ECOLOGY



# Regional scalable priorities for national biodiversity and carbon conservation planning in Asia

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**To achieve the goals of the post-2020 global biodiversity framework, we must identify representative targets that effectively protect biodiversity and can be implemented at a national level. We developed a framework to identify synergies between biodiversity and carbon across the Asian region and proposed a stepwise approach based on scalable priorities at regional, biome, and national levels that can complement potential Convention on Biological Diversity targets of protecting 30% land in the post-2020 global biodiversity framework. Our targets show that 30% of Asian land could effectively protect over 70% of all assessed species relative to only 11% now (based on analysis of 8932 terrestrial vertebrates), in addition to 2.3 to 3.6 hundred billion metric tons of carbon. Funding mechanisms are needed to ensure such targets to support biodiversity-carbon mutually beneficial solutions at the national level while reflecting broader priorities, especially in hyperdiverse countries where priorities exceed 30% of land.**

## INTRODUCTION

The year 2021 will provide several unique opportunities to put the world on a path to a more sustainable future. Meetings scheduled for 2021 include the Convention on Biological Diversity (CBD) COP15 (www.cbd.int/cop/), the International Union for Conservation of Nature (IUCN) quadrennial meeting (www.iucncongress2020.org/), and the 26th Conference of the Parties of United Nations (UN) Framework Convention on Climate Change (COP26: unfccc.int/cop25). These meetings (and the meetings associated with CBD) will include discussions on setting a global target of protecting 30% of the planet by 2030 (*1*, *2*) and encouraging more ambitious global targets, for example, conserving half the planet (*3*–*5*), to effectively and representatively conserve species. At CBD-COP15, the parties must agree on a post-2020 global biodiversity framework to replace the Strategic Plan for Biodiversity (including the Aichi Biodiversity Targets) for the 2011–2020 period. At COP26, each country needs to strengthen their voluntary "Nationally Determined Contributions" (NDCs) to combatting climate change as a critical component of the Paris agreement. Thus, developing synergistic targets with benefits for both COP15 and COP26 commitments would maximize positive outcomes (*6*), and mechanisms to better integrate NDCs into National Biodiversity Strategies and Action Plans (NBSAPs) such as the use of Long-Term Low Emissions Development Strategies are currently being considered (*7*).

Landscape and vegetation (especially forest) management constitute a substantial component of NDCs, and identifying complementarities provides the basis for future targets (*8*). Analysis shows that while Global Environment Facility (GEF)–funded work frequently includes carbon storage (*9*), NBSAPs rarely mention it (*10*). Unfortunately, a mismatch between biodiversity and carbon priorities can harm biodiversity conservation efforts (*11*, *12*). Yet, studies investigating potential carbon-biodiversity synergies across a range of scales (*13*) have demonstrated that carbon conservation can be incorporated into biodiversity conservation planning to maximize co-benefits (*14*). As such, it is timely to generate an implementable framework so that nations can identify such synergistic priorities of biodiversity and carbon and develop complementary outputs highlighting shared goals and targets, to make better use of available funds that aim to meet both climate and biodiversity goals, and to be implementable at the national level.

There are already various assessments of global conservation priorities, such as exploring habitat intactness and developing priorities for different taxa and mechanisms to expand protected area networks to more representatively conserve biodiversity (*15*–*18*). However, developing optimal conservation targets and strategies requires an understanding of how components of the methods influence the outcomes. In many assessments, the choice of scale and variable selection impact on resultant priorities are frequently unclear (*19*). For example, known biodiversity hotspots overlap with carbon storage hotspots for 38% of cases and only 5% with hotspots for restoration (*14*). Yet, how these overlaps change across different scales and at different resolutions is not known, despite clear impacts of the effect of the scale used for analysis (*20*) and methods used to delineate between regions (*21*).

Comparatively few studies have looked at the development of scalable priorities, which can translate broad-scale priorities into implementation at the national scale and are ecologically representative. Furthermore, we must understand how regional, ecologically representative, and national targets can work in synergy to provide a nested approach with complementary targets to give adequate coverage for biodiversity at all scales and how they can be implemented at a national scale. Thirty percent has been suggested as a protected area target for the post-2020 global biodiversity framework (*1*, *2*) and is expected to be implemented at the national level

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despite the unequal distribution of global biodiversity (*19*). Understanding where the 30% national level target may be insufficient to provide coverage of key regions for biodiversity is critical, highlighting when additional funding and further mechanisms may be necessary to provide adequate coverage of biodiversity.

Most countries set conservation priorities at a national or subnational scale, and national reports rarely mention regional or global targets and indicators (*22*). Unfortunately, the summed national priorities for multiple separate countries may miss key areas for biodiversity, especially in the most diverse regions where providing adequate coverage of different species and ecosystems or low-diversity biomes but with unique species may be challenging (*23*). As part of this effort, it is vital to look for synergies across scales, identifying overlaps and differences, to enable effective policy decisions necessary for implementing frameworks such as the 2030 Agenda for the Sustainable Development Goals or post-2020 global biodiversity framework. Here, we build on what has been learnt in other assessments, explore effective and scalable conservation prioritization for biodiversity, and identify possible co-benefits such as carbon storage while minimizing trade-offs where possible to identify and maximize synergies across scales. Furthermore, such targets align not only with the 2030 mission (which is widely supported through the 50 countries of the High Ambition Coalition and aims to protect 30% of the planet by 2030) but also with the UN decade of restoration. These targets have widespread support (*24*), but how effective these area-based targets are and how their impact could be maximized requires further analysis.

Asia stands out as a global priority for urgent conservation action based on both diversity and rates of habitat loss (*25*). The region hosts many of the most biodiverse and ecologically threatened countries on Earth (*26*), more than half the world's population (*27*), and is the source of almost 40% carbon emissions (*28*). Yet, despite these growing human pressures, the Asian region includes 10 of the global top 35 biodiversity hotspots, but only around 9% of land area is protected (*29*, *30*). It is a hotspot of threat for many taxa (*31*) and has some of the world's highest rates of deforestation (*32*). Commodity-driven deforestation in Southeast Asia was one of the largest sources of gross forest-related emissions over the last 10 years (*33*–*35*), which is significant given that tropical deforestation accounts for up to 25% of global emissions (*36*, *37*). Thus, aligning carbon and biodiversity targets has the potential for mutual benefits, and failure to utilize this opportunity may inadvertently lead to perverse incentives, which may drive biodiversity loss (*38*). This region represents a major challenge and priority for global conservation. Asia is the ideal test case for the ability of a framework to identify scalable priorities and synergies across a heterogeneous and complex region, in addition to being a region in urgent need of such an approach. It allows us to explore the ability of this framework to adequately encompass the different facets of regional diversity across diverse ecosystems and taxa.

This study aims to develop a framework to enable two goals. The first is that conservation priority planning at a national scale should be representative of biodiversity across the broader region and synergize climate and species conservation goals to maximize the effectiveness of the 2030 mission and 2050 vision and the mandate of the post-2020 global biodiversity framework. Second, the framework should be capable of identifying priorities at each scale (regional, biome, and national), which, when examined in synergy, could form targets for the post-2020 global biodiversity framework while still enabling action at a national scale. Here, we use terrestrial vertebrates to develop a framework to meet these goals and then assess the ability of this framework to develop effective and practical targets for conserving species and carbon through ranking scalable priorities to provide adequate coverage across ecoregions.

## RESULTS

### Priorities for biodiversity and carbon

Here, we use species richness as a surrogate for biodiversity and explore its representativeness for species and ecoregions. Species richness analysis could only be conducted on vertebrates as representative and comparable data do not exist for most plant and invertebrate groups or even for most aquatic vertebrate species. Distribution of priorities defined as top 30% hotspots varies for each metric and scale, with both synergies and trade-offs between priorities for biodiversity and carbon (Fig. 1 and figs. S1 and S2), with regional-scale hotspots emphasizing the importance of tropical forests, especially in Southeast Asia (Fig. 1A). The impact of biogeographic zones in priority setting should also be accounted for, especially in complex regions such as Southeast Asia, where high species turnover in certain regions (e.g., across biogeographic divides) should also factor into targets (fig. S3).

