems (>1 million planning units) that include nonlinear constraints. |
| Real world usage | Identification of ecological network in Southern Finland (Jalkanen *et al.* 2020). | Great barrier reef Marine Park Zoning in Australia. | Costa Rica's ELSA (UNDP 2022). |

## **Case study 2:** Strategic approaches to restoring ecosystems can triple conservation gains and halve costs – International Institute for Sustainability (IIS), Brazil (Strassburg *et al.* 2018)

*This case study was prepared by IIS and draws closely on a journal paper describing the results of work led by IIS, (Strassburg et al.* 2018).

**Location:** Brazilian Atlantic Forest

**Area analyzed (km²) and ecosystem type:** 51.700 km² of agriculture or livestock areas

**Objective of the spatial analysis:** This study aimed to create a prioritization approach for conserving the Brazilian Atlantic Forest biodiversity hotspot by developing a multicriteria spatial restoration plan. The restoration plan simulated the restoration of approximately 51,700 km² of Legal Reserve deficit in the Atlantic Forest. The objectives of the restoration plan were fourfold: 1) to quantify the costs and benefits of restoration in different scenarios; 2) to identify compromise solutions by quantifying trade-offs between costs and benefits; 3) to assess the impact of restoration block sizes (ranging from 1 to 100 ha) on carbon sequestration, considering economies of scale and analogous ecologies of scale; and 4) to quantify the effects of restricting the maximum proportion of land that can be restored within each planning unit (up to 35%, 65%, and 100%). The findings of this study are intended to inform restoration options aligned with the National Plan for Native Vegetation Recovery (PLANAVEG) and the national legislation on native vegetation protection and land use, specifically the Forest Code of 2012, to support conservation efforts in the Atlantic Forest.

**Methodology:** The multicriteria spatial restoration prioritization approach used in the study consisted of five main steps. First, consultations were conducted with representatives of the Ministry of Environment and other stakeholders of the Atlantic Forest biogeographical region to identify critical variables for inclusion in the modelling process and to develop restoration scenarios that align with policy objectives and stakeholder preferences. Second, variables were gathered and modelled as inputs. Third, a novel multicriteria spatial restoration prioritization framework was developed and implemented as an Integer Linear Programming problem. Fourth, restoration scenarios were simulated. Finally, the solutions and their trade-offs were analyzed and interpreted.

Spatial surfaces were developed to quantify three benefits of biodiversity: conservation, climate change mitigation, and cost reduction. To assess the benefits of biodiversity conservation, species extinction functions were used, which reflect diminishing returns associated with increasing habitat areas for each species. Ecological niche models were developed for endemic amphibians, birds, and woody plants in the Brazilian Atlantic Forest to identify areas that would be suitable habitats for each species if restored. Potential species distribution was used instead of current species distribution, as restoration would expand the available habitat area for the species. This approach departs from the typical method used in conservation prioritization that aims to protect the current species distribution within native vegetation.

Climate change benefits were calculated using a potential above-ground biomass recovery map for the Brazilian Atlantic Forest as a proxy for above-ground potential carbon sequestration in degraded areas. The map, with a resolution of 1 km$^2$, followed the methods of Poorter *et al.* (2016). The total possible above-ground biomass recovery over 20 years of secondary forest growth was calculated based on annual rainfall, rainfall seasonality, and climatic water deficit.

The cost of land restoration for each area within the Brazilian Atlantic Forest was based on the opportunity cost of restoring the land and the cost associated with restoration, whether active or passive. The opportunity cost was estimated as the potential loss of revenue from agriculture or livestock from restored areas, and land acquisition cost was used as a proxy for opportunity cost. This decision was based on an established economic assumption that land acquisition cost reflects the potential future revenues from that land. Spatial data on the distribution of pasturelands and croplands were combined with county-level data on land acquisition costs for these categories.

Using these variables, the objective function of the study determined the optimal amount of forest to restore in each planning unit to maximize ecosystem services benefits, such as biodiversity conservation and carbon sequestration, and/or minimize total costs, including opportunity and restoration costs.

A total of 382 restoration scenarios were evaluated in the study. These included scenarios that assigned different weights to the objectives of maximizing biodiversity conservation, maximizing carbon sequestration, and minimizing the total cost, with variations in the maximum area of the planning unit allowed to be restored (35%, 65%, and 100%) and different restoration project sizes (1 ha, 5 ha, 10 ha, 25 ha, 50 ha, and 100 ha). Additional scenarios were run with restrictions on restoration within state borders, following the proportion of land area to be spared for nature as stated in the Forest Code. Some scenarios also allowed for restoration inside or outside the state in priority areas for biodiversity conservation. Finally, a scenario was run where the restoration target was uniformly distributed among farms in the Atlantic Forest that are not fully compliant with national legislation (referred to as the Baseline scenario). These scenarios reflect a range of possible implementations of the Forest Code.

The restoration scenarios were compared regarding cost-effectiveness, which measures benefits per unit of cost, and trade-off curves between biodiversity conservation and carbon sequestration.

**Main findings from spatial analysis:** The study demonstrated that this approach has the potential to significantly improve the cost-effectiveness of biodiversity conservation in the Atlantic Forest hotspot. A comparison with a baseline scenario of non-systematic restoration revealed an eightfold increase in cost-effectiveness. By implementing a compromise solution, the authors could avoid 26% of the current extinction debt of 2864 plant and animal species in the biome, representing a substantial increase of 257% compared to the baseline. Additionally, the compromise solution resulted in the sequestration of 1 billion tonnes of $CO_2e$, a 105% increase, and a reduction in costs by US$ 28 billion, equivalent to a 57% decrease.

**Challenges and advantages:** Although the study strived to apply best practices to all stages of their analyses, some limitations should be highlighted. Some species distribution models relied on relatively small occurrences, and all presented the usual constraints associated with correlative models. The approach to estimating extinction risk is imperfect, and the climate benefits did not include below-ground biomass or soil carbon. Also, importantly, shifts in species distribution due to climate change were not considered.

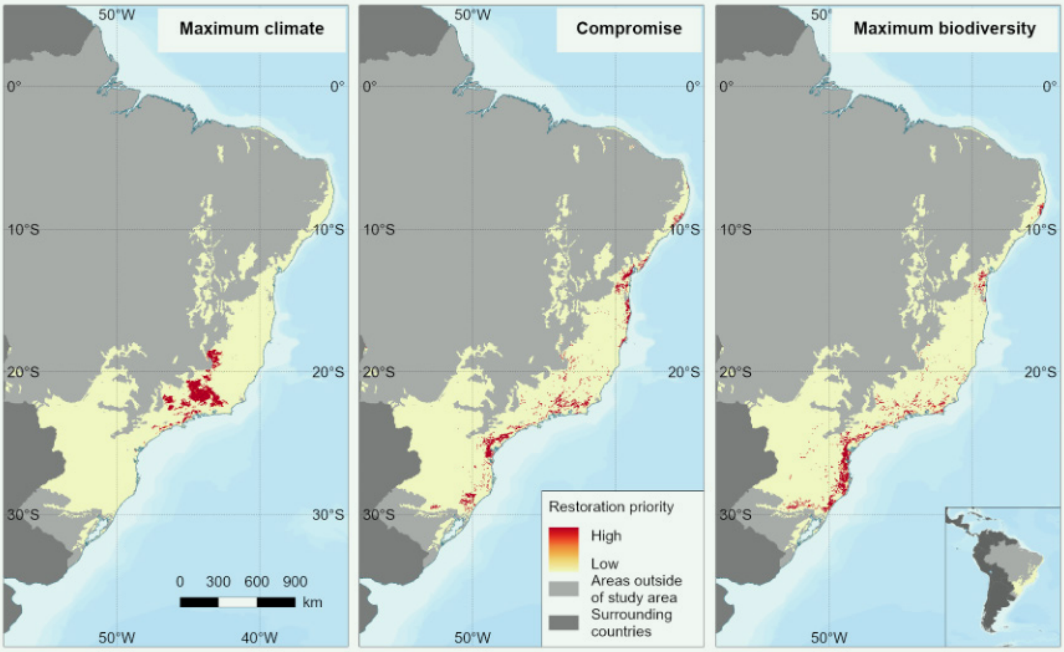

*Figure 4: Restoration prioritization in Brazillian Atlantic Forests. Maps highlighting priority areas with the aim to maximize climate change mitigation benefits, a compromise approach (a trade-off between costs and benefits ) and priority areas with the aim to maximize biodiversity benefits (IIS, 2022 based on methods outlined in Strassburg et al. 2018).*

*Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.*

However, even considering the limitations and assumptions, this work made a big step toward better understanding spatial planning benefits. The approach combined the most comprehensive multicriteria database on large-scale restoration compiled for any region worldwide with innovative breakthroughs in systematic conservation planning methods, including multicriteria integer linear programming (ILP) and the first-ever accounting for economic and ecological efficiencies of scale in systematic planning. It is also customizable to any specific socio-ecological context and set of objectives, allowing it to adapt to any region of the world readily.

Other vital capabilities are precision (ILP can deliver exact optimum solutions superior to the approximations of standard systematic conservation planning software) and the possibility to work with large areas at high resolution (the application had 1.3 million planning units) yet calculate solutions quickly. The method has a crucial advantage due to its ability to quickly map out a solution space with hundreds of combinations of multiple objectives and focus on the outcomes of these scenarios (as opposed to contentious and subjective a priori weighting standards in multicriteria approaches).

The technical advances and high degree of customization to context-specific policies and goals led the Brazilian Ministry of Environment to use the decision-supporting tool and maps introduced here for restoring the Atlantic Rainforest. Moreover, the results led to the replication of the approach with the other five Brazilian biomes as part of the National Plan for Native Vegetation Recovery—PLANAVEG. The potential of this approach for quickly exploring large numbers of scenarios will be of particular importance for two PLANAVEG strategies: Spatial Planning and Monitoring and Finance. These ongoing biome-specific initiatives are incorporating the approach to include customized sets of benefits and costs, such as water (Atlantic Forest); farmers' income (derived from ecosystem services and forest products in all biogeographical regions); pollination (Amazon); firewood production (Caatinga); and ecotourism-related species (Pantanal). The efficiency of the linear programming approach permits the assessment of thousands of variations of factor weightings in a few hours (for applications of the size and complexity presented here). For this reason, stakeholders can select the most desirable allocations based on outcomes, avoiding the often-contentious task of initially assigning relative weights.

