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Review

Multiple-use spatial planning for sustainable development and conservation

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Growing global demands for food, energy, and resources drive competition for space while increasing pressure on natural systems, highlighting the need to balance sustainable resource use with biodiversity conservation. While multiple-use spatial planning provides a pathway to balance this trade-off, there is limited guidance for selecting appropriate optimization approaches and their integration into terrestrial, freshwater, and marine planning processes. Here we explore the current state of multiple-use spatial planning and the challenges that hinder its adoption, including the timing of interventions, economic impacts of planning decisions, capacity building, and alignment with development priorities. We aim to make multiple-use planning more accessible to researchers and practitioners and stimulate its wider uptake to help meet international ecological, economic, and social goals.

Highlights

Balancing conservation and sustainable development goals requires integrating economic, ecological, and social objectives into multiple-use spatial plans.

Recent advances in optimization methods and tools enhance the potential application of multiple-use spatial planning approaches, but adoption remains limited.

Providing guidance on the advantages and limitations of optimization approaches, reconciling terminology, and advancing methods to measure economic costs and benefits is essential if we are to realize the benefits of transitioning from single-use to multiple-use spatial planning.

Better adoption and deployment of quantitative tools for multiple-use spatial planning can ensure transparency in decision-making as we progress towards biodiversity, economic, and social targets at global, national, and local scales.

The growing need for multiple-use spatial planning

Global demands for food, energy, minerals, infrastructure and water are increasing [1,2], intensifying pressure on ecosystems [2,3], and competition for space [4,5]. Human activities have altered 75% of land, impacted 66% of oceans, and reduced >85% of wetlands, with adverse consequences on biodiversity, climate, and people [3]. While development and conservation have commonly been framed as competing goals, they can coexist and provide co-benefits [6]. Overcoming this dichotomy through effective spatial management is essential for balancing long-term sustainable resource use with conservation.

This need is reflected in global policy targets. The United Nations Sustainable Development Goals (SDGs) 14 and 15 call for the protection and sustainable use of terrestrial and marine ecosystems [7], while Target 3 of the Global Biodiversity Framework (GBF) aims to protect 30% of land, waters, and seas by 2030 [8]. Achieving these, alongside other commitments such as clean energy access (SDG 7) and sustainable economic growth (SDG 8), requires strategic allocation of space and resources for multiple sectors. Specifically, Target 1 of the GBF calls for all areas to be 'under participatory, integrated, and biodiversity inclusive spatial planning'. However, there are no clear guidelines for implementation, although definitions and frameworks are forthcoming [9].

Spatial planning (see Glossary) is a process to assess and designate the spatial and temporal arrangement of human uses, including by informing the application of **area-based management tools**, to meet economic, ecological, and social goals [10,11]. Although intended as an integrated approach, decision-making often remains sector-specific [12]. Additionally, many spatial planning processes lack transparency in the definition of planning objectives [13]. As a subset of

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spatial planning, **systematic conservation planning** (**SCP**) provides a structured framework to balance biodiversity conservation with socioeconomic interests by identifying, assigning, and monitoring management actions [14]. A key step in SCP is **spatial prioritization**, which guides the implementation of management actions to meet objectives [15], often using **spatial optimization** to identify cost-effective solutions [16–18]. The interplay among spatial prioritization, **conservation planning**, and broader spatial planning creates a complex landscape for researchers and practitioners. This can lead to inconsistent decision-making, misaligned conservation and development goals, and challenges in stakeholder communication.

We examine the current state of multiple-use spatial planning across realms, clarifying key concepts and terminology, and evaluate optimization approaches for integrating conservation and human uses. Spatial optimization offers a systematic, reproducible, and flexible framework for navigating trade-offs and identifying efficient solutions. We provide guidance to help researchers and practitioners with spatial optimization expertise select suitable methods, overcome uptake barriers, and promote broader adoption of transparent, science-based planning processes.

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Reconciling terminology in multiple-use spatial planning

In general, planning processes should be participatory and need to consider: (i) objectives for spatial allocations; (ii) different uses; (iii) associated management actions; and (iv) features, costs and constraints (Box 1) that can be allocated to different zones (Figure 1D) through an optimization process. A major challenge in understanding key concepts in multiple-use planning, however, is the overwhelming variety of terms and definitions describing similar – or even identical – concepts, with inconsistencies across realms (Box 2).

Box 1. Key concepts in multiple-use spatial optimization

In systematic conservation planning, spatial optimization is preceded by several steps (Figure IA), one of which is defining the decision context. This involves articulating actions for different activities such as agriculture, photovoltaic development, or biodiversity conservation [5]. Spatial optimization then begins with setting fundamental objectives (or goals), such as maintaining ecosystem integrity, enabling sustainable development, or minimizing costs.

Next, spatial data are assembled (Figure IB), and performance metrics are calculated to assess how well the objectives are met (Figure IC). Spatial data underpin the features, costs, and constraints that shape the analysis. Features are spatial elements of interest within a planning region, such as critical habitats for threatened species or areas with energy generation potential [5,23]. Performance metrics for features often include setting a target, such as a minimum level of representation (coverage) by the spatial prioritization. This could be a percentage of suitable habitat for each biodiversity feature [18].

Costs (e.g., land value, maintenance expenses, or lost fishing revenue in wind farm zones), allow for efficiency within the planning process, and are often the main driver of the mathematical objective. The objective function is minimized or maximized. Commonly, the objective function aims to minimize cost, while meeting the constraint of ensuring that targets are met for all features.

Constraints ensure solutions align with real-world policies. For example, constraints can require the plan to stay within a certain monetary budget for a specific sector, or that particular areas must be allocated to specific uses.

These inputs are then used to formulate a mathematical optimization problem ([18]; Figure ID). Correctly formulating the problem to represent the underlying fundamental objectives is key, and one of the most challenging steps, in spatial optimization [66]. When done well, planning achieves data-driven solutions that balance ecological, economic, and policy considerations.

Spatial optimization typically produces binary solutions (Figure IE), where planning units are either selected or not. Often real-world challenges require more flexibility. Management zones allow for solutions beyond simple inclusion/exclusion [35]. Each zone has its own features, targets, costs, and constraints, enabling planners to address diverse objectives (Figure 1C). Despite this flexibility, all zones still operate under a shared objective function, such as minimizing total cost.