Carbon hotspots fall predominantly in the North and rarely match biodiversity hotspots (fig. S1, A to C), but alignment increases at lower latitudes (Fig. 1), especially at the regional scale (Fig. 1D). This indicates that areas of highest species richness that generally fall into the rainforests of Southeast Asia have high potential for carbon storage. However, patterns vary depending on the relative weighting of biodiversity and carbon in synergies (fig. S3). Furthermore, this shows that few biodiversity hotspots outside synergies are currently protected and that even synergies are vastly underprotected across the region (Fig. 1). The importance of carbon reserves in countries such as India and China are only evident at national- or biome-scale analysis, but they are not comparable with the carbon hotspots in Russia when examined on a regional scale (Fig. 1, A and D, and fig. S1).

### Developing scalable priorities

To develop priorities that maximize protection of biodiversity and carbon, we first highlight regional priorities (to maximize carbon and the number of species afforded coverage), then combine biome priorities (for ecological representativeness and diversity breadth), and finally add national priorities as First, Second, and Third Priority Targets, respectively. Where regional priorities within a country exceed 30% of land, areas overlapping between regional and biome priorities should be prioritized to maximize the benefits across species and ecosystem dimensions.

For biodiversity, 41% of priorities overlap between all three scales (Fig. 2A), and priorities under the First Priority Target (all regional priorities—30% of the total area) overlap 46% with the biome scale and 55% with the national scale. Complemented by the Second Priority Target of additional biome priorities that include a further 24% of the total area, as well as various dry and cold areas not included in regional priorities (e.g., West Asia and China-India borders) where diversity may be lower, but unique communities occur. Last, the remaining national priority areas from the Third Priority Target (all three scale priorities combined) show an additional 7% of total priority area, which does not co-occur with other scales.

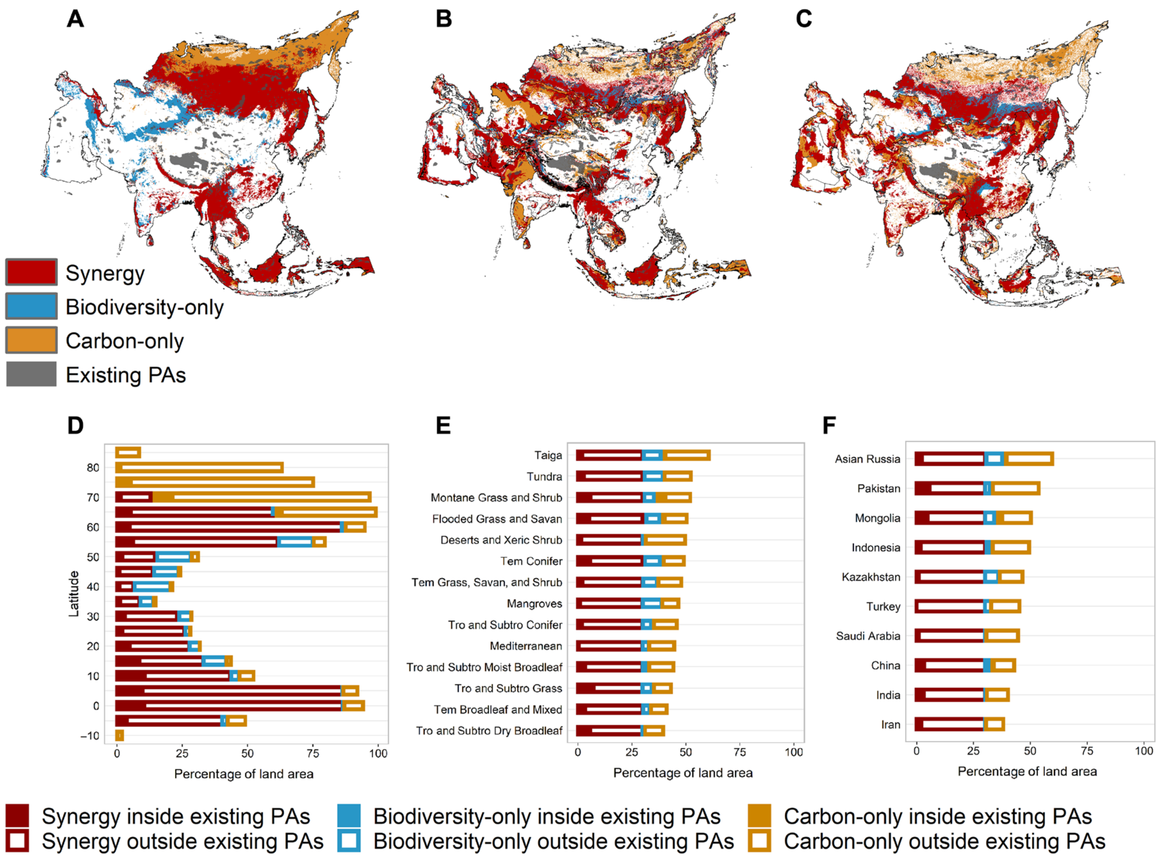


**Fig. 1. The priorities of biodiversity-only, carbon-only, and synergy of both at three scales.** Areas in gray are existing protected areas falling outside the priorities at (**A**) Asian regional, (**B**) biome, and (**C**) national scales, respectively. The synergistic-target priorities are based on the 50% richness as a mask to extract the highest combined values of richness and carbon clipped to 30% land area. Bar charts show the percentages of biodiversity orientation (blue), carbon orientation (orange), and synergy (red) in (**D**) latitudinal, (**E**) biome, and (**F**) national areas, respectively. Hollow bars show priorities outside the current network of protected areas for biodiversity-only (blue), carbon-only (orange), and synergy (red), which could be suitable expansion for new protected areas and focused on each conservation action. See table S1 for the corresponding biome names and their abbreviations. Only the top 10 countries containing the priority area of three metrics are shown in the bar charts at the national scale.

For carbon priorities (Fig. 2B), 25% of priorities only existed at a regional scale and do not overlap with other scales. These regional carbon priorities fall largely in the North, with temperate and boreal forests hosting more carbon but less diversity than tropical forests. Biome scale is more representative, having the largest overlaps (31%) with national scales. National-level analysis also shows a high percentage of unique priorities (not overlapping with other scales) at 20%, with the majority of the additional area by the Third Priority Target falling in the Arabian Peninsula, India, and southern China.

For synergies, 17% of regional priorities do not overlap with other scales. Priorities that overlap between regional and biome highlight the most important areas for biodiversity and carbon synergies, with many falling along the Russian southern borders with Kazakhstan, Mongolia, and China and tropical rainforest in Southeast Asia (Fig. 2C). There is high congruence between biome and national scales with the largest overlap (42%), with only 10% of the remaining unoverlapping national areas contributed by the Third Priority Target.

## Collaborative efforts needed to scale priorities and protect biodiversity

To assess the representativeness of priorities highlighted in our approach, we explored how these priorities overlapped with ecoregions and species ranges. The percentages of both priorities (Fig. 3A) and protection gaps (Fig. 3B) differ strikingly among ecoregions and biomes (table S1).

Almost all the ecoregions (276 of 283 ecoregions) are included in our priorities except some tundra, deserts, and small areas of forests (table S1). Percentage priority coverage in each ecoregion increases from low in cold and dry ecoregions to very high in tropical ecoregions. The greatest gap for priority protection is northeast India–Myanmar pine forests (100% priority, 0% protected), followed by southwest Arabian montane woodlands and grasslands (99.85% priority, but only 0.11% protected). Moreover, intact and disturbed priorities are unevenly distributed at the ecoregion level (Fig. 3C), with more than 50% of priorities in some ecoregions (e.g., Lower Gangetic Plains moist deciduous forests) falling in agricultural areas (table S1). For areas noted as in need of sustainable management and restoration, species present in these areas have insufficient range area within intact habitats for effective protection (defined as a species reaching its area-based target; see Materials and Methods), and thus management and restoration of these agricultural regions are critical in such cases.