**Key stakeholders involved (type of stakeholder, role or level of engagement/participation, representativeness):** The work was initiated through consultations with representatives from the Ministry of Environment and other stakeholders of the Atlantic Forest biogeographical region. They aimed to identify critical variables to be incorporated into their modeling process and develop restoration scenarios aligning with policy objectives and stakeholder preferences.

An international team of experts from various institutions participated in the collection and modeling of input variables, development of a multicriteria spatial restoration prioritization framework, simulation of restoration scenarios, and analysis and interpretation of the results.

**Sources or links:** Paper reference: https://www.nature.com/articles/s41559-018-0743-8

The R package containing the workflow for species distribution modelling is readily accessible and can be installed from https://github.com/Model-R/Model-R.

A repository with example data can be found at https://github.com/Model-R/Back-end/releases/tag/coordenador-IIS.

## **Case study 3:** Maps of 'essential life support areas'(ELSA) for Costa Rica – United Nations Development Programme (Dirección de Cambio Climático; Ministerio de Ambiente y Energía 2022; UNDP 2022; UNDP n.d. -b; UNDP Costa Rica n.d.)

**Location:** Costa Rica, national scale

**Area analyzed (km2):** 51,179 $km^2$

**Ecosystem type:** Mangroves, forests, wetlands, riparian ecosystems, agricultural production areas, urban green areas.

**Objective of the spatial analysis:** The project 'Mapping Nature for People and Planet,' demonstrated how countries can use Systematic Conservation Planning (SCP) to reveal pathways toward the achievement of multiple nature-based goals simultaneously. The objective was to create maps of 'essential life support areas' (ELSAs), which can help countries identify where action to protect, manage, and restore nature can best contribute to a better future for all.

In Costa Rica, this work supported the development of the new National Climate Change Adaptation Plan for 2022-2025 by identifying priority areas where nature-based actions can support: (a) reduction of human vulnerabilities to climate events, (b) secure ecosystem for human population, and (c) promote the adaptation of ecosystems to climate change.

**Methodology:** Through the application of new spatial data technology, inclusive dialogue, strengthened capacity, and policy support, this project inspired hope and a unified vision, coupled with coordinated action for nature. The project followed a nine-step process to ensure the development of a scientific analysis that meets national needs.

In Step 1, national stakeholders defined Costa Rica's climate adaptation policy priorities alongside the Directorate of Climate Change of the Ministry of Environment and Energy, resulting in the above-mentioned climate adaptation objectives. Policy priorities were the foundation of ELSA methodology, as the aim was to create a customized spatial analysis that could support the achievement of the priorities. In Step 2, the project team collected two types of layers: (a) data layers that can serve as a proxy to map the policy priorities (planning objects), where the number of layers per target depends on the complexity of the target; and (b) data to map areas of intervention. In Step 3, national stakeholders defined how Costa Rica approaches protection, restoration, and sustainable management to provide insight into how to spatially map the zones available for each action.

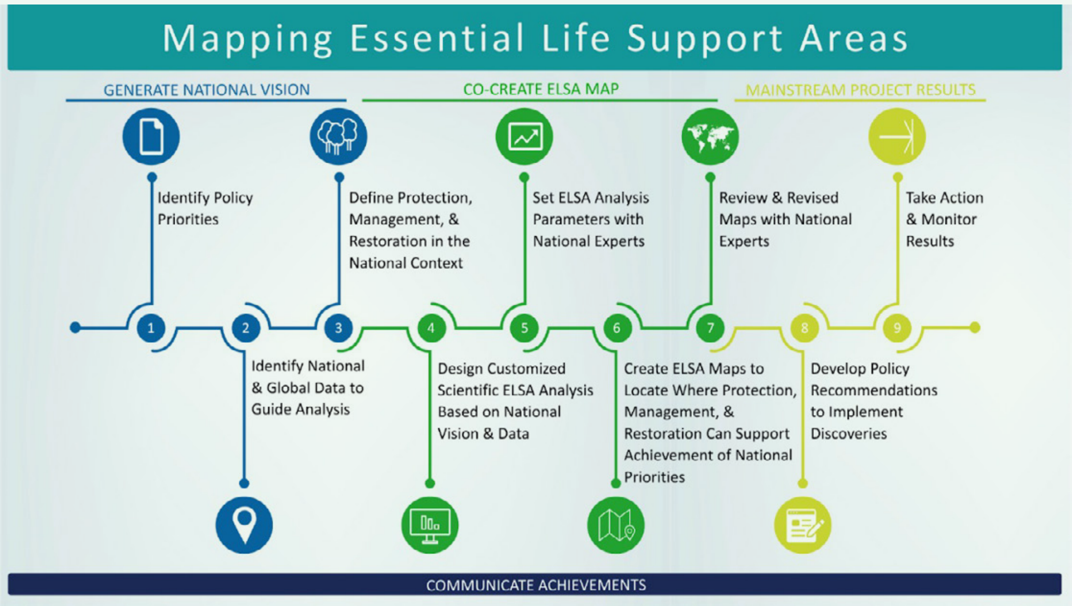

*Figure 5: The ELSA process (UNDP 2021)*

In Steps 4-7, working closely with UNDP's science team, the country shaped the development of a customized Systematic Conservation Planning analysis run in the Costa Rica ELSA Webtool. The tool is open to public use and can be found here. Through a series of consultations, stakeholders agreed on a final ELSA map to guide action for climate change adaptation. In Steps 8-9 the ELSA map and related findings were embedded in the National Adaptation Plan to Climate Change and shared with diverse stakeholders. For more information on the ELSA methodology, please see the ELSA Workbook (UNDP 2022).

**Main findings from spatial analysis:** The analysis identified areas at the national level where actions for protection, restoration, and sustainable management of ecosystems can increase resilience against climate events. Results included suggestions for geospatial interventions related to forest protection and restoration, wetland and watershed restoration, as well as coastal, forestry, and agriculture management. The ELSA Webtool provides an avenue for the Costa Rican government to continue to iterate the analysis and generate new prioritization maps based on changing priorities and data.

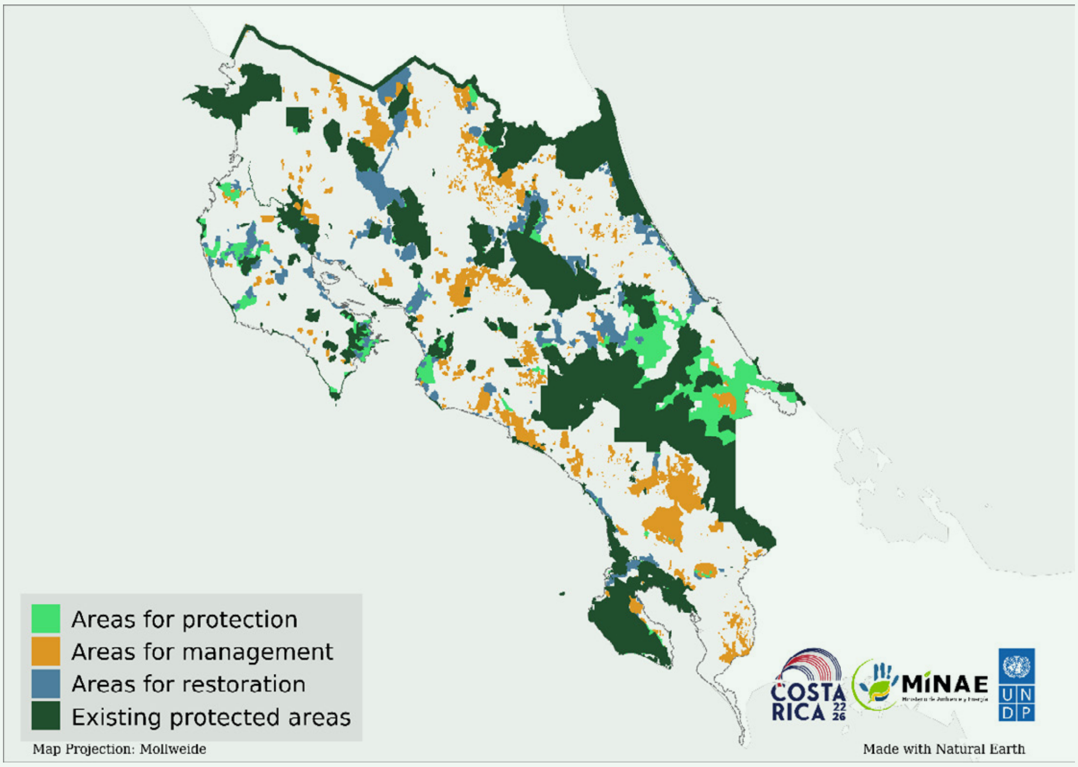

*Figure 6: ELSA climate change adaptation map of Costa Rica (UNDP 2022)*

*Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.*

**Challenges and advantages:** Challenges included (1) the fact that climate adaptation geospatial analysis required advanced data layers (climate change velocity, climate refugia, climate risk) that were still non-existent or difficult to find, and (2) that sustained work will be needed to transition from the National Climate Change Adaptation Plan to action on the ground. The advantages are that this is a wholly nationally-owned approach drawing on the best available data, scientific analyses, and stakeholder engagement. It can use spatial prioritization to identify diverse nature-based actions that support adaptation to climate change and Earth Observation-based policies in the country.

**Key stakeholders involved:** Ministry of Environment and Energy (key national counterpart), Center for High Technology (technical counterpart), National Emergency Commission (expert opinion and data providers), Ministry of Agriculture (expert opinion), University of Costa Rica (expert opinion and data providers), National System for Conservation Areas (expert opinion), National Forestry Financing Fund (expert opinion), United Nations Environmental Programme (expert opinion), GIZ (expert opinion and data providers), Fundecooperacion (expert opinion), Forever Costa Rica Association (expert opinion).