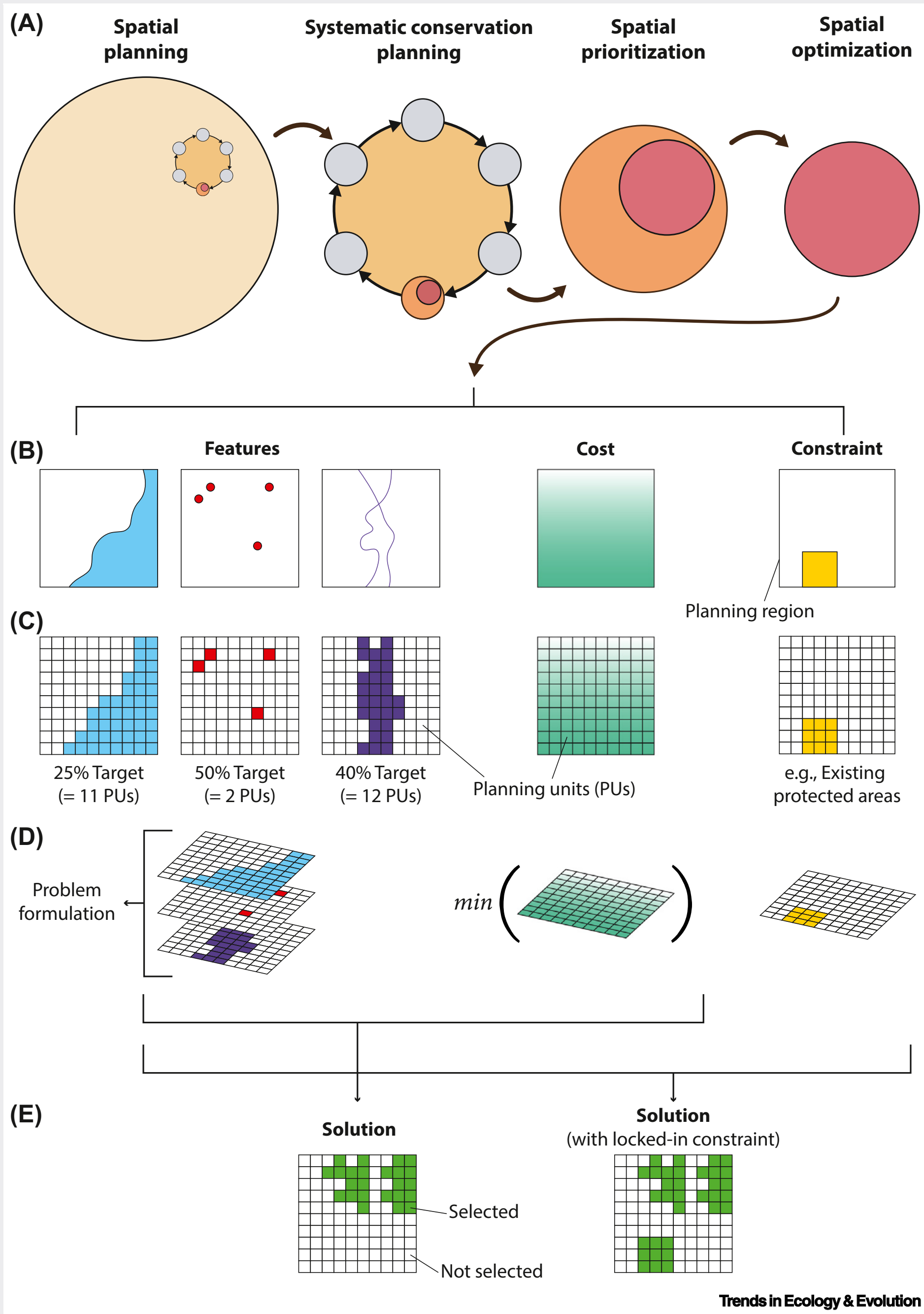

Figure I. Schematic of the main steps in spatial optimization. (A) Relationship between spatial planning, systematic conservation planning (see [14] for detailed descriptions of the individual steps), spatial prioritization and spatial optimization. (B) Collecting spatial input data. (C) Preparing spatial data by converting them into planning units (PUs) and setting targets for each feature. (D) Formulating the spatial optimization problem (here minimizing cost while meeting all feature targets and including the area of the locked-in constraint). (E) Solving the optimization problem with or without locked-in constraints.

While concepts such as **co-location** (i.e., several activities in the same space and time) have clear meanings, others describe similar ideas. For example, multi-use/**multiple-use (spatial) planning** [19], multi-zone/**zoning** [20–22], and multi-sectoral/**cross-sectoral planning** [23] are used interchangeably when referring to including different sectors or communities and their areas of operation in planning processes. Note that we use 'multiple-use' hereafter and reference 'uses' and 'sectors' interchangeably. Reconciling multiple uses is inherent to classical SCP approaches, which focus on designing protected areas for conservation while avoiding conflict with sectors or other 'users' within the planning area. **Users** may share spatial locations or natural resources but differ in their values, rights, interests, and vulnerabilities [24]. Recognizing this distinction is essential for equitable and legitimate planning, with practical implications for participatory processes and responsible application of optimization tools [25].

Adding to this complexity, identical terms can have different definitions in various contexts. Multiple objective or multi-objective (multi-objective hereafter) can refer to the overarching goals of a spatial planning process [26], such as developing scenarios enhancing food security, and/or ensuring biodiversity persistence [5,20,27]. Alternatively, these terms can refer to the mathematical expressions underpinning spatial optimizations with multiple objectives [28,29]. We recommend clearly specifying the context in which 'multi-objective' is used, either in planning processes (e.g., **multi-objective (spatial or conservation) planning**) or in methods (e.g., **multi-objective (spatial) optimization**).

Terms such as **use–use** [30] and co-location [31] are primarily used in spatial planning literature but rarely in SCP. Emerging concepts such as **integrated spatial planning**, driven by initiatives such as Target 1 of the GBF, emphasize holistic approaches aligning biodiversity, climate, and sustainable development [32]. Although 'integrated' is widely used, it is applied in varying contexts with different definitions, which complicate its use [33,34].

This lack of clear definitions across studies hinders the comparability and applicability of planning methods. To ensure planning is inclusive and accessible across sectors, avoid using different terms within a single study unless they represent distinct concepts essential to understanding the research. Additionally, we recommend standardizing terminology across research domains, and introducing new terminology only when existing definitions fail to convey novel concepts.

Optimization approaches for multiple-use spatial planning

Early spatial optimization tools were not designed to allocate space for multiple management actions simultaneously, nor were there political incentives for this. However, advances in computational power, open-access data, and integrated planning policies [9] have driven the development of new planning tools [18,35] and interest in multiple-use spatial optimization [19].

We discuss current spatial optimization approaches most relevant to multiple-use planning (Table 1). This is not a comprehensive list of tools and approaches (Box 3), with many multiple-use planning processes not using optimization methods [36]. Some emerging optimization tools show potential for multiple-use planning through action-based frameworks and **multi-action planning**, but currently focus on conservation goals and threat mitigation, with limited integration of broader human uses or non-conservation outcomes [37]. We frame this section around the problem formulation of common optimization approaches (Figure 1) and discuss multi-objective optimization approaches from other fields that remain under-explored in spatial planning.