The current protected areas are only able to meet area-based conservation targets for 20% of mammals, 12% of birds, 10% of

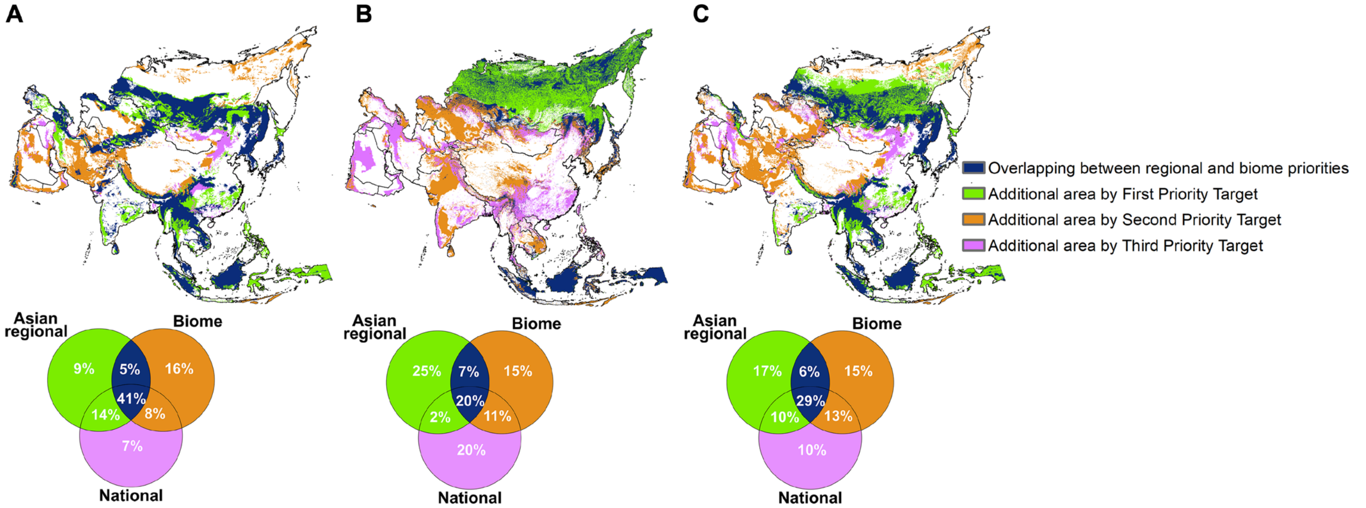


**Fig. 2. Divergence and convergence among priorities determined at three spatial scales for different conservation targets.** (**A**) Biodiversity conservation target. (**B**) Carbon storage conservation target. (**C**) Synergy of biodiversity and carbon conservation target. The area under the First Priority Target (regional priorities) is shown in green and dark blue, the area complemented by the Second Priority Target (regional and biome priorities combined) is shown in orange, and the area complemented by the Third Priority Target (all three scale priorities combined) is shown in purple. The most important areas overlapping with regional and biome scales are shown in dark blue, and Venn diagrams show the percentages of overlapping areas among three scales.

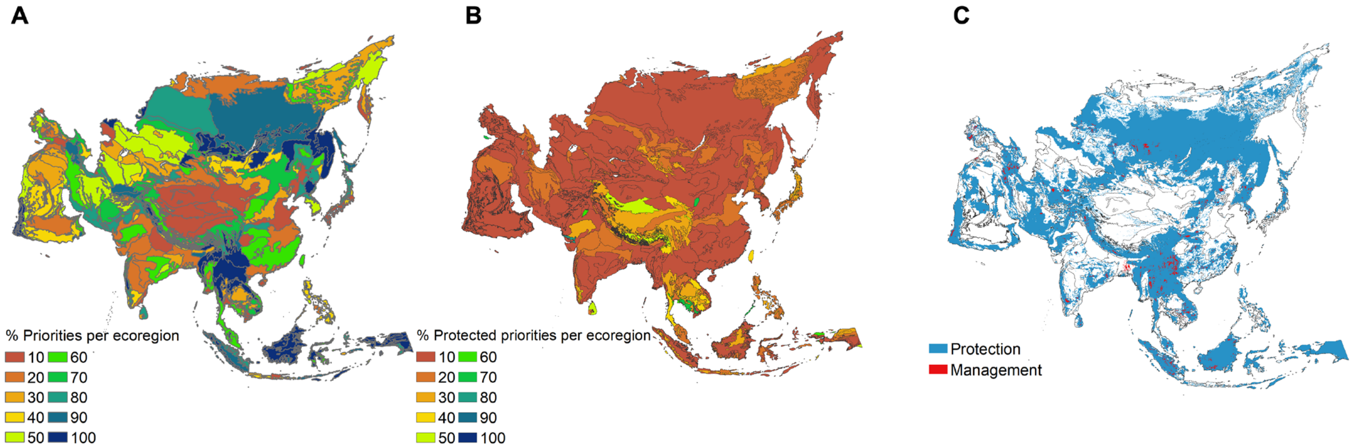


**Fig. 3. The percentages of multiscale priorities and protection status in each ecoregion.** (**A**) Percentage of each ecoregion covered by priorities based on the total area of the three scales combined (yellow to red represents less than 50% priority, and green to blue represents more than 50% priority). (**B**) Percentage of priorities protected by existing protected areas in each ecoregion (yellow to red represents less than 50% protected, and green to blue represents more than 50% protected). (**C**) The multiscale priorities that fall into intact area and require protection (blue) and those falling into human modified areas that require sustainable management and restoration (red).

reptiles, and 8% of amphibians (Fig. 4). Regional priorities have the highest potential to protect species and carbon and, if protected, would increase the percentage of amphibians protected to 84% (increasing current levels by 76%), 79% (+59%) for mammals, 70% (+58%) for birds, and 61% (+52%) for reptiles. Reptiles show particularly high potential gains in critically endangered species if priorities are protected. Although regional priorities provide coverage for the greatest number of species, biome delineation is more effective for carbon priorities. What is also notable is that though current protected areas only include 9% of carbon stock, if we include the synergy priorities, it increases by 30 to 46% (depending on which scale is used).

To assay the percentage of land area in need of protection, Asian countries were divided into four categories based on the percentage of their area prioritized under each target (Fig. 5). All synergy priorities combined under the Third Priority Target almost match the Half-Earth target at 48% of land area and would effectively protect 83% of all assessed species. Many Southeast Asian countries would need to expand protected area networks to more than 50% of the national land area under the First Priority, with countries such as Brunei and Laos requiring protection of more than 90% of their area (fig. S4A). Small countries (e.g., Timor-Leste, Kuwait, and Israel) increase priorities from less than 5% of the national area under the First Priority Target to more than 50% under the Second Priority Target (dryer biomes). These represent biomes that have little representation elsewhere and effectively cover 10% of all species. Meanwhile, most countries have most of their key areas outside protected areas. The top five countries (Asian Russia, China, Indonesia, Kazakhstan,