## 3.5 Participatory mapping approaches

### 3.5.1 What are participatory mapping approaches for spatial analysis and planning?

Participatory mapping refers to collecting and mapping spatial information to assist local communities to comprehend, discuss, build consensus, and make informed decisions regarding their own community and related resources (NOAA 2009). In contrast with other approaches, participatory mapping includes as key actors the IP and LCs who are often the first to experience positive or negative impacts of land-use plans. These approaches acknowledge that IP and LCs have deep knowledge and understanding of their conventional land boundaries and local environment with identifying features relevant to them (e.g., sacred areas), and practices that are often unrecorded but can be represented in a map (Rainforest Foundation UK 2022).

Therefore, in the context of spatial planning and analysis, participatory mapping is an essential means to empower local communities and facilitate their active role in the planning and management of their land (Swanson and Ardoin 2021; UNFCCC n.d.). Enabling participatory and collaborative processes empowers them to be contributors of knowledge rather than just passive beneficiaries (Cone *et al*. 2012) and assists them in acknowledging their potential to contribute to the solutions as a community (WaterAid 2005).

### 3.5.2 Stages to consider in these approaches

The distinctiveness of individual communities and their context means that these approaches are usually flexible and tailored to specific problem contexts, locations (Rifkin and Pridmore 2001; Mazeka *et al*. 2019) and local needs or priorities. However, there are some particular stages to take into account when carrying out participatory mapping (Figure 3).

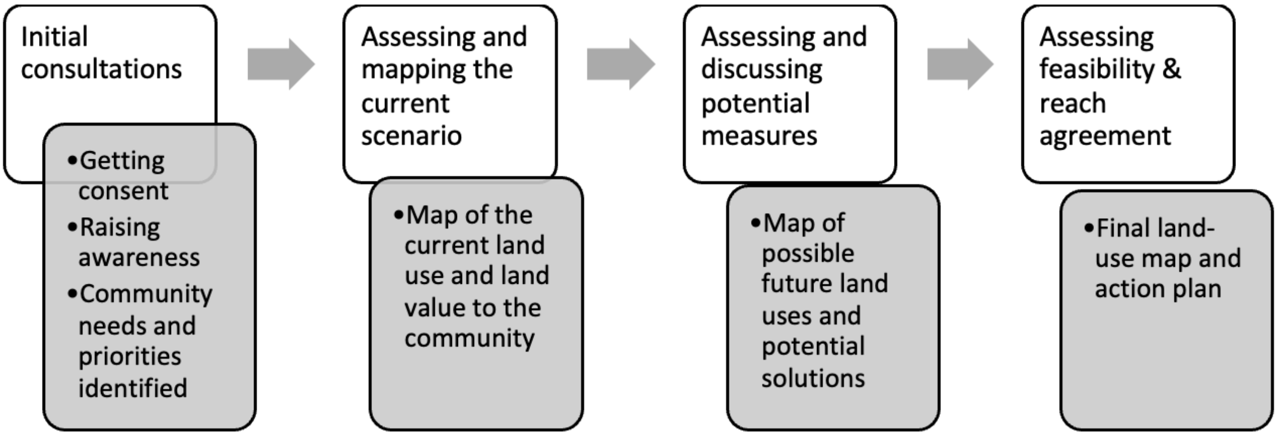

*Figure 7: White boxes show the sequence of stages when conducting a participatory mapping approach, while grey boxes indicate each stage's main output/outcome. This sequence of stages does not exclude other essential steps that need to be considered in any intervention for spatial planning (e.g., the steps mentioned in section 2). Figure created based on NAFRI brief (Ingalls et al. 2019)*

The mapping itself is a continuous exercise carried out throughout the process that supports assessment, discussions, deliberations and decisions. The maps are generated by the community (Swanson and Ardoin 2021), and represent the IP and LCs' spatial knowledge (including their perceptions of their territory and its use) (Nabwire and Nyabenge 2006; Mazeka *et al*. 2019). The maps may also be complemented with external data sources. Depending on the technical support given to local communities, the exercise can range from drawing temporary maps on the ground or sketching maps on paper, to more sophisticated three-dimensional (3D) relief models or advanced analysis based on aerial or satellite images (UNFCCC n.d.).

### 3.5.3 Stakeholder involvement

The key actors are the IP and LCs living in the study area and whose well-being depends directly on the area's natural resources. Therefore, the local people must be closely engaged from the inception of the mapping exercise (e.g., problem and analysis definition) and throughout the whole spatial analysis process (for example, as described in section 3.1). Local communities need to be actively involved in data collection, map development (or adjusting existing local maps), discussions and deliberations, the initial assignment of land uses (e.g., zoning), the solution-designing process (e.g., enhanced land-use planning), and ultimately agreeing on a roadmap to implement the solutions.

### 3.5.4 Technical and social requirements

Participatory mapping approaches need to meet some minimum requirements in addressing both technical and social aspects of the process.

#### Technical aspects:

- **Provide basic technical backstopping in GIS.** Key actors of the participatory mapping do not need previous technical expertise, GIS knowledge and chosen software knowledge. If additional technical knowledge is needed to perform the spatial analysis, an external technical team can provide support.
- **Apply tailored and user-friendly mechanisms.** Tools, methods and training are tailored for each community and context, and it should be simple to learn, understand and analyze.
- **Include traditional and local data disaggregated by sex.** Data collected for spatial analysis, design measures, and planning should feature local data and traditional knowledge.

### Social aspects:

- **Address and respect environmental and social safeguards and other principles related to IP and LCs.** To succeed in local community involvement, it is essential for the coordinator or promoter of the participatory mapping to respect and apply the environmental and social safeguards[2] and other principles for engaging and working with IP and LCs. These include designing interventions that have the communities' free, prior and informed consent, respect and enhance the rights of Indigenous Peoples to their lands, territories and resources, respect and recognize traditional knowledge and livelihood systems, and have a grievance redress mechanism in place, among others (Green Climate Fund 2018). More information about safeguards and principles relevant to IP and LCs in spatial analysis and planning can be found in the SPACES consultation paper titled "Fair, equitable and participatory spatial planning for climate and nature goals" (Brum *et al.* 2019; Systemiq 2023).
- **Agree level of access and sharing.** Regarding data collection, the coordinator or promoter of the participatory mapping must apply safeguards and other principles so IP and LCs can consent to the access to and/or distribution of their traditional and local knowledge.
- **Use of local language.** It is crucial that the process is conducted in the local language of the community. The facilitators that guide the process, as well as the generated tools (maps) need to use the local language.
- **Engage other relevant actors.** The process should include active participation of stakeholders that are key to supporting the analysis and decision-making. These can include governmental officials, researchers and representatives of non-governmental organizations and private sector.

### 3.5.5 Advantages

- **Relevant community data.** Using traditional and local knowledge as primary sources provides insights into customary land uses, land tenure, and land use history, which is not possible to obtain with satellite images alone. In addition, the use of socio-economic data disaggregated by sex can help to improve the understanding of the different risks, benefits, and needs of men and women in relation to land-use planning. A combination of GIS tools/methods with participatory or community-based mapping can contribute to a more comprehensive understanding and a better decision-making process in sustainable natural resources management interventions (Nabwire and Nyabenge 2006).
- **Applicability.** Simple to learn and perform the analysis, and results are usually easy to understand by the community.
- **Inclusive capacity building.** The development of participatory mapping is an excellent opportunity to build capacity within local communities, particularly minorities and other frequently marginalized groups (e.g., elders, youths, women).

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[2] Safeguards are principles or measures aiming to ensure that activities avoid environmental and social risks while promoting benefits (UN-REDD Programme n.d.)

- **Community ownership.** The participatory nature of these approaches improves dialogue between communities and government leading to positive governance, legitimization and application of local knowledge, empowerment, and ultimately ownership (McCall and Minang 2005).
- **Progress in land tenure conflicts.** The approach involves collecting information and creating discussion spaces within the community in a way that enables it to make progress on or even resolve land tenure issues and conflicts.
- **Active role of communities.** Involving IP and LCs from the beginning makes them active contributors to an innovative solution to protect, manage and restore nature. This can challenge the narrative of communities being helpless victims of repeated attacks on their land and environment.

### 3.5.6 Challenges or limitations

- **Mapping methodology and outputs can be too context specific to be replicated or scaled up.** Unlike the computer-dependent approaches with a workflow that can be easily applied to another region or used at a global scale, the spatial analysis methodology used during a community mapping exercise might be too specific to its local context and lands features. Therefore, the mapping methodology and outputs created for one community might not serve others, making it difficult to replicate or scale up.

## **Case study 4:** Participatory Land-Use Planning (PLUP) in Viengkham (Lao PDR) for forest conservation and sustainable development (Bourgoin and Castella 2011; Bourgoin *et al.* 2012; Castella *et al.* 2012)

**Location:** Lao PDR, Luang Prabang Province, Viengkham District.

**Ecosystem type:** Upland agriculture lands and forest

**Objectives of the PLUP in Viengkham:**

- To prevent disputes between villages over land or forest areas by establishing well-defined boundaries for each village's territory.
- Decide on conservation, protection and production forest areas with the villagers and set up village regulations.

**Methodology:** Key steps:

- **Meeting and formation of Village Land Management Committee**, responsible for leading the process. The committee was formed taking in consideration gender parity, ethnicity, age, social and economic status.
- **Data collection:** the team used both household surveys, census and focus group discussions to collect socio-economic data related to geographical situation, accessibility, ethnic composition, population growth, education and health, village history, problem census, economic activities, and current land use. Men and women focus groups (separately) were mainly carried out to identify problems and opportunities associated with agricultural and forest land that could be later addressed in the land management plans.
- **Building a 3D model map of the village landscape:** the technical team built a 3D map from cardboard and plaster materials based on a topographic map of the area.
- **Village boundaries delineation and GPS point demarcation:** Representatives of the neighboring villages were invited to discuss the boundaries with the village committee, using the 3D model as a visualization tool. Once agreed, GPS points were taken, and the village leaders later signed official agreements.
- **Game to simulate land zoning:** A role-playing game for local land zoning and development planning was conducted using "PLUP Fiction" methodology (Bourgoin and Castella 2011) to train committee members on making informed decisions considering different stakeholders' needs.