Aggregating multiple uses into a composite cost

When the primary objective is to meet conservation targets (e.g., 30% of each mappable feature), multiple uses can be aggregated into a single, composite cost metric in spatial optimization

Glossary

Area-based management: regulating human activities within defined spatial areas to achieve ecological, social, and economic goals through inclusive governance, recognition of diverse management approaches, and a shift from measuring coverage alone to evaluating outcomes and equity.

Co-location: allocating multiple sectors in the same space at the same time (e.g., solar energy and farming, or offshore wind farms and aquaculture).

Conservation planning: a strategic process to guide decisions about conserving biodiversity and ecosystems, often using data-driven and spatial tools. While not always systematic, it is often used synonymously with SCP, spatial prioritization, or spatial planning.

Cross-sectoral planning: a planning problem with two or more activities, with or without stakeholders' engagement. It is used interchangeably with inter-sectoral and multi-sectoral planning.

Integrated spatial planning: a participatory process to allocate the spatial distribution of actions for multiple human uses and activities across land, freshwater, and marine realms to achieve several social, economic, and ecological planning objectives simultaneously, while integrating biodiversity considerations.

Multi-action planning: identifying the optimal combination and spatial allocation of management actions to minimize costs while achieving recovery targets within a set budget. It currently focuses on threat abatement, rather than multiple sectors.

Multi-objective (spatial) optimization: a planning problem with multiple objective functions in a single problem.

Multi-objective (spatial or conservation) planning: a planning problem defined by multiple objectives (goals). It can overlap with multiple-use planning if objectives are driven by different uses.

Multiple-use (spatial) planning: a planning problem including multiple sectors which do not necessarily need to share the same space (i.e., they can be adjacent). Nature may or may not be included.

Spatial action mapping: a conservation planning approach identifying where and how specific actions, their actors, and anticipated impacts can best contribute to achieving

(Box 1; Figure 1A). This typically involves calculating a new composite cost value based on the weighted [38,39] or unweighted sum [40,41] of multiple cost values. This is common practice in SCP, where minimizing economic costs (e.g., opportunity costs or foregone revenue) can increase stakeholder support and adoption [38]. When economic cost data are unavailable, many analyses use existing aggregated datasets, such as 'human use/footprint' [42,43] or 'vulnerability/disturbance/cumulative effects' scores [44,45] as cost metrics.

However, composite costs risk obscuring the influence of individual sectors and can disproportionately disadvantage certain sectors by avoiding areas that incur higher opportunity costs due to their inherent economic value (e.g., industrial fishing vs artisanal fishing) or due to weighting choices. Composite cost metrics can also be problematic where cost values have different units [e.g., summing fishing effort (hours), enforcement costs (dollars), and accessibility (km)] [46]. In such cases, composite costs assume a linear relationship between cost metrics (e.g., agricultural land suitability) and fundamental objectives (e.g., reducing impacts of protected areas on agriculture). Although it is common to normalize cost metrics prior to computing a composite cost metric (e.g., linearly re-scaling values), outcomes can be sensitive to the choice of normalization procedure and statistical outliers [47]. Where costs with different units are available, best practice is to develop scenarios for each cost value or adopt a constraint-based approach if appropriate.

Beyond technical limitations, composite costs can also overlook sectoral goals, vulnerabilities, historical rights, and capacities to adapt to spatial planning decisions. For example, creating a single fisheries cost layer can obscure impacts of planning processes on small-scale versus industrial operators, potentially leading to inequitable outcomes and reducing the legitimacy of planning decisions. Accounting for stakeholder-specific objectives can improve equity without compromising conservation efficiency [24]. Addressing these issues early in the planning process, when defining the objectives, can help ensure more equitable and robust outcomes.

Setting constraints for individual uses

Constraints can also be set for multiple-use spatial optimization [18]. Constraints can represent user-defined budget limits such as the maximum lost revenue or minimum area requirements (Box 1; Figure 1B). In contrast to a single composite cost, constraints treat each cost metric separately, offering greater control and flexibility over how individual uses are considered [39,48].

Although constraints overcome some of the limitations associated with using composite costs, they share some limitations (Table 1). However, exploring different scenarios by including or excluding constraints can clarify the impact of each use on the resulting planning scenario, making this a better approach when the required sector-specific data (e.g., opportunity costs) are available.

Using zones to incorporate multiple uses explicitly

Zoning is one of the most accessible methods for allocating spatial management actions, and is increasingly used in research [4,5,23,34] and practice (e.g., Tun Mustapha Marine Park, Malaysia, [49] and the Essential Life Support Area framework [32] with preliminary results in [50]). Incorporating multiple uses through zoning helps to reduce potential conflicts among sectors and can maximize sectoral benefits by assigning tailored management actions in individual zones. By allocating features, costs and constraints to specific zones, planners can introduce flexibility into the optimization process and resulting scenarios (Figure 1C; [20,21]).

conservation goals. It emphasizes action-based outcomes and exploring trade-offs.
Spatial analysis: the process of developing, modeling, evaluating or combining spatial datasets to understand a problem.
Spatial optimization: the use of mathematical algorithms (exact or heuristic) to determine the best spatial allocation of resources or actions based on specific criteria.
Spatial planning: a public process for assessing and determining how human activities are distributed across space and time to meet ecological, economic, and social objectives. It may, but does not necessarily, include nature. Can be applied to marine or land-use.
Spatial prioritization: a component of larger frameworks (e.g., SCP) that is focused on allocating actions in space and time, which could use optimization or other approaches. Within this context, it is often used interchangeably with 'spatial conservation prioritization', which includes nature.
Systematic conservation planning (SCP): a structured framework for identifying, assigning, and monitoring areas for biodiversity conservation, restoration, or sustainable management in several steps. SCP is guided by core principles of complementarity, irreplaceability, representativeness, adequacy, connectivity, and efficiency, and often uses decision-support tools to balance the conservation of biodiversity – the core objective of SCP – with social and economic considerations. A key step is spatial prioritization.
Trade-off analysis: a method for evaluating competing objectives in spatial planning, such as conservation versus economic development, but also among stakeholders in terms of who bears costs and obtains benefits.
Use–use interactions: methods for assessing synergies and risks among multiple uses.
User: an individual or group that interacts with a particular area or resource. Users can vary in goals, access rights, impacts, and connections to place, and include stakeholders, rightsholders, and other interest groups.
Zoning: development of a plan with management zones. These can involve single-action zones (e.g., offshore wind, fishing and conservation zones) or multiple-action zones (e.g., sustainable management zone). Zones can contain

multiple uses and/or address multiple objectives.