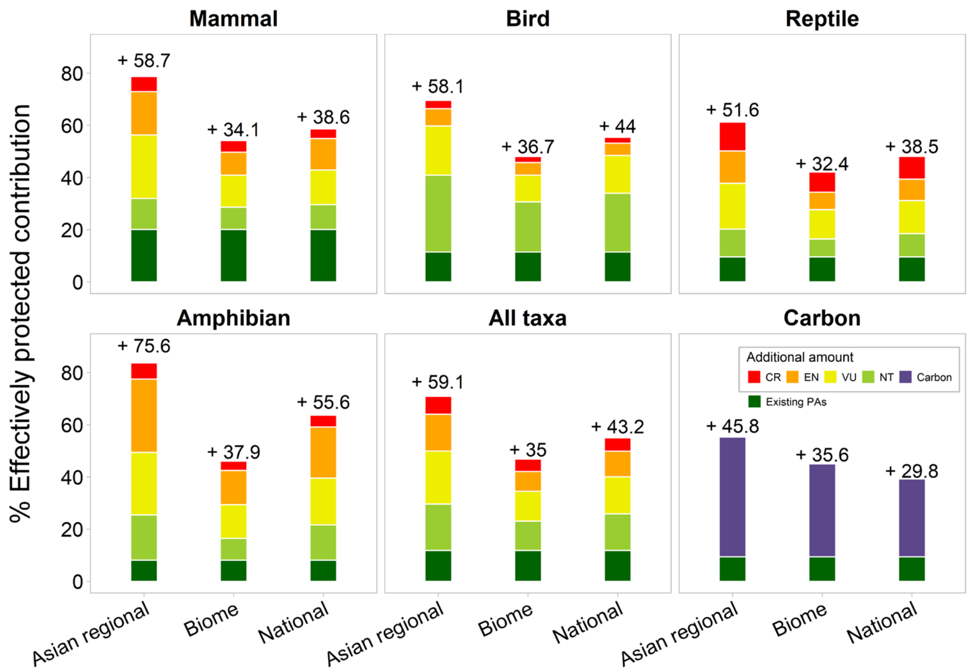


**Fig. 4. Variation in species coverage across taxa and carbon storage with existing protected areas adding synergy priorities identified at three scales: Asian regional, biome, and national, respectively.** Effective protection means the representative vertebrates achieved the area-based target (see Materials and Methods). The numbers above bars are the additional percentage of species achieving the target of effective protection for each taxonomic group and IUCN threat category (CR, critically endangered; EN, endangered; VU, vulnerable; NT, near threatened) as well as protection potential for carbon storage after adding synergy priorities.

and Iran) with the largest expansion potentially contributing 63% of the Asian priorities outside existing protected areas and effectively protect 52% of Asian species under the Third Priority Target. Indonesia had the greatest number of threatened species, but only 6% are protected by existing protected areas, with the largest increase of species protection (57%) by the expansion of the First Priority Target, 6% increase by the Second Priority Target, and no additional protection by the Third Priority Target (fig. S4B). Some other tropical regions show similar patterns (i.e., Philippines, Sri Lanka, Vietnam, Malaysia, Thailand, and Laos) as all of these include diverse tropical forest. Although the priorities of the First Priority Target are insufficient to entirely prevent extinction caused by habitat loss and degradation, they perform very well at effectively covering most species especially in diverse countries. Birds and reptiles have larger effective protection increments (8 to 10%) than the other two taxonomic groups by expanding the area under the Second Priority Target.

### Determining appropriate modes of conservation and restoration

While ambitious plans to protect biodiversity could protect most of the species based on priorities highlighted here, some of these priorities fall into agricultural and highly disturbed regions (Fig. 3C). At a biome level, Mediterranean forests, woodlands, and scrub are most in need of restoration or sustainable management with 20% of priorities falling in degraded areas (and only 2% are protected), followed by tropical and subtropical dry broadleaf forests with 9% (and 18% protected) (table S1). Ironically, the rock and ice biome was the best protected at 36%, which predictably needed almost no restoration. It should also be noted that many ecoregions have already lost huge amounts of their area; for example, in tropical and subtropical dry broadleaf forests, only 29% is intact despite 20% of synergy priorities falling within this biome.

In total, 20 ecoregions show at least 10% of their priorities to be in need of sustainable management and restoration, with 10 ecoregions at 20% and 3 ecoregions at more than 30%. The two ecoregions in greatest need of restoration or sustainable management are the Lower Gangetic Plains moist deciduous forests with 51% of priorities falling into agricultural areas (with only 6% protected) and Sundarbans freshwater swamp forests with 40.5% (entirely unprotected). The Irrawaddy dry forests also showed 31% of priorities in degraded areas (0.2% protected), while Tonle Sap freshwater swamp forests have 28% of priorities in degraded areas (although 67% of the area is protected).

Many ecoregions and biomes have a disconnect between their importance for biodiversity and currently protected areas. Tropical and arid landscapes across this region, especially in South Asia, have particularly large areas in need of restoration and sustainable management, some of which have no protection at present. At a country level, Lebanon, Singapore, Bangladesh, and Cambodia have particularly large priority areas in such need (fig. S5). Contrastingly, only a few generally small countries have most of the priorities protected; while priorities shown here provide a good coverage across ecoregions, few are currently protected (Fig. 3).

## DISCUSSION

Translating high-level targets into practical and implementable approaches that can be applied at a national level is challenging. There is an urgent need for national and regional planning frameworks to enable effective target setting to bridge the gap between the aims of

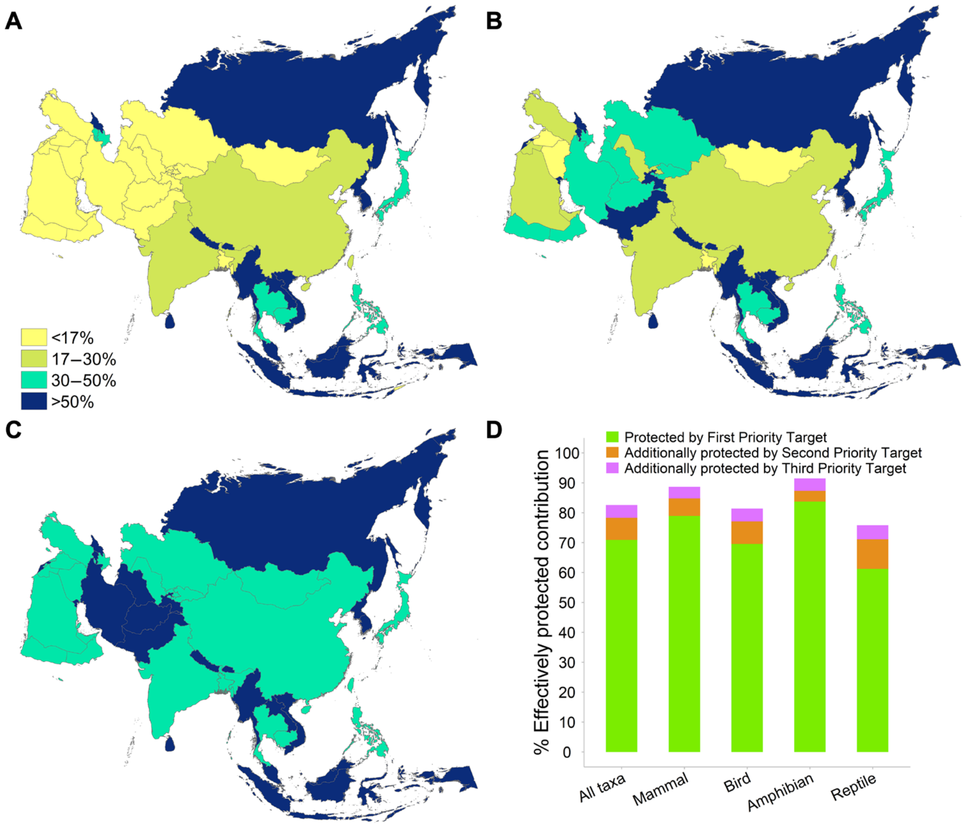


**Fig. 5. Different percentages of priorities in each country under three conservation targets.** Asian countries are divided into four categories according to percent area to be protected at (**A**) First Priority Target, (**B**) Second Priority Target, and (**C**) Third Priority Target, respectively. (**D**) Bar charts show the accumulated effectively protected contribution to each taxonomic group after adding priorities of three conservation targets in a stepwise manner.

targets and their effective fulfilment. Our results show that different scales have very different outcomes in generating priorities, and these have a fundamental impact on their abilities to identify areas that effectively protect biological diversity.