- **Participatory Land Zoning:** By applying learnings from the simulation game, the village Land Management Committee negotiated their land-use zoning using the 3D model map. First, members marked and defined current land use, making adjustments that later were digitalized in a 2D map by the technical team. Then the 2D map was used to compare existing land use with the needs and plans conveyed by the community. After various interactions and negotiations, a new land-use plan was designed (QGIS software and Excel based tools).
- **Village Land Management rules and PLUP agreement:** Land-use management and rules that regulate specific land-use zones were determined and agreed upon, including a set of sanctions to penalize non-compliance. Keeping livestock and crops was only permitted in designated areas, while the community would oversee delimited sites for forest protection and conservation, limiting extractive actions. A **Village Action Plan** was developed, including feasible agricultural land management and forest protection/conservation. This Action Plan, along with a village boundary agreement, the description of the land-use zones, the final land-use plan map and the land management rules, were signed by the District Governor, District offices of Agriculture and Forestry (DAFO) and the Land Management (DLMA) heads, and village and village cluster heads.

**Key results and lessons from the experience:**

- Clearly defined forest areas around the village for protection/conservation and sustainable management.
- Landscape connectivity was improved by creating corridors between conservation forests within Viengkham.
- Inter-village boundaries were clearly delimited, which strengthened tenure security, and reduced conflicts.
- The process helped resolve various land conflicts between neighbouring villages after different parties were able to debate their disagreements and negotiate with mediation support provided by the district team.
- Simulations games helped train community members in land zoning and fostered an understanding that decisions on location and area of different land-use types have socio-economic implications.

**Key stakeholders involved:** Villagers, the head of the village cluster, village head, district governor, representatives and technicians from District offices of Agriculture and Forestry (DAFO) and of Land Management (DLMA).

## 3.6 Mixed approaches

### 3.6.1 What are mixed approaches?

A spatial analysis approach can be considered mixed when it combines the computer modelling component of the computer-dependent approaches (suitability-first or Systematic Conservation Planning) with the active role of local communities present in the participatory mapping. Here, local communities are key actors involved during the stages of setting objectives, identifying input data and analyzing results, while the analysis itself is performed by a technical team (see Figure 1 for list of aspects usually considered in all spatial analysis approaches). This is different from standard computer-dependent approaches where stakeholder participation is not mandatory. At the same time, mixed approach methodologies are different from participatory mapping, where communities themselves perform spatial analysis, rather than a technical team.

Planning a mixed spatial analysis includes building or enhancing the communities' understanding about the computer-dependent approach to identify the best way of merging it with the strong participation of these stakeholders to answer the question. Therefore, to adapt this methodology to a specific project, it is crucial to bring together experts on both approaches, as well as decision-makers and other interested parties and impacted groups. Communication between these groups can be challenging as the level of familiarity with the methodologies, terminologies, and context could vary considerably. Consequently, the mixed spatial analysis may require longer and more careful planning than other approaches.

Once agreed, the mixed analysis plan should be transparently communicated to all parties (e.g., coordination, technical team, stakeholders, and decision-makers) so that they understand the next steps, the advantages and limitations of the chosen techniques, and the expectations from each party.

Capacity building activities for actors involved in the analysis (coordination and technical teams, stakeholders and decision-makers) can increase its effectiveness. The coordination team might need to build skills of various participants to ensure clear communication. Training the technical team is important as members with knowledge of computer-dependent approaches might lack expertise in planning and delivering participatory workshops (and vice-versa). Making sure the stakeholders understand the analysis and its limitation can improve the quality and usefulness of their inputs. Finally, building capacity among the decision-makers increases the chances of results being implemented.

### 3.6.2 Technical requirements

The required technical capacity, tools and data will vary depending on the computer-dependent approach selected (see sections 3.2.3 and 3.3.3 “technical requirements” for detail). However, there are some general considerations:

- This type of analysis can involve more actors than other methodologies as experts in both types of approaches are needed, in addition to facilitators to coordinate the deep involvement of communities.

- This approach can require more time than others due to the need to coordinate experts from different fields, clarify differences in terminologies and ensure all groups of actors understand and follow their roles.
- Coordination team needs strong knowledge of environmental and social safeguards, as highlighted in section 3.1.2.
- Detailed documentation of conflicts and their solutions ensures that the progress of the analysis is recorded and can be revisited, if needed.
- Extra time and budget might be required for additional discussion and extra steps in case results from computer-dependent analysis and participatory mapping don't fully agree. For example, a degraded area with roads can be identified as a priority for restoration actions due to its high potential to act as a nature-based solution for climate change mitigation (high value for carbon and biodiversity). However, this area may also have been identified by the local communities as important for their connection with their current water sources. Additional discussion and analysis could find a good compromise between these different requests.

### 3.6.3 Stakeholder involvement

Active participation of local communities (aiming for equal gender balance) throughout the development of the spatial analysis is mandatory in this approach.

### 3.6.4 Advantages

- Combines the advantages of the selected computer-dependent approach (see sections 3.2 and 3.3) with the benefits contributed by the community-led approach (see section 3.4).
- Builds local capacity for land-use analysis and planning, empowers communities and marginalized groups or minorities by including them into the decision-making process.
- Creates a record of traditional and local knowledge held by different stakeholders, especially relevant to topics for which spatial data are of poor quality or inaccurate.

### 3.6.5 Challenges

- Planning this analysis can take more time than others in order to ensure that computer-dependent analysis and participatory mapping are complementary and not overlapping.
- Stakeholders may need time and support to be familiar with the use of maps and spatial data.
- Managing time and budget can be challenging if additional steps such as workshops or refinement of results are needed to resolve conflicts between results from computer-dependent analysis and participatory mapping (García-Rangel *et al.* 2017).

## **Case study 5:** Provincial REDD+ Action Plans, UN-REDD Programme Viet Nam (Mant *et al.* 2013; García-Rangel *et al.* 2017)

**Location:** Viet Nam, national and sub-national scale

**Area analyzed (km2) and ecosystem type:** During the UN-REDD Phase I Programme, the national spatial analysis (~313,429 km$^2$ (FAO n.d.)) was focused on forests (Mant *et al.* 2013). Following that, during the UN-REDD Phase II Programme, the results of phase I were complemented by participatory mapping and workshops in five pilot provinces: Ca Mau, Binh Thuan, Ha Tinh, Bac Kan and Lao Cai (García-Rangel *et al.* 2017).

**Objective of the spatial analysis:** Identify areas where REDD+ actions aimed at reducing emissions from deforestation and through sustainable forest management would also have the potential to deliver multiple benefits.

**Methodology:** Suitability-first spatial analysis was adopted to create two national-scale synthesis maps: one showing the potential areas for reducing deforestation (highest levels of forest loss, highest carbon densities and number of threatened terrestrial vertebrate species) (Figure 8) and the other showing potential areas for sustainable management of forests (highest levels of production forest, highest carbon densities and number of threatened species) (Figure 9). Then, in five pilot provinces, these synthesis maps were complemented with results from participatory mapping and participatory workshops. For each province, participatory workshops created maps of priorities for REDD+ actions. These two sets of maps combined with additional computer-dependent analysis, stakeholders' knowledge and field visits created the final Provincial REDD+ Action Plans.

**Main findings:** The first synthesis map highlighted seven provinces as potential areas for reducing deforestation, while the second synthesis map identified six provinces as potential areas for sustainable management of forests. Four provinces were present in both synthesis maps (Dak Nong, Gia Lia, Lam Dong, and Quang Binh) showing the potential of these regions for both objectives.

Building on these synthesis maps, the UN-REDD Viet Nam Phase II Programme made use of participatory mapping approaches to make the maps relevant for local scale planning and implementation. Several iterations were needed to combine findings from the computer-dependent analysis with findings from the participatory workshops. Analysis of feasibility, risks and benefits were performed at local level and reflected the different circumstances of each province. The process of creating Provincial REDD+ Action Plans for the five pilot provinces provided many lessons, guidance and templates that were employed in the development of PRAPs for other provinces.