However, this flexibility comes with trade-offs since zoning requires more data and greater expertise to capture the complex interactions among sectors and with biodiversity [51,52]. The limitation of summing costs still exists within zones and opportunities to account for synergies across sectors remain limited [18,35]. For example, sectoral benefits of different zones can accrue in non-additive ways, but current optimization tools struggle to incorporate such interactions, though [37] allows multiple actions to spatially overlap, capturing their combined effects. Additionally, it is impossible to use different objective functions for each use in each zone (e.g., simultaneously maximizing benefits for one use, while minimizing costs for another use). Best practice is to keep the number of zones – and consequently, the complexity of the plan – within a manageable range for communication, management and enforcement.

Multiple objectives in spatial optimization

Most decision-support tools supporting multiple-use spatial optimization share a limitation: they only consider a single mathematical objective in the problem definition that relates to the sector-specific goals for minimization or maximization during optimization (Box 1) – although constraints can theoretically be viewed as types of objectives. In practice, planning processes often

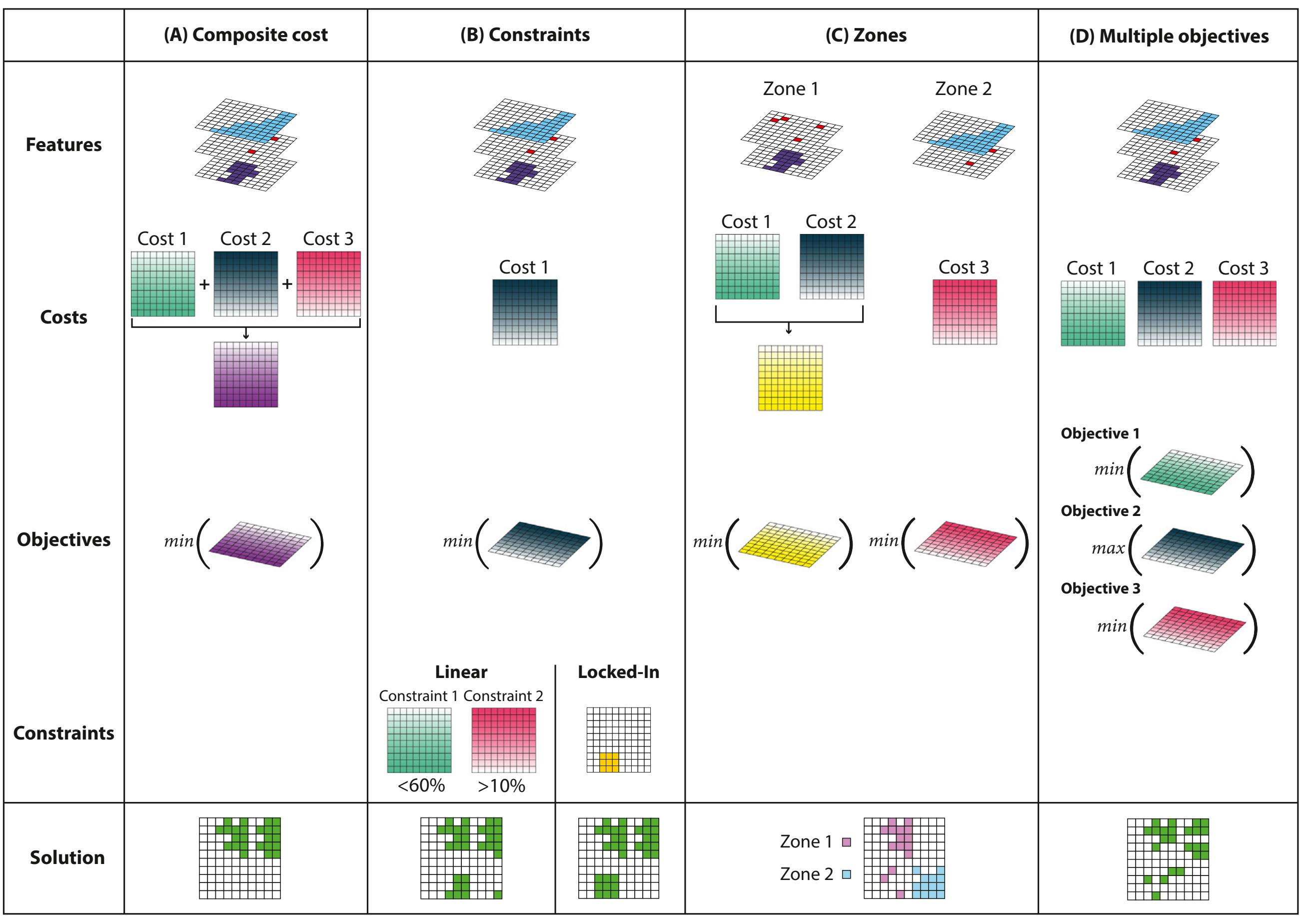

Figure 1. Approaches for incorporating multiple uses in spatial optimization. (A) Composite cost. Incorporating different uses by aggregating them in a combined cost layer. (B) Constraints. Constraining the solution with either budgets for different uses (linear constraints) or by locking-in areas for existing uses (locked-in constraint). (C) Zones. Formulating and solving a zoning problem, where each zone has distinct features and associated costs to be minimized, resulting in a single solution with different management zones. (D) Multiple objectives. Including multiple uses through multi-objective optimization by setting a different objective for each use.

have multiple objectives [28,29,53] which can be simultaneously addressed using multi-objective optimization (Figure 1D), a well-studied concept in computer science and engineering [54].

Multiple-objective optimization approaches can broadly be classified as *a priori* or *a posteriori* [53]. *A priori* approaches incorporate priorities pre-optimization by specifying the relative importance of different objectives [53]. For example, the hierarchical method optimizes each objective sequentially, only allowing for a pre-specified level of reduction in quality between subsequent objectives [55]. Another *a priori* approach, which is more common in ecology [53,56], is the weighted-sum method that involves using a linear combination of multiple objective functions based on user-defined weights. *A posteriori* approaches create a set of solutions to choose from based on stakeholder preferences post-optimization, thus requiring knowledge about the particular trade-offs [53].

Multi-objective optimization offers the most flexible approach to multiple-use spatial planning, allowing more nuanced evaluation of competing objectives and **trade-off analyses** across sectors than single-objective methods. While some accessible tools exist [56], current applications rely on custom algorithms, such as using genetic algorithms in specific case studies [57,58], limiting their accessibility and adoption by non-specialists. Thus, custom multi-objective optimization algorithms within a SCP framework have not yet been subject to the rigorous testing in common software tools for spatial optimization such as Marxan [16], prioritizr [18], and Zonation [17].

