



# Synergies and trade-offs in achieving global biodiversity targets

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**Abstract:** After their failure to achieve a significant reduction in the global rate of biodiversity loss by 2010, world governments adopted 20 new ambitious Aichi biodiversity targets to be met by 2020. Efforts to achieve one particular target can contribute to achieving others, but different targets may sometimes require conflicting solutions. Consequently, lack of strategic thinking might result, once again, in a failure to achieve global commitments to biodiversity conservation. We illustrate this dilemma by focusing on Aichi Target 11. This target requires an expansion of terrestrial protected area coverage, which could also contribute to reducing the loss of natural habitats (Target 5), reducing human-induced species decline and extinction (Target 12), and maintaining global carbon stocks (Target 15). We considered the potential impact of expanding protected areas to mitigate global deforestation and the consequences for the distribution of suitable habitat for >10,000 species of forest vertebrates (amphibians, birds, and mammals). We first identified places where deforestation might have the highest impact on remaining forests and then identified places where deforestation might have the highest impact on forest vertebrates (considering aggregate suitable habitat for species). Expanding protected areas toward locations with the highest deforestation rates (Target 5) or the highest potential loss of aggregate species' suitable habitat (Target 12) resulted in partially different protected area network configurations (overlapping with each other by about 73%). Moreover, the latter approach contributed to safeguarding about 30% more global carbon stocks than the former. Further investigation of synergies and trade-offs between targets would shed light on these and other complex interactions, such as the interaction between reducing overexploitation of natural resources (Targets 6, 7), controlling invasive alien species (Target 9), and preventing extinctions of native species (Target 12). Synergies between targets must be identified and secured soon and trade-offs must be minimized before the options for co-benefits are reduced by human pressures.

**Keywords:** Aichi targets, biodiversity, carbon storage, Convention on Biological Diversity, forest loss, protected area, threatened species, vertebrates

Sinergias en las Metas de Conservación

**Resumen:** Después de su fracaso en alcanzar una reducción significativa de la tasa global de pérdida de biodiversidad en 2010, los gobiernos del mundo adoptaron 20 nuevas metas ambiciosas de biodiversidad Aichi para ser alcanzadas en 2020. Los esfuerzos para alcanzar una meta particular puede contribuir al alcance de otras, pero metas diferentes a veces pueden requerir soluciones conflictivas. Consecuentemente, la falta de pensamiento estratégico puede resultar, una vez más, en un fracaso en el alcance de las metas globales de conservación de la biodiversidad. Ilustramos este dilema con la Meta Aichi 11. Esta meta requiere una expansión de la cobertura de áreas protegidas terrestres, lo cual podría contribuir también a la reducción de la pérdida de hábitats naturales (Meta 5), la reducción de la declinación y extinción de especies inducida

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por humanos (Meta 12) y el mantenimiento de las reservas globales de carbono (Meta 15). Consideramos el impacto potencial de la expansión de áreas protegidas en la mitigación de la deforestación global y las consecuencias para la distribución de hábitat adecuado para >10000 especies de vertebrados de bosque (anfibios, aves y mamíferos). Primero identificamos lugares donde la deforestación puede tener el mayor impacto sobre los bosques remanentes y luego identificamos sitios donde la deforestación puede tener el mayor impacto sobre vertebrados de bosque (considerando hábitat adecuado para las especies). La expansión de las áreas protegidas hacia localidades con las mayores tasas de deforestación (Meta 5) o con el mayor potencial de pérdida de hábitat para especies (Meta 12) resultó en la configuración de redes de áreas protegidas parcialmente diferente (superposición cerca de 73%). Más aun, este acercamiento contribuyó a la protección de casi 30% más de reservas globales de carbono que el anterior. Mayor investigación de las sinergias y compensaciones entre metas proporcionaría luz sobre estas y otras interacciones complejas, como las interacciones entre la reducción de la sobreexplotación de recursos naturales (Metas 6, 7), el control de especies exóticas invasoras (Meta 9), y la prevención de extinciones de especies nativas (Meta 12). Las sinergias entre metas debe ser identificada y asegurada pronto y las compensaciones deben ser minimizadas antes que las opciones de co-beneficios sean reducidas por presiones humanas.

**Palabras Clave:** almacenamiento de carbono, área protegida, biodiversidad, Convención de Diversidad Biológica, especies amenazadas, metas Aichi, pérdida de bosques, vertebrados

## Introduction

World governments were committed to reducing significantly the global rate of biodiversity loss by 2010, but the combined effects of increased human pressures and inadequate conservation responses prevented the achievement of this goal (Butchart et al. 2010). Consequently, in 2010, parties to the Convention on Biological Diversity (CBD) adopted 20 new ambitious “Aichi biodiversity targets” to be met by 2020 (CBD 2010). Meeting these targets will be challenging (Venter et al. 2014) and will require funding to increase by at least an order of magnitude (McCarthy et al. 2012). Recognizing the existence of synergies and trade-offs between different targets would ease the effort and optimize spending of limited conservation resources. Considering the relationships between targets may illuminate clear opportunities for strategies that contribute to meeting multiple targets for the same investment (Venter et al. 2014). Currently, plans are not on track to meet most of the Aichi Targets by 2020 (Tittensor et al. 2014); thus, there is a need to consider the potential significance of these synergies and trade-offs. This type of analysis is also of key relevance in the longer term (i.e., beyond 2020), given the synergistic effects of threats such as land-use change and climate change and their predicted impact on global biodiversity (Mantyka-Pringle et al. 2015; Visconti et al. 2015).