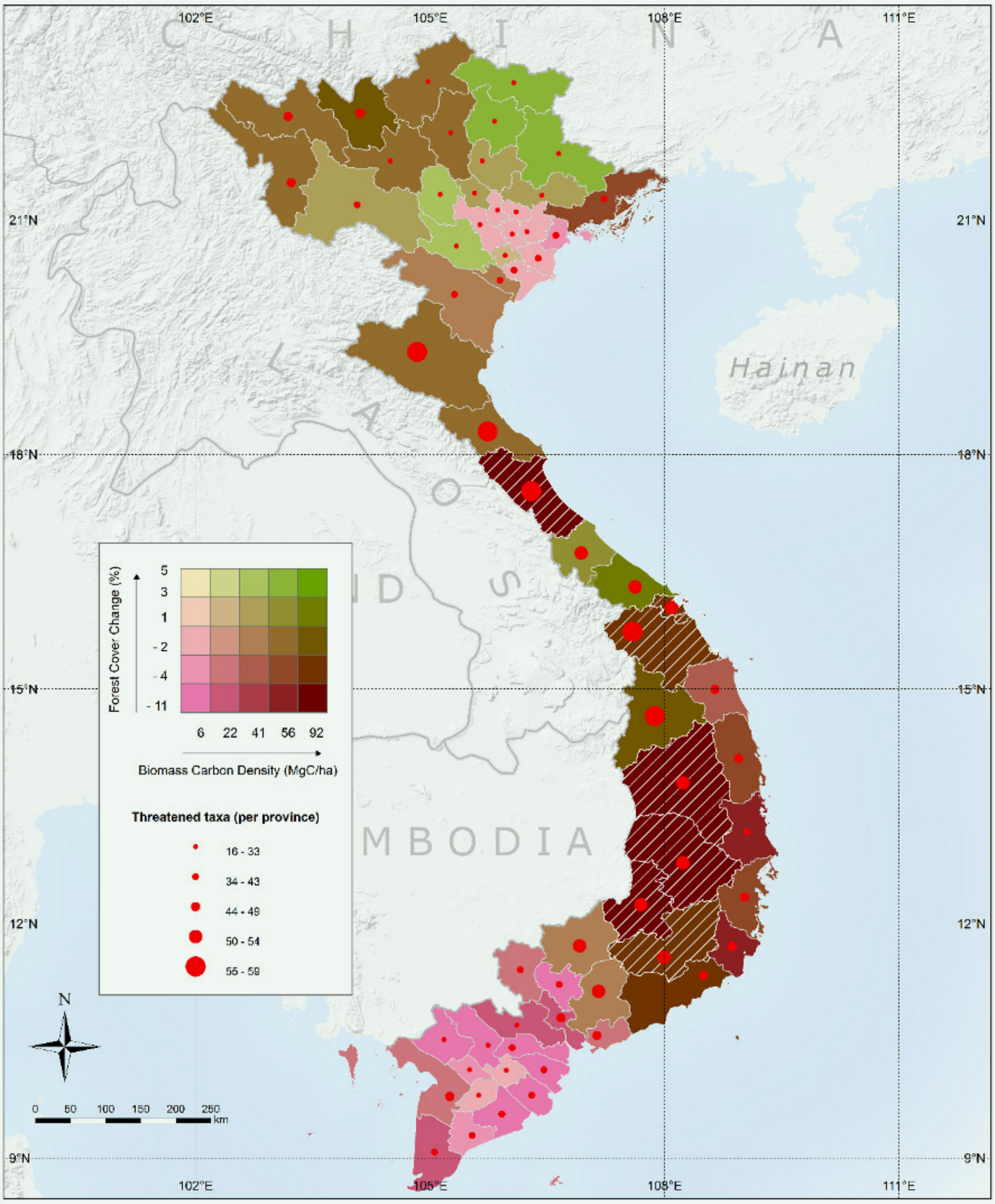

*Figure 8. Forest biomass carbon, forest cover change, and threatened species richness (Mant et al. 2013). This map shows carbon, loss of carbon, biodiversity and conservation value. Provinces which have high forest biomass carbon density, high historical rates of deforestation and high threatened species richness are highlighted.*

*Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.*

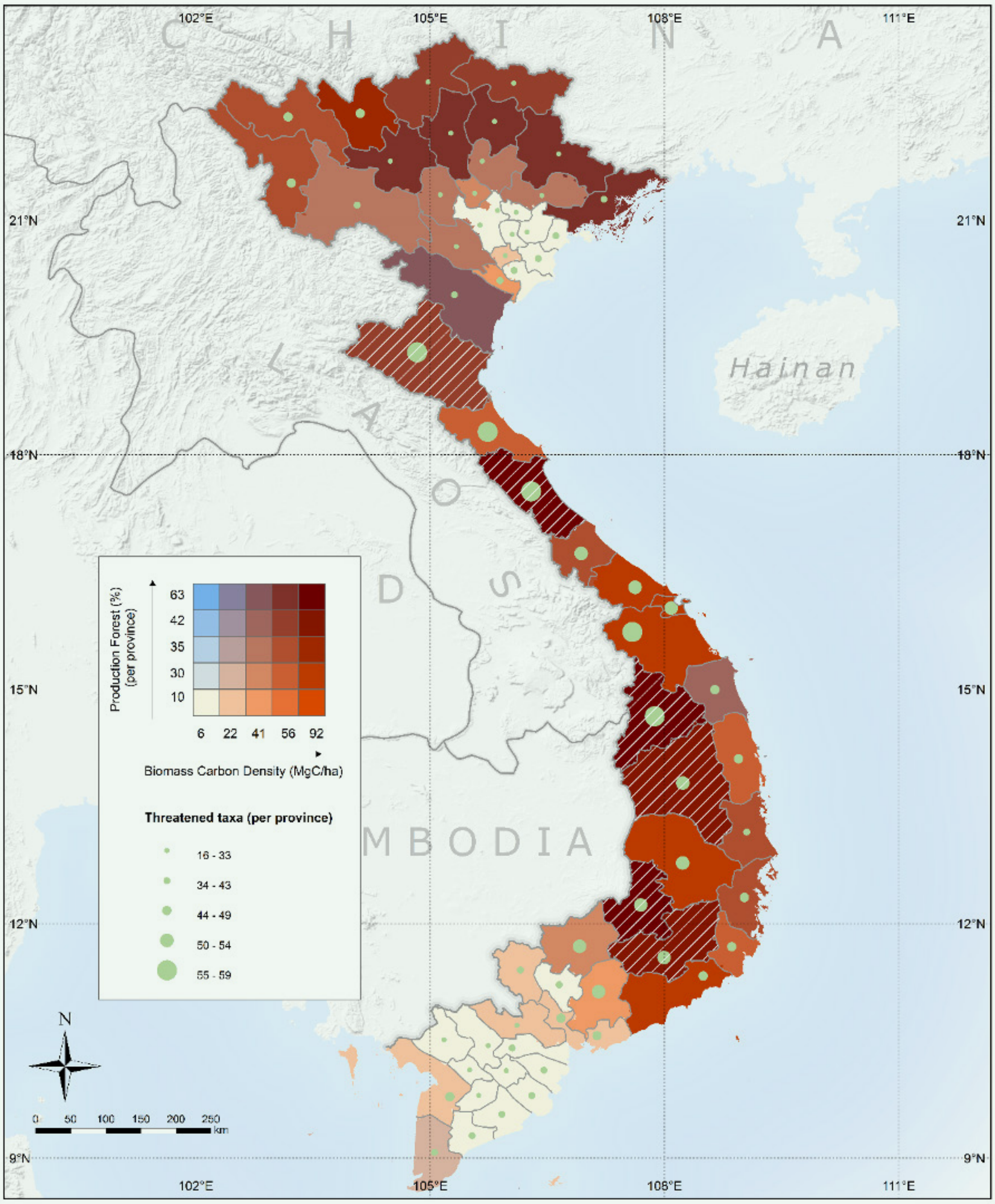

*Figure 9. Forest biomass carbon density, percentage production forest, and threatened species richness (Mant et al. 2013). This map visualizes forest carbon stock distribution, biodiversity and conservation importance. Provinces with high biomass carbon, high threatened species richness and large areas of production forest are highlighted.*

*Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.*

**Advantages:** Adopting the mixed approach to develop the five pilot Provincial REDD+ Action Plans allowed to build capacity for REDD+ planning and implementation within stakeholders. The deep involvement of stakeholders led to greater understanding of the different methods employed and of how results were achieved. This was advantageous to increase transparency and promote ownership of the plans among the ones responsible for implementing them.

**Challenges:** Data on some topics, such as biodiversity, were absent or difficult to access. Other challenges related to data were “the use of different definitions and categories in forest data over different periods of time; the complex and detailed nature of data on forest resources; the discovery of differences between mapped information and the reality on ground, or the perceptions of stakeholders; and difficulties in accessing some data held by departments outside of the forest sector” (García-Rangel *et al.* 2017).

**Key stakeholders involved:** REDD+ national partners, provincial technical staff, local stakeholders

## **Case study 6:** Community Resource Mapping in Sustainable Natural Resource Management – Southwestern Uganda (Nabwire and Nyabenge 2006)

**Location:** Uganda, Bubaare sub-country, Kabale district.

**Ecosystem type:** Kyantobi watershed

**Objectives of the community resource mapping:**

- Identify key features of the landscape
- Analyze the status of critical areas of natural resources degradation
- Assess impacts of land management practices, conservation, and conflict resolution
- Develop solutions and implement collective intervention strategies
- Monitor changes in the natural resources, the impact of better management interventions and inform decision making

**Methodology:** A computer-dependent analysis was performed to create the spatial information used as a starting point for the community resource mapping. The community was constantly supported by a technical GIS node (based in the district) about various spatial analyses, including biophysical, socio-economic and cultural evaluation of production systems, among others. The participatory approach was held during the whole process.

- **Preparation of inputs:** watershed boundaries were delineated based on geo-referenced satellite images, aerial photographs and topographic map sheets. It included secondary data like ecological and socio-economic parameters of the watershed area taken from literature and key informants from the community. This work was supported by the ICRAF GIS node in Kabale and using the ArcView 3 GIS package.
- **Community resource mapping:** after a series of workshops raising awareness on community resource mapping and its benefits, the community drew sketches of their villages' landscapes, highlighting the occurrence, distribution, access and use of vital resources within the community. This included features like roads, soil types, slopes, soil erosion, water run-off areas, settlements, etc. Topography map sheets were used to classify height, slope degrees and land-use changes that had occurred over time. The sketch maps were later transferred into topographic maps to create scaled outputs.

- **Transect surveys:** The community mapping team, which included farmers that know the area well and local council leaders (formed by men, women, young people and elderly), walked along defined transects to evaluate and analyze current status of natural resources, identifying key issues to discuss later.
- **Analysis of the status of the natural resources base:** with the maps developed and surveys conducted, it was possible to see what the community perceives as problems, identify the community's priorities and propose solutions accordingly. Those inputs enabled the community to have informed discussions on land-use practices, risk management, and incorporate local knowledge to design the solutions.
- **Development of Action Plans:** Based on the analysis, community farmers, with the support of the FORRI-ICRAF team, developed an action plan to tackle prevailing problems and resource base conditions. The plan adopted an enhanced agroforestry system in the community and included indigenous knowledge.