Multi-objective optimization works best with well-defined and conflicting objectives. However, it is time-consuming and data-hungry, requiring greater mathematical and programming expertise to

Box 2. Differences among realms in multiple-use spatial planning

Terrestrial, marine, and freshwater realms face similar threats, including habitat degradation and biodiversity loss driven by extractive activities and unsustainable development [1]. While the number of protected areas is increasing globally (Figure I), all realms remain behind in meeting international conservation targets. However, research within each realm often operates in isolation, leading to methodological differences shaped by their unique characteristics.

A key difference in spatial optimization across realms lies in how each integrates multiple sectors. Marine research predominantly employs multiple-use planning, using zoning approaches to minimize conflicts and promote coexistence [4,20,27]. While there is multiple-use planning in terrestrial and freshwater realms [5,33], it focuses on integrating multiple objectives, particularly prioritizing ecosystem services such as carbon storage and flood retention [21,22,57]. Terrestrial planning frequently employs trade-offs to balance conservation with competing land uses, such as biodiversity recovery and renewable energy expansion [5]. It also more commonly employs custom optimization methods to handle multiple objectives, including hierarchical frameworks [55] and genetic algorithms [57], especially in urban contexts. Freshwater research, by contrast, often employs **spatial action mapping** and prioritizes actions for threat abatement, allocating space to combat invasive species, weeds, and unsustainable agriculture [89]. This has driven the development of optimization tools for cost-effective multi-threat management [37].

Many methodological differences among realms stem from their physical properties and history. The three-dimensional structure of marine environments complicates connectivity but offers co-location opportunities, whereas terrestrial systems are largely constrained to two dimensions, limiting overlapping uses. On land, a long history of single-use allocation, such as for protected areas, necessitates trade-off management rather than multiple-use integration. By contrast, the marine realm – with a more recent history of economic and protected area expansion (Figure I) – still suffers from a 'Tragedy of the Commons'. With many resources still openly accessible and space often not yet allocated to a single use, traditional and emerging sectors are expanding rapidly, accelerated by advancing technology enabling access to previously unexploited regions such as the deep sea and the high seas [2]. While this expansion represents a risk to biodiversity, it also affords novel zoning opportunities compared with on land where property ownership is common. Freshwater systems, though often smaller and more vulnerable to localized threats, also include large and complex systems such as transboundary river basins experiencing cumulative pressures at broad spatial scales [90]. A persistent challenge in freshwater multiple-use spatial optimization is accounting for off-site impacts, such as upstream–downstream interactions, which requires incorporating hydrological connectivity and cross-boundary effects [90,91]. These challenges are not only technical but also institutional, requiring coordination across jurisdictions, sectors, and governance levels.

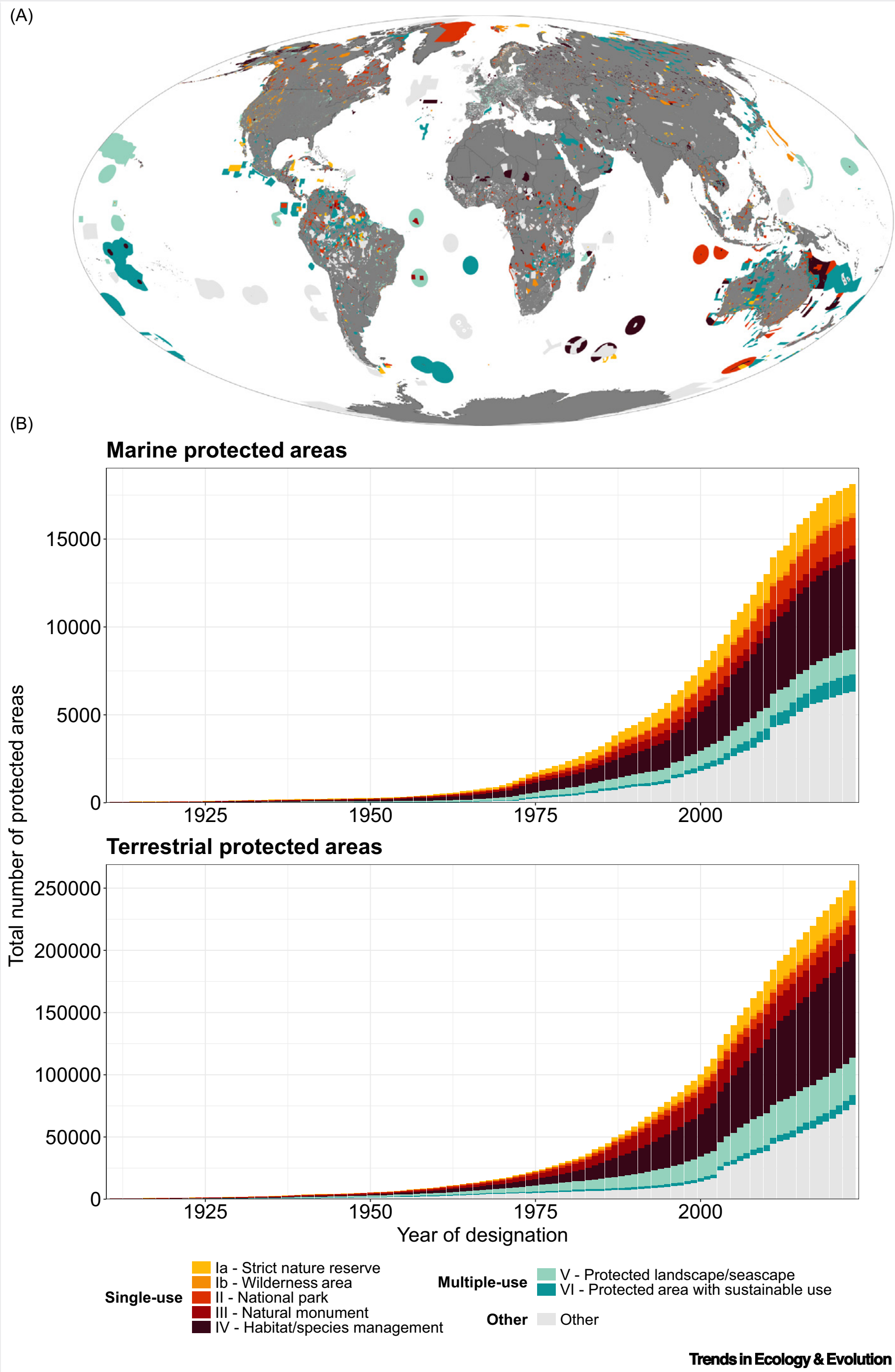

Figure I. Global marine and terrestrial multiple-use and single-use protected areas. (A) Geographic distribution of protected areas classified by the International Union for Conservation of Nature (IUCN) categories. Single-use categories (shades of red/orange; I–IV) include Ia, strict nature reserve; Ib, wilderness area; II, national park; III, national monument; and IV, habitat/species management. Multiple-use categories (shades of blue/green; V–VI) include V, protected landscape/seascape; and VI, protected area with sustainable use. Areas not assigned an IUCN category are shown as 'Other.' (B) Number of protected areas by IUCN category over time. Figure adapted and updated from [92].