By producing a multiscale framework to enhance target setting that incorporates local to regional synergies of biodiversity and ecosystem services, we can map common goals and relate them to national and regional approaches to achieve the CBD's 30% protected area target while also meeting climate targets. Targets of 30 and 50% global protection have been called for by a number of sources [e.g., (*2*, *4*, *5*, *39*–*44*)], but understanding what is actually optimal requires understanding the trade-off between different percentages of protection and their efficacies, representativeness, and how optimal targets may vary in different countries and regions. Our synergistic-target maps at all scales do show that 30% of the area represents an effective solution for conservation of the majority of species (Fig. 4) but is not enough in megadiverse countries.

Targets cannot merely focus on conserving global or regional level hotspots, and including biome scale within our framework provides coverage of different communities as some ecosystems naturally host fewer species, but should still be incorporated into conservation targets to maximize representation of species and taxa. Given that most ecosystems are not well mapped, providing alternate methods to identify and protect representative regions for conservation is crucial to develop effective targets, which is challenging without standardized methods to analyze biodiversity data. The successor to Aichi Target 11 should ensure new protected areas in representativeness using approaches such as those detailed here. Thus, here, we assess the potential gains in species coverage and ecoregion coverage, which could result from using these approaches to generate national targets for future conservation.

### Performance of priorities of different scales

While Aichi Target 11 is regarded as the most successful Aichi target (*10*), the specifications aiming at representativeness are often overlooked. No framework has been widely implemented or created to translate priorities into actions that are both representative regionally and can be implemented feasibly at the national scale (*16*). Our analysis highlights the idea that regional and biome priorities can help set appropriate national conservation targets to facilitate decision-making in national conservation actions (Fig. 5). Likewise, priorities could be generated at subnational levels through the direct incorporation of subnational units, ecosystems, or ecosystem typologies (*45*, *46*) based on the same framework. However, the Asian region is too heterogeneous to have a coherent centralized outlook; expanding regional conservation cooperation into subregions could be far more effective. Thus, regional-scale endeavors would be facilitated by more autonomy of subregions as recognized by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) within UN processes, such as the Association of Southeast Asian Nations (fig. S3D).

Yet, because of the uneven distribution of biodiversity, the appropriate threshold for how much is needed to conserve different proportions of biodiversity varies across scales, and the percentage of the region in need of protection does begin to plateau after 30% protected at a regional scale (fig. S6). A much higher percentage is needed if based on biome or national levels since there is huge variability between each level. Therefore, while a 30% target could provide protection for the 71% of all assessed species across the region, megadiverse countries such as Indonesia require disproportionate levels of protection (fig. S4). Synergies noted here would provide protection for most of the species in addition to 2.3 to 3.6 hundred billion metric tons of stored carbon across these regions if they are protected (Fig. 4 and fig. S7), yet few such areas are currently protected.

### Finding synergies between biodiversity and carbon priorities

Exploring possible co-benefits for prioritizing carbon and biodiversity hotspots can both enable the fulfilment of climate targets and facilitate conservation, when done cautiously to prevent conserving carbon-rich areas at the expense of biodiversity. Prioritizing and restoring tropical forests for climate targets could provide dual benefits for carbon and biodiversity. Within this analysis, the demonstration on a regional scale that greatest synergies occur in the South suggests that GEF and other relevant funds could be allocated to regions that provide the highest co-benefits between biodiversity and carbon or other ecosystem services.

Carbon-only priorities based on the least-cost methods may miss both biodiversity and synergy hotspots and may actively fuel the plantation of monocultures at the expense of native systems (*47*, *48*). Studies illustrate that less diverse forests may be less effective at mitigating against climate change than diverse forests especially in seasonal systems (*49*–*51*). Similarly, studies also show that degraded tropical forests often have a reduced ability to store and sequester carbon (*44*, *52*); thus, biodiversity-carbon synergies are crucial to reduce negative trade-offs. Furthermore, explicitly referencing function and intactness should be a core specification within No Net Loss (NNL) (*53*–*55*). NNL goals should include adequate representation of biodiversity using frameworks like this and prevent the equation of native forests and tree monocultures in targets.

Therefore, efforts targeted at mitigating climate change and biodiversity not only are more effective but also benefit conventions such as the CBD and complement the Paris agreement to be delivered effectively (*56*). Examples of this can include nature-based solutions and REDD+ that aim to fund synergies between biodiversity and other initiatives such as climate mitigation (*8*, *57*). To advance on Paris Agreement NDCs, for example, China is aiming to "have $CO_2$ emissions peak before 2030 and achieve carbon neutrality before 2060." Thus, there is an urgent need to identify synergies for biodiversity conservation and carbon as a basis for action. Such frameworks can also assess the degree to which key areas are already protected as a first step toward effective targets. This is especially important in a region such as Asia, where tree plantation is a major driver of loss of natural forests (*58*), making the region especially vulnerable to measures that mitigate climate change at the expense of native biodiversity and highlighting the need to protect existing priorities before planting new "forests" for biodiversity and carbon gain. The preferential treatment of unprotected existing native areas, especially old-growth forest, should be the highest priority for climate and biodiversity efforts.

### Setting new targets

Existing protected areas only cover around 9% of the Asian region and provide effective protection for less than 10% of amphibian and reptile species (Fig. 4 and fig. S7) as their hotspots are almost entirely unprotected (fig. S8), as are the majority of ecoregions (table S1). The need for more inclusive indicators of biodiversity has been demonstrated for a number of taxa (*59*, *60*). The targets proposed here would reduce the imbalance in the lack of protected area coverage for amphibians (only 8% currently) and potentially provide a coverage similar to that of mammals, providing effective protection for 84% of amphibians and reptiles (with increases up to 76%; 363 amphibian and 482 reptile species: Fig. 4).

Countries generally protect sparsely populated, arid, and high-altitude biomes much more than those that face higher pressures for productive land (such as lowland habitat) (*61*), yet our restoration targets also highlight the fact that agricultural landscapes cannot be ignored in conservation plans to provide effective protection for all species (*62*). Expanding from existing protected areas without an empirical basis to identify key areas may misdirect conservation targets and encourage the expansion of protected areas into places with low human impact, or similar communities to those already effectively protected, but which achieve little extra biodiversity protection; thus, including multiple metrics can generate more effective priorities.

When countries select 30% of their land area for protection, priorities should be identified by first prioritizing global priorities, followed by continental (regional) and then biome priorities. Regional priorities were used as the first priority as they have the highest conservation efficiency of species and carbon per unit area, whereas biome priority represents ecoregion conservation and thus increases representativeness and diversity. When less than 30% of a country's area falls into broader-scale priorities, then national priorities should be used to reach the national 30% target. When broad-scale priorities exceed 30% of national land, then overlap area between broad-scale priorities should be top prioritized to maximize the number and diversity of species protected. For example, Indonesia has 70% of land within unprotected regional priorities, but it would be impossible to protect such a large percentage of the country. Thus, in a case like Indonesia, we can optimize the approach by protecting the overlapping area of regional and biome priorities, consisting of 41% of the national land area; thus, by using such a ranking approach, we can maximize the diversity that can receive effective protection per unit area.

However, species richness alone does not account for other measures of endemism or evolutionary distinctiveness. While our priorities do capture hotspots of endemism (e.g., Bi Doup, Ha Giang, and Lao Cai in Vietnam and Kanchanaburi in Thailand), unique ecosystems such as these require additional consideration, such as inclusion of the red list of ecosystems or ecosystem typologies to ensure representative protection coverage. It should also be noted that, even when implemented, measures of protected area effectiveness and monitoring are still needed and are lacking for the majority of protected areas across the Asian region (https://pame.protectedplanet.net/) (*63*, *64*).