**Key results and lessons from the experience:**

- Various socio-environmental problems and risks were identified (i.e., deforested and degraded areas, areas prone to soil erosion, intensive arable farming that has depleted soil nutrients and contributed to severe run-off, low biomass, scarce fuel wood sources, floods and landslides risk).
- Communities developed their own indicators to characterize the quality of the community natural resources, which helped them to identify appropriate agroforestry technologies and strategies. Consequently, communities identified sites suitable for sustainable agroforestry and soil and water conservation activities.
- Integration of indigenous and local knowledge helped define more appropriate and sustainable agroforestry techniques (e.g., selection of indigenous trees) and identify issues related to accessing and distributing resources and the changes that had occurred over time. Data collection disaggregated by sex could have greatly benefited this process, especially in identifying different needs better and helping ensure that the "community priorities" identified were equally representative of men and women.
- The community resource maps have been valuable for requesting funding for agroforestry work and other developmental activities to the local development fund and other development organizations.
- The data recorded allowed the development of the watershed area's prevailing biophysical and socio-economic parameters inventory, which could be helpful as baseline data for future evaluation of intervention impacts.

**Key stakeholders involved:** Local people from Kabale communities, local council leaders, representatives and technicians from World Agroforestry Centre (ICRAF) and the Forestry Resource Research Institute (FORRI), and the NGO Africare.

# 4

# Final remarks

Spatial analysis approaches assess biophysical, geographical, socio-economic, cultural and other factors to identify locations with the potential to provide different benefits. This may involve analyzing spatial or spatio-temporal relationships to highlight potential environmental, economic, and social benefits, risks (García-Rangel *et al*. 2017) and show where trade-offs are greatest. In this way, spatial analysis can provide valuable information to support decision-making on the use of nature-based solutions to jointly tackle nature, climate and sustainable development goals.

This review has described four broad approaches to performing spatial analysis: suitability-first, spatial conservation prioritization, participatory mapping and mixed. They range from highly analytical approaches (suitability-first and systematic conservation planning) to others with the active participation of local stakeholders at their core (participatory mapping and mixed). Using any of these four approaches can help to answer many questions on nature-based solutions potential, but socio-cultural contexts, technical capacity, data availability, time availability and budget can make one approach more appropriate than another.

While any of the approaches can be embedded within a wider spatial planning process, it is crucial to stress that every spatial planning process can benefit from the active participation of a diverse and inclusive group of stakeholders. The aim should be to create a partnership between different groups of actors impacted by the problem or solution, whether that involves a participatory or mixed mapping approaches. Active participation in decision-making goes beyond consultation into consensus-building, and is much more likely to yield results with buy-in and longevity.

# 5

# References

Adams, V.M., Visconti, P., Graham, V. and Possingham, H.P. (2021). Indicators keep progress honest: A call to track both the quantity and quality of protected areas. *One Earth*. 4(7), 901–906. doi: 10.1016/J.ONEEAR.2021.06.014.

Álvarez-Romero, J.G., Adams, V.M., Pressey, R.L., Douglas, M., Dale, A.P., Augé, A.A., *et al.* (2015). *Integrated Cross-Realm Planning: A Decision-Makers' Perspective*. 1 November. 191. Elsevier. doi: 10.1016/j.biocon.2015.07.003.

Ardron, J.A., Possingham, H.P. and Klein, C.J. (2010). Marxan good practices handbook, Version 2. *Pacific Marine Analysis and Research Association, Victoria, BC, Canada*. 165,

Ball, I.R., Possingham, H.P. and Watts, M. (2009). Marxan and relatives: software for spatial conservation prioritisation. *Spatial Conservation Prioritisation: Quantitative Methods and Computational Tools*. 185, 195.

Belle, E.M.S., Burgess, N.D., Misrachi, M., Arnell, A., Masumbuko, B., Somda, J., *et al.* (2016). Climate change impacts on biodiversity and protected areas in West Africa, Summary of the main outputs of the PARCC project, Protected Areas Resilient to Climate Change in West Africa. *UNEP-WCMC, Cambridge, UK*.

Bourgoin, J. and Castella, J.-C. (2011). 'PLUP FICTION': Landscape Simulation for Participatory Land Use Planning in Northern Lao PDR. *Mountain Research and Development*. 31(2), 78–88. doi: 10.1659/MRD-JOURNAL-D-10-00129.1.

Bourgoin, J., Castella, J.C., Pullar, D., Lestrelin, G. and Bouahom, B. (2012). Toward a land zoning negotiation support platform: 'Tips and tricks' for participatory land use planning in Laos. *Landscape and Urban Planning*. 104(2), 270–278. doi: 10.1016/J.LANDURBPLAN.2011.11.008.

Brum, F.T., Graham, C.H., Costa, G.C., Hedges, S.B., Penone, C., Radeloff, V.C., *et al.* (2017). Global priorities for conservation across multiple dimensions of mammalian diversity. *Proceedings of the National Academy of Sciences*. 114(29), 7641–7646. doi: 10.1073/pnas.1706461114.

Brum, F.T., Pressey, R.L., Bini, L.M. and Loyola, R. (2019). Forecasting conservation impact to pinpoint spatial priorities in the Brazilian Cerrado. *Biological Conservation*. 240, 108283. doi: 10.1016/J.BIOCON.2019.108283.

Castella, J.-C., Kieffer, C. and Berton, S. (2012). *Participatory Land Use Planning (PLUP)*.

CBD (2022). *Kunming-Montreal Global Biodiversity Framework*. Montreal. https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf.

Chambers, R. (2010). A Revolution Whose Time Has Come? The Win-Win of Quantitative Participatory Approaches and Methods. *IDS Bulletin*. 41(6), 45–55. doi: 10.1111/J.1759-5436.2010.00181.X.

Chaplin-Kramer, R., Neugarten, R.A., Sharp, R.P., Collins, P.M., Polasky, S., Hole, D., *et al.* (2022). Mapping the planet's critical natural assets. *Nature Ecology & Evolution 2022 7:1*. 7(1), 51–61. doi: 10.1038/s41559-022-01934-5.

Chausson, A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C.A.J., Kapos, V., *et al.* (2020). Mapping the effectiveness of nature-based solutions for climate change adaptation. *Global Change Biology*. 26(11), 6134–6155. doi: 10.1111/GCB.15310.

Cinner, J. (2018). How behavioral science can help conservation. *Science*. 362(6417), 889–890. doi: 10.1126/SCIENCE.AAU6028.

Cone, J., Rowe, S., Borberg, J. and Goodwin, B. (2012). Community planning for climate change: Visible thinking tools facilitate shared understanding. *Journal of Community Engagement and Scholarship*. 5(2), 7–19.

Critchley, M., Sassen, M. and Umunay, P. (2021). *Mapping Opportunities for Cocoa Agroforestry in Côte d'Ivoire: Assessing Its Potential to Contribute to National Forest Cover Restoration Targets and Ecosystem Services Co-Benefits*. UNEP World Conservation Monitoring Centre. Cambridge UK. https://resources.unep-wcmc.org/products/WCMC_RT081.

Cuesta, F., Peralvo, M., Merino-Viteri, A., Bustamante, M., Baquero, F., Freile, J.F., *et al.* (2017). Priority areas for biodiversity conservation in mainland Ecuador. *Neotropical Biodiversity*. 3(1), 93–106. doi: 10.1080/23766808.2017.1295705.

Dirección de Cambio Climático; Ministerio de Ambiente y Energía (2022). *Plan Nacional de Adaptación Al Cambio Climático de Costa Rica, 2022 - 2026*. San José, Costa Rica. https://cambioclimatico.go.cr/wp-content/uploads/2022/04/NAP_Documento-2022-2026_VC.pdf.

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., *et al.* (2015). Nature-based solutions: New influence for environmental management and research in Europe. *GAIA - Ecological Perspectives for Science and Society*. 24(4), 243–248. doi: 10.14512/GAIA.24.4.9.

ESRI (2018). Spatial Analysis Definition | GIS Dictionary. https://support.esri.com/en-us/gis-dictionary/spatial-analysis. Accessed December 2022.

European Comission (2015). *Nature-Based Solutions & Re-Naturing Cities. Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'*.

Fajardo, J., Lessmann, J., Bonaccorso, E., Devenish, C. and Muñoz, J. (2014). Combined Use of Systematic Conservation Planning, Species Distribution Modelling, and Connectivity Analysis Reveals Severe Conservation Gaps in a Megadiverse Country (Peru). *PLOS ONE*. 9(12), e114367. doi: 10.1371/JOURNAL.PONE.0114367.

FAO (n.d.). Country Profiles. https://www.fao.org/countryprofiles/index/en/?iso3=vnm. Accessed December 2022.

Game, E.T., Kareiva, P. and Possingham, H.P. (2013). Six Common Mistakes in Conservation Priority Setting. *Conservation Biology*. 27(3), 480–485. doi: 10.1111/COBI.12051.

García-Rangel, S., Hicks, C., Ravilious, C., Williamson, A. and Nguyen, T.P. (2017). *Integrated Land-Use Planning for REDD+: Lessons from Combining Spatial Analysis and Participatory Approaches at the Sub-National Level in Viet Nam*. UN-REDD Viet Nam Phase II Programme, Hanoi.

Graham, V., Baumgartner, J.B., Beaumont, L.J., Esperón-Rodríguez, M. and Grech, A. (2019). Prioritizing the protection of climate refugia: designing a climate-ready protected area network. https://doi.org/10.1080/09640568.2019.1573722. 62(14), 2588–2606. doi: 10.1080/09640568.2019.1573722.

Green Climate Fund (2018). *Indigenous People Policy*. https://www.greenclimate.fund/sites/default/files/document/ip-policy.pdf.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T. and Ohlson, D. (2012). *Structured Decision Making: A Practical Guide to Environmental Management Choices*. John Wiley & Sons.

Groves, C.R. and Game, E.T. (2016). *Conservation Planning: Informed Decisions for a Healthier Planet. Roberts and Company Publishers*. Greenwood Village, Colorado.

Hanson, J.O., Schuster, R., Morrell, N., Strimas-Mackey, M. Edwards, B.P.M., Watts, M.E., Arcese, P., *et al.* (2022). *Prioritizr: Systematic Conservation Prioritization in R. R Package Version 7.1.1*. https://cran.r-project.org/package=prioritizr.