Table 1. Multiple-use spatial optimization approaches, including planning goals, benefits, limitations, data needs, and example tools with references[a]

Approach	Planning goal	Benefits	Limitations	When to use	Minimum data requirements
Composite cost [39,40,43,45,91,103] *Software:* Marxan, prioritizr, Zonation	Support primary planning objective (e.g., conservation) while reducing overall conflicts (e.g., avoid areas with high opportunity costs) *Output:* A set of priority areas for implementing a single management action (e.g., protected area establishment) to achieve the primary planning objective (e.g., biodiversity conservation)	Easy to communicate Low computational burden Low data requirements Low technical capacity requirements	Obscures sector-specific trade-offs May disadvantage certain user groups Assumes linearity between costs and objectives Sensitive to normalization and outliers Problematic for costs with incompatible units Weighting of costs subjective Cannot tailor management strategies to specific uses	One primary planning objective; limited data availability or technical capacity; quick, broad guidance needed	Planning units; composite cost layer based on cost information of multiple sectors; feature expectations; criteria for feature representation (e.g., targets, weights)
Constraints (linear [48,85]; locked-in/out [20,45,48,104,105]) Software: Marxan, prioritizr, Zonation	Support primary planning objective (e.g., conservation) while integrating sector-specific compromises (e.g., set budget limits for other sectors) *Output:* A set of priority areas for implementing a single management action that meets the primary planning objective while (i) satisfying several constraints (e.g., costs to sectors below thresholds; linear constraint) (ii) including or excluding specific areas from the solution (e.g., area of an existing wind farm; locked-in/out constraint)	Fairly easy to communicate Computational burden: low (locked-in/out constraints); medium (linear constraints) Data requirements: low (locked-in/out constraints); medium (linear constraints) Technical capacity requirements: low (locked-in/out constraints); medium (linear constraints) Allows accounting for uses separately rather than combining them and thereby does not disadvantage certain uses Allows for some exploration of sector-specific trade-offs	Requires detailed, sector-specific data (e.g., opportunity costs) Harder to communicate compared to composite costs (linear constraints) Sensitive to thresholds used to encode sector-specific objectives (e.g., when locking out particular areas or specifying linear constraints) Cannot tailor management strategies to specific uses	One primary planning objective; moderate data availability and technical capacity when linear constraints used; when sector-specific trade-offs matter	Planning units; cost layer; feature expectations; criteria for feature representation (e.g., targets, weights); constraint information: binary layer of locked-in/out region (locked-in/out constraints) or continuous cost surfaces with budgets for each sector (linear constraints)
Zones [4,5,22,27,34]	Support multiple planning	Supports integration of multiple	High data requirements	Multiple planning	Planning units; current allocation

Software: Marxan with Zones, prioritizr	objectives requiring different management actions in each zone (e.g., establishing wind farms for energy production, farms for agriculture, and protected areas for conservation) *Output:* A scenario with priority areas for implementing a variety of different management zones	planning objectives Enables tailored management strategies for each use Reduces potential conflicts among sectors Allows some co-location or adjacency of different uses Enables zone-specific (i.e., sector-specific) features, targets, and costs Provides flexibility in optimization and scenario design Widely used and accessible for real-world implementation	High technical capacity requirements Decision-intensive to set objectives and optimization parameters for each zone Difficult to explore trade-offs among objectives Assumes linearity between costs for different objectives Complexity increases with number of objectives and zones, affecting communication, management, and enforcement High computational burden	objectives; tailored management per sector needed; high data availability and technical capacity	of each management zone; cost layer per zone; feature expectations per zone; criteria for feature representation (e.g., targets, weights) in each zone or combination of zones
Multiple objectives [28,55,56] *Software:* Restoration Opportunities Optimization Tool (ROOT); custom algorithms	Simultaneously optimize multiple conflicting objectives across sectors (e.g., maximize revenue for one sector while minimizing cost to others) *Output:* A scenario with priority areas, potentially for implementing a variety of different management zones, that balance multiple, potentially conflicting objectives	Simultaneous consideration of conflicting objectives Provides comprehensive trade-off insights Flexible approach accommodating diverse sector goals Better reflects complex planning realities with multiple goals	High data requirements High technical capacity requirements Decision-intensive to set objectives and optimization parameters for each objective Complexity increases with number of objectives, affecting communication, management, and enforcement Lack of widely accessible, user-friendly implementations (e.g., R packages, graphical user interfaces) Limited testing and validation in systematic conservation planning contexts High computational burden	Multiple, well-defined, conflicting objectives requiring comprehensive trade-off evaluation; very high data availability and technical capacity	Planning units; objective functions based on planning objectives; cost layer or equivalent based on planning objectives; feature expectations; either a budget for the cost layer or criteria for feature representation (e.g., targets, weights) or both depending on the objectives

[a]We provide examples for each approach across tools and realms. While we use the terms locked in, locked out, and linear constraints to describe functionality across decision-support tools, these concepts may be implemented differently or referred to using alternative terminology. For example, locked-in and locked-out areas can be represented using masks in Zonation. A linear constraint-like approach can also be implemented in Marxan by incorporating data for multiple objectives as features (separately). This is because the feature targets in Marxan are implemented as a soft linear constraint, where unmet targets incur penalties via the species penalty factor. Similarly, in Zonation, using an additive benefit function with a feature-specific step function contributes a soft linear constraint to the problem definition. For more explicit guidance on general spatial optimization and SCP beyond integrating multiple uses, practical guidance on applying these approaches, and to facilitate comparisons across realms and spatial scales readers should refer to [19,100–102].

Box 3. Tools in spatial planning

Within spatial planning, a range of tools are available for distinct purposes and **spatial analyses**. These can be categorized into tools for assessing spatial interactions, evaluating cumulative effects, and supporting decision-making [10], although more detailed classifications have been proposed based on specific use cases [93].

Tools that assess spatial interactions among activities help identify synergies and conflicts among sectors by taking into account the characteristics of an area, vested interests, and existing sectoral activities [10]. Multi-criteria analysis is widely used for assessing spatial interactions, integrating various criteria to evaluate trade-offs [94,95]. Specialized software, such as Seanergy [96], provide workflows to analyze spatial overlaps and dependencies among activities, offering insights into potential conflicts or co-benefits.