Our analysis demonstrates that current protection across Asia is neither comprehensive nor representative. Diverse ecoregions frequently have the greatest protection gaps in what percentage of the priorities are protected; West Asia and South China show notable gaps between protection and priority, as do areas of India that are also in need of sustainable management and restoration with many priorities falling within agricultural areas (Fig. 3B and table. S1). Such areas correspond to cities and farms, condition 1 of the three global conditions (*65*). In the most heavily transformed condition 1 areas, setting a target such as restoration of 20% of native vegetation cover is more realistic than a significant protected area percentage target but would still help biodiversity and carbon goals and provide other valuable ecosystem services (*66*). Tropical diverse systems are often the least protected despite both high species richness and high rates of turnover (table S1). Our analysis highlights the additional area required to effectively conserve species across most tropical Southeast Asian countries, but this may be especially challenging to achieve given the high rates of habitat loss unless special efforts are made to reverse these trends (*59*).

For the global biodiversity framework to provide an effective mechanism to effectively conserve biodiversity and minimize rates of species loss, frameworks are needed to identify and fund the conservation of these areas, in addition to ensuring that once established protected areas effectively combat biodiversity loss. Such mechanisms would need to provide financially viable means to enable countries to develop without the continued loss of natural ecosystems and species, such as capacity building to increase efficiency in existing sectors or developing modes to pay for the provision of ecosystem services. In addition, certification schemes could be developed to boost profitability of more sustainable and low impact modes of development, especially where Western buyers may be prepared to pay a premium for such goods (*67*, *68*).

Human needs cannot be neglected if conservation is to be effective, and other mechanisms that enable conservation such as targets for natural habitat within working landscapes (*66*) must also be considered. Human needs and commodity production must be integrated into solutions, and to conserve some species, ensuring their survival requires maintaining populations and reconnecting fragmented habitats within agricultural areas. Targets should also recognize and reflect the three global conditions (*65*), developing financially viable ways to conserve and restore key regions. Priorities highlighted here have the potential to provide effective coverage of species ranges and, if integrated into national and regional planning frameworks such as China's ecological conservation redlines, provide a useful mechanism for reducing future biodiversity loss in the face of rapid rates of habitat loss and degradation (*59*, *69*). These priorities include those in intact landscapes to be protected and those to be sustainably managed or restored (based on areas where species are only found in agricultural areas). Areas to be restored make up 2.3% of all priorities, with the largest areas (73%) falling in Lebanon (fig. S5) and parts of South Asia, which provide ideal areas for reforestation as part of climate action priorities in the UN Decade of restoration. These disturbed priority areas are relatively small, and targeting efforts to sustainably manage and restore them provide a unique opportunity to target climate change mitigation efforts in areas where they may have the greatest benefit to biodiversity.

Mechanisms for conservation across diverse and working landscapes, such as other effective area-based conservation measures (OECMs), need to be developed, especially given that commodity extraction in Asia is one of the major drivers of continued regional habitat loss (*59*) and agricultural areas cannot be overlooked in effective regional conservation efforts. A lack of funds should be highlighted as a major barrier to complete completing conservation targets; thus, both additional funding from central bodies such as the GEF and stakeholders across multiple sectors (such as the private sector) are needed for regions where priorities exceed 30% of the national land area, including the development of supplemental frameworks, to provide alternate means of funding to support the protection of these areas over a longer term (*70*). Furthermore, enhancing awareness of the need for better synergies can reduce perverse incentives and ensure that targets from various UN conventions are implemented in a complementary manner and reduce trade-offs wherever possible, such as the synergistic priorities shown here.

### Making targets work

At the end of a "decade of biodiversity," we have continued on a trajectory of global biodiversity loss, and maintaining "business as usual" means continuing this trend. Yet, a focus on area-based targets without mechanisms to ensure quality and representativeness has been shown to have perverse outcomes for biodiversity (*71*). We must ensure that the decade of ecosystem restoration ahead has a greater positive impact on biodiversity and that this restoration is targeted at areas with the greatest potential for biodiversity gains. The challenges associated with balancing priorities has been noted (*42*), yet limited guidance is available on the mechanisms needed to translate carbon and biodiversity priorities to national-based targets or explore the cross-scale synergies and representativeness on larger (such as regional) scales.

Our second aim is more challenging, as many regional priorities fall outside national priorities in biodiversity hotspots and greatly exceed a 30% threshold, showing that a uniform 30% target is not sufficient in high-diversity countries (Fig. 5), and optimizing priorities should be a core part of NBSAPs. Our framework for ranking prioritization also makes the implementation on national conservation goal of individual countries more feasible and practical, scaling targets to maximize species coverage while implementing at a national scale. For countries where more than 30% of the country falls within regional or biome priority, additional methods, funds, and support from bodies such as the GEF are needed.

However, our framework was based on a subset of vertebrates, and ideally, such analysis should take account of a more diverse range of taxa, necessitating the development of standards and guidelines for how data used to develop NBSAPs are collected and made available. Given the diverse range of life-history strategies shown by the taxa included here, it is likely that adding further species would not cause significant changes in priorities identified (especially given that diversity in many of these taxa may directly relate to plant diversity), but better data across taxa are still needed for better targeted conservation strategies. The standardization of NBSAP data collection would enable comparable analysis across regions and taxa, and funds are already made available to help countries develop these assessments as necessary. While priorities outlined here provide useful targets for conservation, such data would enable better data for monitoring, calibration, and testing of these targets and ensure that they are scalable and ecologically representative.

Mechanisms could include additional funds to help develop alternative livelihoods and facilitate modes of sustainable development and technology transfer that enable land sparing, in addition to green finance policies, green bonds, and financial regulations. Such sustainability and "climate-focused" initiatives must target synergies between biodiversity and carbon and avoid protecting carbon-only priorities where they fall in low-diversity areas. Targeted programs prioritizing economically viable ways to reduce pressure on remaining habitat and transition away from unsustainable development and subsidizing the implementation of such approaches may provide viable long-term solutions to both maximize carbon storage and prevent the loss of biodiverse ecosystems, which may otherwise be converted into commodity production.

### Synthesis

Using a framework such as that used here can provide the scalability needed to ensure representative targets that both work to protect regional biodiversity and reduce climate change while still being applicable at the national level (fig. S9). As priorities determined at different scales vary, obtaining maximum representation of species and carbon for targets requires prioritization of regional targets followed by biomes, before incorporating national-level priorities. While 30% of land can protect up to 71% of species in the region overall, this would require considerably larger areas for the most diverse countries such as Indonesia (Fig. 5). The Half-Earth target can increase the number of effectively protected species to 86% of species at a regional level (fig. S10). These regional priorities, however, are difficult to accomplish given the large areas required within some megadiversity countries. Using this scalable approach, the proposed protected area will be expanded from 30% land area under the First Priority Target to 48% under the Third Priority Target. The excessive conservation pressure on megadiversity countries is thus reduced, and conservation goals are more practicable in such countries. Moreover, for hyperdiverse countries, developing priorities based on overlap between scales provides a pragmatic approach to maximize effectiveness in the smallest area possible.