Ingalls, M., Hett, C., Thannasack, P., Phyoyyavong, K., Rasso, B., Chanthasumlet, Y., *et al.* (2019). New Directions for Participatory Land Use Planning: Can Bottom-Up Approaches Achieve a Win-Win for Sustainable Development and Forest Conservation?

Jalkanen, J., Toivonen, T. and Moilanen, A. (2020). Identification of ecological networks for land-use planning with spatial conservation prioritization. *Landscape Ecology*. 35(2), 353–371. doi: 10.1007/s10980-019-00950-4.

Jones, K.R., Klein, C.J., Grantham, H.S., Possingham, H.P., Halpern, B.S., Burgess, N.D., *et al.* (2020). Area Requirements to Safeguard Earth's Marine Species. *One Earth*. 2(2), 188–196. doi: 10.1016/J.ONEEAR.2020.01.010.

Jung, M., Arnell, A., Lamo, X. de, García-Rangel, S., Lewis, M., Mark, J., *et al.* (2021). Areas of global importance for conserving terrestrial biodiversity, carbon and water. *Nature Ecology & Evolution 2021 5:11*. 5(11), 1499–1509. doi: 10.1038/s41559-021-01528-7.

Kahneman, D. (2011). *Thinking, Fast and Slow*. macmillan.

Kapos, V., Wicander, S., Salvaterra, T., Dawkins, K. and Hicks, C. (2019). The role of the natural environment in adaptation. *Background Paper for the Global Commission on Adaptation*.

Kirkman, S.P., Holness, S., Harris, L.R., Sink, K.J., Lombard, A.T., Kainge, P., *et al.* (2019). Using Systematic Conservation Planning to support Marine Spatial Planning and achieve marine protection targets in the transboundary Benguela Ecosystem. *Ocean & Coastal Management*. 168, 117–129. doi: 10.1016/J.OCECOAMAN.2018.10.038.

Kukkala, A.S. and Moilanen, A. (2013). Core concepts of spatial prioritisation in systematic conservation planning. *Biological Reviews*. 88(2), 443–464.

Lessmann, J., Muñoz, J. and Bonaccorso, E. (2014). Maximizing species conservation in continental Ecuador: a case of systematic conservation planning for biodiverse regions. *Ecology and Evolution*. 4(12), 2410–2422. doi: 10.1002/ECE3.1102.

Linke, S., Hermoso, V. and Januchowski-Hartley, S. (2019). Toward process-based conservation prioritizations for freshwater ecosystems. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 29(7), 1149–1160. doi: 10.1002/AQC.3162.

Lira-Noriega, A., Aguilar, V., Alarcón, J., Kolb, M., Urquiza-Haas, T., González-Ramírez, L., *et al.* (2015). Conservation planning for freshwater ecosystems in Mexico. *Biological Conservation*. 191, 357–366. doi: 10.1016/J.BIOCON.2015.07.004.

Mant, R., Swan, S., Anh, H.V., Phuong, V.T., Thanh, L.V., Son, V.T., *et al.* (2013). *Mapping the Potential for REDD+ to Deliver Biodiversity Conservation in Viet Nam: A Preliminary Analysis*. Prepared by UNEP-WCMC, Cambridge, UK; and SNV, Ho Chi Minh City, Viet Nam.

Margules, C.R. and Pressey, R.L. (2000). Systematic conservation planning. *Nature 2000 405:6783*. 405(6783), 243–253. doi: 10.1038/35012251.

Mazeka, B., Sutherland, C., Buthelezi, S. and Khumalo, D. (2019). Community-Based Mapping Methodology for Climate Change Adaptation: A Case Study of Quarry Road West Informal Settlement, Durban, South Africa. *The Geography of Climate Change Adaptation in Urban Africa*. 57–88. doi: 10.1007/978-3-030-04873-0_3.

McCall, M.K. and Minang, P.A. (2005). Assessing participatory GIS for community-based natural resource management: claiming community forests in Cameroon. *Geographical Journal*. 171(4), 340–356. doi: 10.1111/J.1475-4959.2005.00173.X.

Milz, D. (2022). The Hidden Benefits of Facilitated Dialogue. *Journal of Planning Education and Research*. 42(1), 19–35. doi: 10.1177/0739456X18798903.

Moilanen, A., Anderson, B.J., Eigenbrod, F., Heinemeyer, A., Roy, D.B., Gillings, S., *et al.* (2011). Balancing alternative land uses in conservation prioritization. *Ecological Applications*. 21(5), 1419–1426. doi: 10.1890/10-1865.1.

Monteiro, L.M., Brum, F.T., Pressey, R.L., Morellato, L.P.C., Soares-Filho, B., Lima-Ribeiro, M.S., *et al.* (2020). Evaluating the impact of future actions in minimizing vegetation loss from land conversion in the Brazilian Cerrado under climate change. *Biodiversity and Conservation*. 29(5), 1701–1722. doi: 10.1007/s10531-018-1627-6.

Nabwire, B.B. and Nyabenge, M. (2006). Community Resource Mapping in Sustainable Natural Resource Management: A Case Study of SW Uganda. *The Electronic Journal of Information Systems in Developing Countries*. 25(1), 1–8. doi: 10.1002/J.1681-4835.2006.TB00165.X.

NOAA (2009). *Stakeholder Engagement Strategies for Participatory Mapping*. https://coast.noaa.gov/data/digitalcoast/pdf/participatory-mapping.pdf.

Poorter, L., Bongers, F., Aide, T.M., Almeyda Zambrano, A.M., Balvanera, P., Becknell, J.M., *et al.* (2016). Biomass resilience of Neotropical secondary forests. *Nature 2016 530:7589*. 530(7589), 211–214. doi: 10.1038/nature16512.

Rainforest Foundation UK (2022). Participatory Mapping. Mapping For Rights. https://www.mappingforrights.org/participatory-mapping/. Accessed August 2022.

Rifkin, S.B. and Pridmore, P. (2001). *Partners in Planning: Information, Participation and Empowerment*. Macmillan London.

Rittenhouse, C. (2017). Conservation planning: informed decisions for a healthier planet. *Landscape Ecology 2017 32:11*. 32(11), 2219–2221. doi: 10.1007/S10980-017-0577-9.

Roy, H.E., Pocock, M.J.O., Preston, C.D., Roy, D.B., Savage, J., Tweddle, J.C., *et al.* (2012). Understanding citizen science and environmental monitoring. *Final Report on Behalf of UK-EOF. NERC Centre for Ecology & Hydrology and Natural History Museum*. 10–11.

Ruiz-Frau, A., Kaiser, M.J., Edwards-Jones, G., Klein, C.J., Segan, D. and Possingham, H.P. (2015). Balancing extractive and non-extractive uses in marine conservation plans. *Marine Policy*. 52, 11–18. doi: 10.1016/J.MARPOL.2014.10.017.

Sarkar, S., Pressey, R.L., Faith, D.P., Margules, C.R., Fuller, T., Stoms, D.M., *et al.* (2006). Biodiversity Conservation Planning Tools: Present Status and Challenges for the Future. https://doi.org/10.1146/annurev.energy.31.042606.085844. 31, 123–159. doi: 10.1146/ANNUREV.ENERGY.31.042606.085844.

Schroth, G., Läderach, P., Martinez-Valle, A.I., Bunn, C. and Jassogne, L. (2016). Vulnerability to climate change of cocoa in West Africa: Patterns, opportunities and limits to adaptation. *Science of The Total Environment*. 556, 231–241. doi: 10.1016/J.SCITOTENV.2016.03.024.

Sexton, J.O., Song, X.P., Feng, M., Noojipady, P., Anand, A., Huang, C., *et al.* (2013). Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. http://dx.doi.org/10.1080/17538947.2013.786146. 6(5), 427–448. doi: 10.1080/17538947.2013.786146.

SPACES (n.d. -a). FAQs. https://spacescoalition.org/en/about. Accessed December 2022.

SPACES (n.d. -b). Resources. https://www.spacescoalition.org/en/resources. Accessed December 2022.

Strack, M., Davidson, S.J., Hirano, T. and Dunn, C. (2022). The Potential of Peatlands as Nature-Based Climate Solutions. *Current Climate Change Reports*. 8(3), 71–82. doi: 10.1007/s40641-022-00183-9.

Strassburg, B.B.N., Beyer, H.L., Crouzeilles, R., Iribarrem, A., Barros, F., Siqueira, M.F. de, *et al.* (2018). Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. *Nature Ecology & Evolution 2018 3:1*. 3(1), 62–70. doi: 10.1038/s41559-018-0743-8.

Strassburg, B.B.N., Iribarrem, A., Beyer, H.L., Cordeiro, C.L., Crouzeilles, R., Jakovac, C.C., *et al.* (2020). Global priority areas for ecosystem restoration. *Nature 2020 586:7831*. 586(7831), 724–729. doi: 10.1038/s41586-020-2784-9.

Swanson, S.S. and Ardoin, N.M. (2021). Communities behind the lens: A review and critical analysis of Visual Participatory Methods in biodiversity conservation. *Biological Conservation*. 262, 109293. doi: 10.1016/J.BIOCON.2021.109293.

Systemiq (2022). *Putting Spatial Planning on the Map: How High-Ambition Countries Are Achieving Nature and Climate Goals. A Product of the SPACES Coalition*. https://spacescoalition.org/en/resources.

Systemiq (2023). *Fair, Equitable and Participatory Spatial Planning for Climate and Nature Goals. A Product of the SPACES Coalition*.

Tanneberger, F., Appulo, L., Ewert, S., Lakner, S., Ó Brolcháin, N., Peters, J., *et al.* (2021). The Power of Nature-Based Solutions: How Peatlands Can Help Us to Achieve Key EU Sustainability Objectives. *Advanced Sustainable Systems*. 5(1), 2000146. doi: 10.1002/ADSU.202000146.

Triviño, M., Kujala, H., Araújo, M.B. and Cabeza, M. (2018). Planning for the future: identifying conservation priority areas for Iberian birds under climate change. *Landscape Ecology 2018 33:4*. 33(4), 659–673. doi: 10.1007/S10980-018-0626-Z.