Cumulative-effect assessment (CEA) tools evaluate combined impacts of human activities and their pressures on ecosystem components and functions [97]. CEAs often entail scoring cumulative impacts based on intensity of pressures, ecosystem sensitivity and recovery potential, and the distribution of uses [97]. Effective CEA should incorporate direct, indirect, and interactive effects, reflecting nonlinear and compounding impacts [98]. This is particularly relevant in marine planning where multiple stressors interact in complex ways [97], and in freshwater planning where multiple, interacting on-and off-site stressors can produce nonlinear and compounding impacts across catchments [99].

Decision-support tools translate analytical outputs into actionable planning strategies. They focus on data, analysis, forecasting, and stakeholder engagement [10]. Data tools support data collection, sharing, validation, and integration across stakeholder and rightsholder groups[v], but can also serve as 'geoportals', improving discoverability, documentation, and appropriate use of spatial data[vi]. Systematic conservation planning is an example of an analysis tool to identify cost-effective planning solutions that balance ecological and socioeconomic objectives (e.g., [16]). Forecasting tools, including ecosystem modeling frameworks [77], simulate future scenarios to predict consequences of different management strategies. Engagement tools, such as participatory planning software and web-based platforms, facilitate inclusive and equitable planning processes by visualizing planning alternatives, co-designing scenarios, and gathering feedback [50].

While each tool has a specific purpose, they are complementary and can be integrated into comprehensive planning frameworks. For instance, outputs from multi-criteria analyses can inform spatial optimization [94], and spatial optimization outputs can feed into forecasting models to assess economic and ecological consequences of implementing specific planning solutions [74]. Some tools are multifunctional, supporting visualization, modeling, and participatory planning[vii], and can interoperate with others (e.g., Marxan) to support integrated workflows.

formulate sector-specific objectives. Moreover, the challenge of engaging stakeholders in multi-objective optimization remains unclear. To make multi-objective optimization techniques more accessible to a wider audience and support a more comprehensive approach to multiple-use spatial planning, future research could focus on integrating them into existing or new software tools for spatial planning.

Choosing an optimization approach based on planning goals, data availability and technical capacity

Selecting an appropriate optimization approach requires understanding the governance, and public-private engagement context to ensure that resulting spatial prioritizations align with institutional mandates, legal frameworks, jurisdictional overlaps, and management capacity within the planning region. These factors, typically identified early in the planning process, will influence whether approaches like zoning or multi-objective optimization will be viable.

Once using an optimizing decision-support tool is deemed appropriate, and sufficiently introduced to stakeholders, rightsholders and other interested parties, the choice of approach should be guided by the overall goals of the plan. This involves balancing the desired level of detail in the planning scenario with available data, domain-specific expertise and technical skills (Table 1). While composite costs and constraint-based approaches are more accessible, zoning and multi-objective optimization offer greater flexibility and precision but require more data and specificity in the decision context. In data-limited regions – where information about sectoral activities, ecological and socioeconomic data are limited – composite costs or constraint-based approaches may be the only feasible option to include multiple sectors. However, planners can leverage global datasets and proxy indicators (applied with caution to ensure contextual relevance) or adopt participatory mapping approaches[viii] to help address information gaps. Where data remain insufficient for a given approach, planners may need to consider alternatives with lower data requirements. Given all this, we recommend revising the optimization approach during planning exercises as new information on data quality and availability emerges. Even the most sophisticated approaches can be ineffective or misleading if not supported by adequate data. Still, this should not preclude initial planning efforts as transparent communication about data limitations can help to build trust, and over time, improved engagement and data contributions often emerge as stakeholders gain confidence in the tools and process.

Identifying and addressing research gaps

Quantifying benefits and costs

Evaluating benefits and costs is key for allocating management actions, yet efforts to quantify their full scope remain limited. This is particularly important in multiple-use spatial planning, where many costs and benefits – including those beyond market benefits [23] – must be assessed to ensure equity and efficiency across sectors [25] and to avoid favoring high-revenue industries while undervaluing conservation and small-scale resource use [24,59].

While some studies now incorporate indirect benefits such as ecosystem services [22,43,60] through valuation frameworks such as InVEST[i], non-market benefits reflecting societal priorities, such as cultural significance [61], remain underrepresented. Although difficult to quantify, these benefits can be included through stated preference methods (e.g., contingent valuation and choice experiments) that estimate willingness to pay [62]. However, these methods face challenges, such as sensitivity to survey design and spatial heterogeneity in responses [63].

Although spatial planning scenarios commonly minimize opportunity costs such as lost profits in fisheries or agriculture [48], efficient multiple-use spatial planning needs to consider downstream sectoral costs. These include establishment, maintenance, management and compliance costs [61], as well as accounting for collaboration costs, including negotiation, coordination, and conflict resolution across sectors.

To ensure fairness and efficiency, defining and valuing costs and benefits should be a participatory process, co-developed with stakeholders and rightsholders to support procedural equity [64]. Additionally, distributional equity – how benefits and costs are shared across different groups – and recognitional equity – acknowledging the rights and knowledge systems of marginalized groups – requires attention to avoid reinforcing existing inequalities and strengthen social legitimacy of planning processes [64].

Future research could identify frameworks for quantifying spatial benefits and costs across sectors and novel methods for embedding them into optimization problems. Where sufficient data exists, multi-objective optimization can help maximize sectoral benefits while minimizing costs. Improving the accessibility of these methods for planners will require better visualization of trade-offs and user-friendly, open-source tools. In data-limited regions [59,65], proxies such as area-based costs can provide initial estimates [23], but overlook sectoral differences, and indirect and non-market benefits. Since spatial optimization outcomes are driven by benefit and cost data, ensuring their accuracy and relevance is critical for effective multiple-use planning.

Problem definition and interpretation

A challenge in spatial planning is to formulate the problem effectively. Designing planning scenarios requires clearly defining objectives, identifying actions, understanding system behaviors following management decisions, and accounting for constraints such as resource availability and prior commitments [66]. This is more complex in multiple-use spatial planning where trade-offs among sectors must be considered. Poorly formulated problems can lead to inefficient outcomes, missed opportunities to balance competing uses, and inequities among sectors. This challenge is compounded by a disconnect between planners and decision-makers. Planners commonly rely on decision-makers to articulate objectives and potential actions, whereas decision-makers might lack the technical and scientific expertise to define effective objectives in planning processes.

Bridging this gap requires building capacity, not only in technical skills to allow for mutual discourse about problem formulation and decision-support tools, but in fostering collaboration among planners, stakeholders, and policymakers. Engaging decision-makers throughout the process ensures that objectives reflect real-world scenarios and stakeholder values, making plans more actionable and effective [50]. In resource-limited regions, capacity-building initiatives could support training in decision science principles, decision-support tools, and participatory approaches [6]. National working groups or interministerial commissions that represent the interests of different sectors may help establish a common language and understanding of the planning process. The development of interactive platforms and software tools that allow stakeholders to engage directly in the planning process (e.g., [50][ii–iv]) will also foster the effective communication of planning approaches, outcomes, and trade-offs.