To provide effective and achievable goals for the CBD and stem biodiversity loss, additional financially viable mechanisms are needed to enable conservation in larger areas in hyperdiverse countries where 30% of land is insufficient to provide effective protection for native biodiversity. Biodiversity and climate funds should be used preferentially within such regions and mechanisms developed to ensure that complementary targets can heighten funds available to support conservation and improve storage ability through nature-based solutions to climate change. Furthermore, some priorities fall within agricultural areas and will need sustainable management and restoration if they are to maintain the unique communities. Finding economically viable approaches to maintaining diversity in these countries will require explicit financial mechanisms, while the business community has started to engage with the CBD. Approaches that allow effective implementation of targets such as green finance

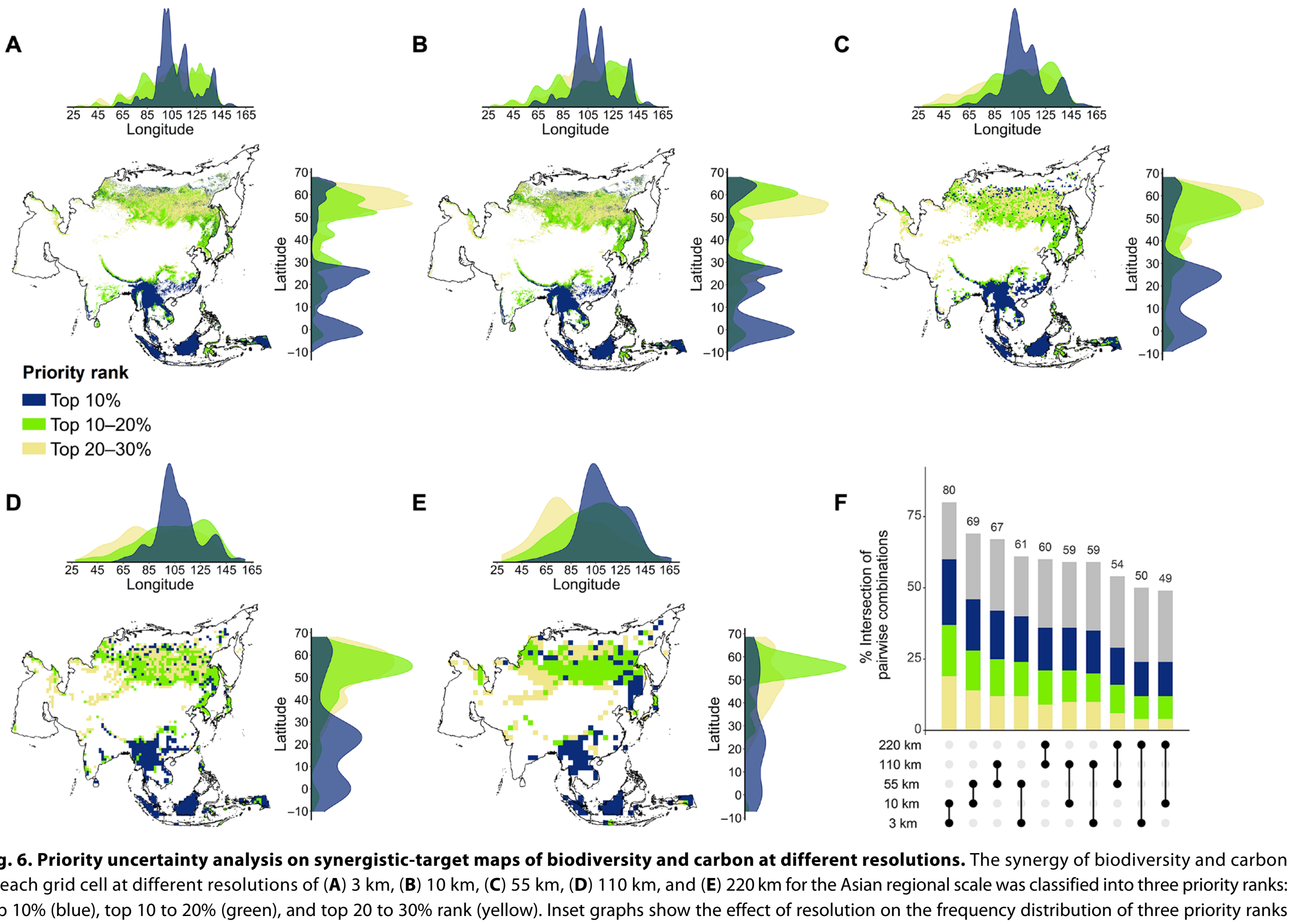


**Fig. 6. Priority uncertainty analysis on synergistic-target maps of biodiversity and carbon at different resolutions.** The synergy of biodiversity and carbon in each grid cell at different resolutions of (**A**) 3 km, (**B**) 10 km, (**C**) 55 km, (**D**) 110 km, and (**E**) 220 km for the Asian regional scale was classified into three priority ranks: top 10% (blue), top 10 to 20% (green), and top 20 to 30% rank (yellow). Inset graphs show the effect of resolution on the frequency distribution of three priority ranks along longitudes and latitudes, respectively. The *y* axis shows the counts of grid cells with the same priority ranks along longitudes or latitudes. (**F**) Upset plot for intersections of pairwise resolutions. Bars indicate percentage of spatial overlapping with pairwise resolution combinations. Filled dots show which combination each bar represents. Spatial consistency, defined as priority rank matches within overlapping areas between pairwise resolution combinations matching ranks, is denoted by the appropriate color, and mismatches between priority ranks at different resolutions are shown in gray.

and certification schemes should be applied to enable sustainable management across landscapes in addition to conservation in key regions as highlighted within this framework to most effectively meet the ambitious targets within the post-2020 global biodiversity framework.

## MATERIALS AND METHODS

### Mapping taxon distribution

We focused our analysis on terrestrial vertebrate classes (mammals, birds, reptiles, and amphibians) that were extracted for the Asian region from the available global species distribution data for 8932 terrestrial vertebrate species. Mammal (1587 species) and amphibian (1171 species) distribution data were obtained from the IUCN Red List database (IUCN 2019) (*72*), while bird (3612 species) range maps were obtained from Birdlife International (*73*). Data on the distribution of reptiles (2562 species) were obtained from the Global Assessment of Reptile Distributions database (1156 species) (*74*) and IUCN (1406 species). To refine each species' range to close to the true area of habitat in which the species could potentially persist, we obtained habitat preferences from the IUCN Red List database (*72*). Whenever no habitat preferences were recorded for a given species, we refined the full range by removing the areas considered to be artificial habitats, although this could exclude areas suitable for some generalist species (but unlikely to be key to their distribution), and agricultural and urban landscapes were retained for species not located in other land cover types. Species distributions were trimmed by newly published habitat maps (*75*) that follow the IUCN habitat classification system to minimize commission errors (false presences) and then were rasterized into 3 km by 3 km grids in Arcmap10.3 as their final distribution maps within the Asian region.

### Estimating the carbon storage of the ecosystem

We created a map of carbon storage across Asia by combining soil organic carbon and the carbon stored in aboveground and belowground vegetation. We used recently published harmonized maps of aboveground and belowground biomass carbon density (*76*) and summed both to estimate biomass carbon using the mosaic function in ArcMap10.3. Vulnerable soil organic carbon was defined as those carbon stocks that could potentially be lost during the coming 30 years as a result of land use based on the Intergovernmental Panel on Climate Change according to the method used by Jung *et al.* (*77*) and with further support from Soto-Navarro *et al.* (*14*). We did not apply emission factors as most estimates are outdated and may not reflect changes in fire regime and other factors. Thus, all carbon at appropriate depths in mineral (30 cm) and organic (200 cm) was treated as vulnerable soil carbon based on the methods used by Jung *et al.* (*77*). Soil organic carbon was downloaded for all depths from Hengl and Wheeler (*78*), and the 30-cm layers were combined for the clipped study region to estimate vulnerable mineral soils. Organic soils were classified as Histosols based on the USDA (United States Department of Agriculture) classification (*77*) and downloaded from Hengl and Nauman (*79*). The Histosol layer with a probability of more than 5% was reclassified to provide a mask of organic soils and clipped to the region and then the 30- to 200-cm soil organic carbon layers were extracted from Hengl and Wheeler (*78*) in ArcMap. Mineral and organic soil carbon were then combined in ArcMap to provide a map of vulnerable soil carbon for the entire region. Lastly, we summed the carbon storage from biomass and vulnerable stocks to generate the combined total carbon storage (metric tons of carbon per hectare) and aggregate to 3-km resolution to match the biodiversity data.