UN-REDD Programme (n.d.). Safeguards & multiple benefits. https://www.un-redd.org/work-areas/safeguards-multiple-benefits. Accessed December 2022.

UNDP (2021). Mapping Nature for People and Planet in Uganda. ELSA Webtool Manual. https://www.learningfornature.org/wp-content/uploads/2021/06/ELSA__Uganda_-_Webtool_2-comprimido.pdf. Accessed December 2022.

UNDP (2022). *Integrated Spatial Planning Workbook*. United Nations Development Programme: New York.

UNDP (n.d. -a). Mountain Ecosystem-based Adaptation in Uganda. UNDP Climate Change Adaptation. https://www.adaptation-undp.org/projects/mountain-eba-uganda. Accessed December 2022.

UNDP (n.d. -b). Mapeo de la naturaleza para las personas y el planeta en Costa Rica: Taller para ELSA enfocado en adaptación al cambio climático. Learning for Nature. https://www.learningfornature.org/es/mapping-nature-for-people-and-planet-in-costa-rica-elsa-workshop-focused-on-climate-change-adaptation/. Accessed December 2022.

UNDP Costa Rica (n.d.). Mapeo de la naturaleza para la adaptación al cambio climático en Costa Rica. https://pnudcr.exposure.co/mapeo-de-la-naturaleza-para-la-adaptacion-al-cambio-climatico-en-costa-rica?source=share-pnudcr. Accessed December 2022.

UNEP-WCMC and IUCN (2021). *Protected Planet: The World Database on Protected Areas (WDPA)*. Cambridge, UK: UNEP-WCMC and IUCN. www.protectedplanet.net.

UNEP and IUCN (2021). *Nature-Based Solutions for Climate Change Mitigation*. Nairobi and Gland. https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/37318/NBSCCM.pdf.

UNFCCC (2015). *Paris Agreement. FCCC/CP/2015/10/Add.1*. https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

UNFCCC (2022). Sharm el-Sheikh Implementation Plan. *Sharm El-Sheikh Climate Change Conference - November 2022*. https://unfccc.int/sites/default/files/resource/cop27_auv_2_cover decision.pdf.

UNFCCC (n.d.). Participatory Mapping. https://www4.unfccc.int/sites/NWPStaging/pages/item.aspx?ListItemId=23242. Accessed December 2022.

United Nations Environment Programme (2022a). *Resolution Adopted by the United Nations Environment Assembly on 2 March 2022. Nature-Based Solutions for Supporting Sustainable Development*. Nairobi: United Nations Environment Programme. UNEP/EA.5/Res.5.

United Nations Environment Programme (2022b). *Nature-Based Solutions: Opportunities and Challenges for Scaling Up*. https://wedocs.unep.org/20.500.11822/40783.

Vancutsem, C., Achard, F., Pekel, J.F., Vieilledent, G., Carboni, S., Simonetti, D., *et al.* (2021). Long-term (1990–2019) monitoring of forest cover changes in the humid tropics. *Science Advances*. 7(10), doi: 10.1126/sciadv.abe1603.

Villarreal-Rosas, J., Sonter, L.J., Runting, R.K., López-Cubillos, S., Dade, M.C., Possingham, H.P., *et al.* (2020). Advancing Systematic Conservation Planning for Ecosystem Services. *Trends in Ecology and Evolution*. 35(12), 1129–1139. doi: 10.1016/J.TREE.2020.08.016.

Visconti, B.P., Butchart, S.H.M., Brooks, T.M., Langhammer, P.F., Marnewick, D., Vergara, S., *et al.* (2019). Protected area targets post-2020. *Science*. 364(6437), 239–241. doi: 10.1126/science.aav6886.

VividEconomics (2020). *State and Trends of Deforestation in Côte d'Ivoire (2019-2020)*. Report prepared for the UK Space Agency. https://www.vivideconomics.com/wp-content/uploads/2020/07/State-and-Trends-of-Deforestation-in-CdI-1.pdf.

Walcott, J., Thorley, J., Kapos, V., Miles, L., Woroniecki, S. and Blaney, R. (2015). *Mapping Multiple Benefits of REDD+ in Paraguay: Using Spatial Information to Support Land-Use Planning.* Cambridge, UK.

Wan, J.Z., Wang, C.J. and Yu, F.H. (2017). Spatial conservation prioritization for dominant tree species of Chinese forest communities under climate change. *Climatic Change 2017 144:2*. 144(2), 303–316. doi: 10.1007/S10584-017-2044-7.

WaterAid (2005). Community mapping. A tool for community organising. https://washmatters.wateraid.org/publications/community-mapping-a-tool-for-community-organising-2005-0.

Wu, Q. (2020). geemap: A Python package for interactive mapping with Google Earth Engine. *Journal of Open Source Software*. 5(51), 2305. doi: 10.21105/JOSS.02305.

# 6

# Annex

## 6.1 Suitability-first tutorials

UN-REDD Programme tutorials developed by UNEP-WCMC can be accessed via: http://bit.ly/gistools-redd. At the time of writing, these are:

**1. Open-source: QGIS**

- Creating an Open Foris Xubuntu Live USB - the basics (English).
- Introduction to QGIS 1.8 – the basics (English, French, Mongolian).
- Introduction to QGIS 2.8 - the basics (French).
- Introduction to QGIS 2.18 (English).
- How to georeference a scanned map or image (English).
- Extracting and processing IUCN Red List species data using a vector method (English).
- Extracting and processing IUCN Red List species data using a raster method (English, French, Mongolian).
- Evaluating the importance of forests for soil stabilization and limiting soil erosion (English, French, Spanish, Mongolian).
- How to produce a matrix style legend using both vectors and rasters (English, French, Mongolian).
- Adding below-ground biomass to a dataset of above-ground biomass and converting to carbon (English).
- Understanding and comparing carbon datasets (English, French).
- Building spatial workflows to identify potential areas for undertaking a REDD+ intervention using the Graphical Modeler (English, French).
- Mapping areas of importance for multiple benefits of REDD+ using QGIS 2.18 (English).
- Assessing the relative importance of forests for landslide mitigation using QGIS 2.14 (English).
- Assessing the relative importance of forests for wind erosion control using QGIS 2.18 (English).
- Processing and visualising fire data to identify potential pressures from fires on forest using QGIS 2.18 (English).

**2. ArcGIS Desktop: ArcMap**

- Extracting and processing IUCN Red List species data using a vector method (English, Spanish, Vietnamese).
- Extracting and processing IUCN Red List species data using a raster method (English, Spanish).
- Evaluating the importance of forests for soil stabilization and limiting soil erosion (English, Vietnamese).
- How to produce a matrix style legend with raster data (English, Spanish, Vietnamese).
- Building spatial workflows to identify potential areas for undertaking a REDD+ intervention using Model Builder (English, Spanish).

**3. Other open-source tools**

- Evaluating the importance of forests for water provision and limiting soil erosion: A modelling approach using WaterWorld (English, French, Spanish).

## 6.2 Relevant tools for Systematic Conservation Planning

| Tool | Description | Website |
|---|---|---|
| Marxan | Marxan is the most commonly used conservation planning decision tool (See table 3 for more information). Continued development of Marxan has resulted in multiple upgrades and variations of the framework to enhance key aspects of the spatial prioritization process, including multiple management zones (Marxan with Zones), accounting for uncertainty (MarProb), directional ecological connectivity considerations (Marxan Connect), and graphical user interfaces to ease its use (e.g.: Zonae cogito) | https://marxansolutions.org/ |
| Prioritizr | (See Table 3 for more information) | https://prioritizr.net/ |
| Zonation | (See Table 3 for more information) | http://tools.envirolink.govt.nz/dsss/zonation/ |
| CAPTAIN (Conservation Area Prioritization Through Artificial Intelligence) | New approach (2022) based on Artificial Intelligence with a focus on static and dynamic features (i.e., change through time: climate change, LU change, species-specific sensitivity to change). It has only been tested on simulated data yet, and Madagascar case study (Silvestro *et al.* 2022) | https://www.captain-project.net/ |
| ConsNet | Software equipped with tools for the design of conservation area networks to represent biodiversity. Based on a landscape divided in planning units, it identifies portfolios of sites that meet representation targets for species while considering ecological (e.g., connectivity) and socio-economic constraints (e.g., minimization of costs). | https://sites.google.com/site/michaelciarleglio/consnet |
| oppr | This seems a full new framework of conservation planning for species conservation. Many similarities with others (especially Prioritizr, has equivalent syntax in R) but also differences – e.g. uses spatially explicit actions and applies the expected outcome of their implementation for species. | https://prioritizr.github.io/oppr |
| raptr | Similar to Marxan (minimum-set problem), introducing new formulations of the reserve selection problem to cover “representative samples of the variation (environmental, genetic) of each feature (species)”, Initial formulation from Faith and Walker (1995), based on the “environmental diversity” reserve selection framework.<br>Few citations and uses. Same author co-developed Prioritizr which builds on this software. Prioritizr does not include all the same methods, but Hanson *et al.* (2020) proposed a use of Prioritizr inspired by a simplified version of this. | http://jeffrey-hanson.com/raptr/, (best suited for using genetic data in spatial planning). |

## 6.3 References

Faith, D.P. and Walker, P. (1995). Diversity: a Software Package for Sampling Phylogenetic and Environmental Diversity. User's Guide.

Hanson, J.O., Rhodes, J.R., Butchart, S.H.M., Buchanan, G.M., Rondinini, C., Ficetola, G.F., *et al.* (2020). Global conservation of species' niches. *Nature* 2020 580:7802. 580(7802), 232–234. doi: 10.1038/s41586-020-2138-7.

Silvestro, D., Goria, S., Sterner, T. and Antonelli, A. (2022). Improving biodiversity protection through artificial intelligence. *Nature Sustainability* 2022 5:5. 5(5), 415–424. doi: 10.1038/s41893-022-00851-6.

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