Scheduling actions over time

Most spatial optimization assumes management actions are implemented simultaneously. In reality, implementation is often incremental, with dynamic changes in costs, ecological conditions, and stakeholder and government priorities [65,67,68]. This is even more complex in multiple-use spatial planning, where different sectors follow their own timelines and funding schedules. Still, limited information exists on multiple-use spatial planning over time [69].

Studies that consider time mostly focus on ecological priorities, such as conserving highly vulnerable and irreplaceable areas [70] and accounting for climate change [23] or other future impacts [71]. Spatial optimization processes rarely consider how costs and benefits evolve dynamically throughout the implementation phase, despite spatial plans commonly undergoing periodic reviews to allow for adaptive management [72]. Conservation strategies should also undergo regular reviews to evaluate their effectiveness and support adaptive management to respond to changing environmental conditions [67].

Addressing this gap requires developing approaches that integrate temporal dimensions into multiple-use spatial planning. This would enable planners to prioritize actions over time, enhancing realism, adaptability and efficient resource allocation [73]. For countries struggling to meet targets, a phased implementation strategy could align with changing national budgets. Still, developing tools that can schedule actions over time could require significant technical advances in the underlying optimization techniques (e.g., stochastic dynamic programming). However, even technically advanced approaches must consider real-world political and societal dynamics, including election cycles and shifting societal and political priorities [68]. These dynamics can accelerate or delay planning and implementation, and failing to account for them can result in scenarios that are well designed in theory but difficult to deliver. Future efforts could therefore consider strategies such as scenario-based phasing, institutional risk assessments, and alignment with national development planning processes.

Ensuring that multiple-use spatial plans have economic impact

A key gap in multiple-use spatial planning is its limited ability to capture broader socioeconomic impacts of planning decisions measured using economic indicators, including national GDP, sector-specific revenue, or implementation and enforcement costs [61]. Without these insights, decision-makers lack a clear understanding of economic trade-offs, which can hinder adoption of plans, broader community support, and alignment with SDGs. This gap is especially pertinent where achieving global policies requires reconciling conservation with national economic priorities.

Bridging this gap involves integrating multiple-use spatial planning with bioeconomic modeling and economic forecasting to evaluate economic impacts of planning decisions [74,75]. Models such as GLOBIOM [76] can help to assess land-use competition among agriculture, bioenergy, and forestry, evaluating impacts of land-use change on greenhouse gas emissions and food security. In marine environments, bioeconomic models such as BOATS [77] can explore effects of protected area expansion on fisheries revenues [74,75]. Across realms, GTAP-InVEST assesses the impact of land-use changes by estimating economic returns of conserving biodiversity through protecting ecosystem services compared to exploiting natural resources in agriculture and fisheries [78]. Comprehensive frameworks and tools that integrate spatial optimization with bioeconomic modeling, economic forecasting, and scenario analysis are needed to support decision-makers in balancing trade-offs between the economy and the environment [79].

Aligning SCP with broader development priorities

Conservation scientists often prioritize biodiversity conservation without considering sustainable development, while policymakers frequently view conservation as secondary to economic growth – a key driver of national and regional planning decisions [80]. This disconnect is problematic because many international targets are framed at the national level, requiring governments to balance conservation with other priorities. Elevating the importance of conservation in national decision-making will require a deeper understanding of interconnections among biodiversity, the economy, and human wellbeing [81], and their integration into spatial planning processes.

This involves a shift from focusing on actions to reduce economic losses associated with designating protected areas [59] toward proactively addressing economic and societal consequences of biodiversity loss and unsustainable economic trajectories [82]. It requires recognizing the economic and social benefits of conservation, and ensuring that planning explicitly incorporates ecosystem services and their role in supporting key economic sectors [83,84].

However, aligning conservation with development goals also involves managing real and contentious trade-offs with powerful economic and political interests. Conflict-sensitive approaches – such as conflict mapping and stakeholder negotiation within spatial planning processes [85,86] – can help to manage these tensions and ensure equitable and politically sustainable planning outcomes [87]. Participatory approaches – where stakeholders co-develop planning scenarios – can further ensure that conservation and economic activities are interdependent components of long-term sustainability [32].

While such processes also face challenges, including time, cost, and risks of procedural participation reinforcing existing power dynamics [88], some countries are beginning to address these issues through legal reforms aimed at strengthening representation in line with GBF targets and SDGs [68]. Achieving this vision requires uniting conservation scientists, policymakers, and relevant stakeholders, beyond their sectoral boundaries.

Concluding remarks

Multiple-use spatial planning offers a promising pathway for achieving the ecological, economic, and social goals outlined in the GBF and SDGs. Despite the complexities of integrating multiple sectors – due to a wide range of methods and sometimes inconsistent terminology – a suite of approaches exists to facilitate systematic, effective and transparent multiple-use planning. These approaches differ in data requirements, complexity, and specificity in integrating sectoral objectives.

Future research could focus on improving the accessibility of multiple-use spatial planning approaches (see Outstanding questions), alongside developing methods for quantifying costs and benefits of multiple uses. Expanding the scope of multiple-use spatial planning to include economic and social impacts will increase its relevance to stakeholders and policymakers. Ultimately, collaborative efforts are essential to ensure that advances in multiple-use spatial planning align with real-world decision-making.

Outstanding questions

Despite multi-objective optimization providing a comprehensive way to balance competing priorities, it remains technically complex. How can multi-objective optimization approaches be made more accessible to spatial planners?

Effective multiple-use spatial planning – especially multi-objective optimization – requires acknowledging and managing trade-offs, which can be challenging in practice. How can we better integrate trade-off discussions into spatial planning to ensure meaningful and practical optimization outcomes?

Spatial plans often assume static conditions, yet economic, ecological, and social factors evolve over time and are not reflected in planning scenarios. What methods can address the temporal dimension of multiple-use spatial planning?

Enhancing tools with new functionalities to reflect complex planning problems can improve decision-making but increases complexity, making them more difficult to use and their outputs challenging to communicate. Can we develop spatial planning tools that better balance functionality, usability and communication?

The coexistence of multiple uses presents both conflicts and opportunities. Conflicts arise when spatial allocations negatively impact adjacent activities, while synergies emerge when shared spaces support multiple objectives. What are the most effective strategies to identify conflicts and synergies among multiple uses and incorporate them in spatial optimization?

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Declaration of interests

The authors declare no competing interests.

Resources

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

[ii] https://marxanplanning.org

[iii] https://ncc.carleton.ca

[iv] https://mathmarecol.shinyapps.io/WSMPA2/

[v] www.ppgis.net/

[vi] https://unbiodiversitylab.org/en/

[vii] www.natureserve.org/products/natureserve-vista

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