### Mapping synergy priorities of biodiversity and carbon storage

The priorities for biodiversity and carbon storage are defined as the highest value regions clipped to 30% land area (based on the potential area-based conservation targets for 2030) for each zone of the scales using the Zonation conservation prioritization software (*80*). These scales included regional scale (Asian range), subregional scale [Central Asia, North Asia, Northeast Asia, South Asia, Southeast Asia, and West Asia, based on the IPBES (2018) (*81*) units and showcased in the Supplementary Materials], biome scale (*40*), and national scale.

Synergies and trade-offs depend on the relative importance given to conservation of biodiversity and carbon storage. We compared proportion composition of carbon and effectively protected biodiversity based on different synergistic-target maps by extracting the highest combined values of biodiversity and carbon with different biodiversity weights (fig. S11). With decreases in the biodiversity threshold, the efficiency of biodiversity conservation decreased while the conservation proportion of carbon stock increased. When synergistic-target maps were generated by the equal weights of biodiversity and carbon, i.e., using all the biodiversity range (100%) to extract as above, we found that the carbon benefited the most, while the biodiversity had the lowest conservation proportion (fig. S11). Therefore, to optimize the balance between priorities, a threshold of top 50% of biodiversity considering Half-Earth (50% land for biodiversity-only prioritization) was prioritized to trade off with carbon. By designing our targets in this way, we can avoid protecting high-carbon and low-biodiversity plantations and other similar areas (fig. S2). Consequently, our final synergistic-target priorities started from the top 50% of species richness hotspots as a mask to extract the highest combined values of biodiversity and carbon when clipped to 30% of land to better reflect the importance of high biodiversity while ensuring carbon potential and thus providing a sensible balance between the two.

To identify where the strategic conservation action should have substantial benefits for biodiversity, carbon, and both, the priorities (top 30% hotspots) of biodiversity-only, carbon-only, and synergy of both were overlapped at regional, biome, and national scales, respectively. To consider possibilities for creating new protected areas, the extent to which biodiversity, carbon, and synergy priorities fell outside existing protected areas was also investigated.

To examine the multiscale trade-offs between targets, priorities of biodiversity, carbon storage, and synergy of both were overlapped with three scales including regional, biome, and national priorities using the mosaic function in ArcMap 10.3. The top 30% hotspots across taxonomic groups—mammals, birds, reptiles, and amphibians—were overlapped using the same approach. The similarities and distinctions across scales and taxa were displayed as Venn diagrams built using the Venn Diagram package (*82*) in R software (*83*) with the proportion of overlapping areas to analyze the relationships to explore how priorities vary across different scales and taxonomic dimensions.

### Optimizing resolution

The choice of resolution has a significant implication on the results. While coarse resolutions have been recommended for IUCN maps (*20*), inaccuracies from commission can be corrected for by using appropriate filters (here, based on a recent land cover map integrated with species listed distributions). However, lower resolutions have the potential for inaccuracies in narrow or small areas, such as narrow countries, peninsulas, and islands. Here, we contrasted a range of resolutions (3, 10, 55, 110, and 220 km) to explore the effectiveness of each resolution and ensure that the selected resolution was appropriate. While resolutions under 110 km generally did reasonably, even in some narrow countries (Laos, Nepal, and Vietnam), islands (Indonesia and Philippines), and peninsulas (Myanmar and Thailand) above 110 km, substantial parts of these areas could not be analyzed, which is significant when high island endemism is considered. Resolutions under 110 km have the highest spatial overlap of priority areas (80% intersection between 3 and 10 km and 69% intersection between 10 km and 55 km), whereas this decreases at increasingly coarse spatial scales. Conservation priorities showed good spatial consistency between 3 km and other resolutions (61 and 47% for them, respectively) under 110 km (Fig. 6), thus highlighting that higher resolutions represent richness patterns much better than coarse scales in accurately defining conservation priorities when treated with appropriate filters. Furthermore, maps at 3-km resolution had higher conservation efficiency for species than other coarser scales based on accumulation curves of species that met area-based targets (fig. S6). Thus, a relatively high resolution of 3 km was used in all other analyses to account for turnover in heterogeneous regions, and because majority of the area was insular or island coastal areas, it would show lower diversity if large portions of the cell fall over the ocean, meaning priorities for much of Southeast Asia are impossible at coarser resolutions, and 3 km was optimal at most scales.

### Mapping ecoregion coverage

Synergies of biodiversity and carbon based on the 30% by 2030 priorities for each scale were summed using mosaic function, and the area and percent area within each ecoregion were calculated using the tabulate area function in Arcmap10.3. To determine the percentage of each ecoregion that may have at least some capacity to retain diversity, we used artificial habitats (*75*) such as arable or pasture land and plantation areas as a mask to extract the entire priorities and to calculate the proportion of the priorities under human disturbance in each ecoregion for sustainable management and then the proportion of the remaining priorities for protection.

We excluded all marine and "proposed" protected areas in the data of the World Database on Protected Areas (*84*). The UNESCO Man and Biosphere Reserves were also excluded for their high overlap with other types of protected areas (all core zones overlapped with nationally designated protected areas) and zones (i.e., buffer and transition zones) falling within multiple functions (*85*), which often included large areas of agricultural land. For protected areas without boundary information, we approximated their boundaries by generating a circular area around its location with the size reported in the area attribute. We merged the protected areas and those for China (www.resdc.cn/) and dissolved overlapping areas to create a 3 × 3 km grid map of existing protected areas. We treated a 3 km by 3 km grid cell as "protected" if more than half of its area overlapped with existing protected areas. This was connected with the entire priority area using joins and relates to assess what percentage of the priority within each ecoregion and what percentage of the entire priorities in each ecoregion are covered by the existing protected areas to determine whether the framework effectively captures different ecoregions and which ecoregion had a large proportion of protection gaps for further attention.

### Identifying the contribution of priorities

The amount of habitat potentially available for conservation was calculated to determine whether a species reached effective protection by examining range coverage by the proposed conservation areas. We used the Butchart *et al.* (*23*) approach to assign scaling targets of species distribution size equating 10% of their range to wide-range (>250,000 km$^2$) species and 100% of their range to small-range (<1000 km$^2$) species. For species with intermediate range size, the percentage target was obtained by log-linear interpolation between these percentages using the base package in R software (*83*) following previous studies (*23*, *25*). We calculated the percentage of species that met effective protection criteria using existing protected areas and combined protected areas and identified synergy priorities at all scales, respectively, by taxonomic group and threatened category to explore the ability to effectively protect these different groupings. All the bar charts were made by the ggplot2 package (*86*) in R (*83*).

### Setting conservation targets for countries

To optimize the 30% conservation goal considering multiscale benefits and to implement at the national level, we set different conservation targets ranking the priorities in a stepwise manner: (i) First Priority Target, requiring all regional priorities with the highest conservation efficiency; (ii) Second Priority Target, adding biome priorities to the First Priority Target to provide better representativeness; and (iii) Third Priority Target, combining all the priorities of the three scales from region to country. We calculated the percentage of priorities of different targets contained in each country to identify the contribution and responsibilities to achieve the conservation goals of each country under different targets. Then, we calculated what percentage of priorities falling in artificial habitat should be sustainably managed in each country. To identify how well protected species are in each country, we used area-based representation targets to define the amount of habitat each species needed for protection to be considered safeguarded for the future based on the Butchart approach (*23*). We calculated what percentage of species (including the IUCN categories from Near Threatened to Critically Endangered) had effective protection within existing protected areas and would have extra protection if priorities were protected in each country. For species with ranges spanning across national borders with a range of 20,000 km$^2$ or less (corresponding to species that may qualify as vulnerable on the IUCN Red List based on the area-based metric; www.iucnredlist.org/resources/redlist-guidelines), we assigned the protection responsibilities (in terms of the number of species that can obtain effective coverage of their range) to every country in the Asian region.

## SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/7/35/eabe4261/DC1

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