Under Aichi Target 11, governments recognize that protected areas (PAs) are an effective conservation tool and commit to protecting at least 17% of the planet's terrestrial surface by 2020, especially areas of particular importance for biodiversity and ecosystem services. In the wake of the 2014 World Parks Congress, which called for countries to make better progresses toward this goal (Sandwith et al. 2014), we considered how such expansion of the PA network could directly contribute to the achievement of other targets. Through a case study

on forests, we considered whether Target 11 could be achieved by adding or expanding PAs at the forefront of rapid loss of natural habitat, where the highest rates of forest loss occur, to maximize the contribution to meeting Target 5 (reducing the loss of natural habitat). Alternatively, PAs could be designated in areas where habitat loss is currently negatively affecting the highest number of forest species, including both currently threatened species and species that might become so in the face of continuing habitat loss, to maximize the contribution to meeting Target 12 (preventing the extinction and improving the conservation status of species).

A number of studies have considered potential synergies in biodiversity target achievement, mostly by investigating how expansion of PAs can contribute to the reduction in risk of species extinction (e.g., Joppa et al. 2013; Venter et al. 2014; Butchart et al. 2015). In parallel, potential interactions between biodiversity and social targets have been investigated globally, such as those between species conservation and agricultural production (Dobrovolski et al. 2014). Although the trade-offs between socio-political objectives and conservation objectives have been investigated at the local scale (Faleiro & Loyola 2013), little attention so far has been paid to trade-offs between conservation targets themselves, especially at a global scale. For example, where the highest rates of habitat loss occur in areas of high species richness, a synergy between achievement of Aichi Targets 5 and 12 is achievable. However, there are also situations where high rates of habitat loss occur in areas with limited biodiversity, whereas species-rich areas may suffer lower levels of habitat loss. Those situations may lead to a conflict between achievement of Targets 5 and 12.

The comparison of maps of global forest change (Hansen et al. 2013) and maps of the extent of suitable habitat (sensu Rondinini et al. [2011] and Buchanan et al. [2011]) for forest-dependent vertebrates (amphibians,

birds, and mammals, as described below) would exemplify synergies and trade-offs between Targets 5, 11, and 12. Measuring the carbon stored in forest habitats would allow evaluation of the contribution of Targets 5 and 12 to Target 15 (maintenance of ecosystem resilience). Terrestrial vertebrates represent a tiny fraction of all living species (Mora et al. 2011), but reasonable concordance has been found, for example, in biogeographical patterns (Kier et al. 2009) and conservation needs (Joppa et al. 2013) of vertebrates and plants. Amphibians, birds, and mammals are the only large terrestrial classes with globally available assessments of distribution and extinction risk (Hoffmann et al. 2010). These groups are often used in global assessments of progress toward biodiversity conservation (Butchart et al. 2010, 2015; Hoffmann et al. 2010; Tittensor et al. 2014).

We used a global-scale approach to quantitatively explore the synergies and trade-offs between some of the most discussed Aichi targets. We evaluated how the expansion of PAs (Target 11) could contribute to reducing habitat loss (Target 5), halting human-induced extinctions (Target 12), and safeguarding stored carbon to maintain ecosystem resilience (Target 15). In doing so, we stress the need for more strategic thinking in setting and implementing international environmental policy to maximize synergies in conservation efforts, anticipate trade-offs in achieving biodiversity targets, and identify timely resolutions.

## Methods

We measured the net change in global forest cover during 2000–2012 at a resolution of 1 km by counting pixels of forest loss and forest gain from global maps at an original resolution of 30 m (Hansen et al. 2013). The original data consisted of binary raster maps including cells that had lost or gained forest cover. In resampling these rasters at a 1 km resolution, we derived continuous map values (-1 to +1) representing the net proportional change in spatial forest cover in the resampled grid cells. A number of different resolutions have been used in global-scale analyses, and it was not our purpose here to evaluate the sensitivity of analyses to resolution settings. However, Pouzols et al. (2014) performed a global-scale spatial prioritization analysis on vertebrate species in which they used incremental resolutions (from 1.7 to 20 km) and found the results to be robust to the choice of alternative resolutions.

We calculated a neighborhood rate of forest change, representing for each grid cell the average amount of forest change that occurred in its surrounding area (i.e., the first-order neighbor pixels). This allowed us to estimate the local rates of forest change (at a 3 × 3 km resolution) that occurred from 2000 to 2012. Assuming a short-term business-as-usual scenario, we used this neighborhood

rate to extrapolate expected forest change rates to 2020. We multiplied the rate of forest change by the originally mapped tree cover in year 2000 (Hansen et al. 2013) to identify places where deforestation might have the highest impact on remaining forests. We then multiplied the rate of forest change by the aggregate amount of suitable habitat of 10,747 forest-dependent vertebrates: 3,658 amphibians (Ficetola et al. 2015), 5,595 birds (Buchanan et al. 2011) and 1,494 mammals (Rondinini et al. 2011). We measured the aggregate habitat in each grid cell by counting the number of species for which suitable habitat was present. In this way, we calculated the potential aggregated impact of deforestation on forest species. Habitat suitability models used in this analysis are available upon request from G.F.F. (amphibians), G.M.B. (birds), and C.R. (mammals).

To avoid identifying highly deforested areas as potential options for PA expansion, we considered only those pixels that had lost no more than 50% of their original forest cover (i.e., less than half forest cover lost from 2000 to 2012) and repeated the test with a lower threshold of 33% (i.e., less than one-third forest cover lost from 2000 to 2012). We then excluded all pixels already included in the current PA network by considering those PAs designated and associated with a digitized polygon in the World Database of Protected Areas (WDPA) (IUCN & UNEP-WCMC 2013). Alternative approaches are available to include PAs with an unknown boundary in the WDPA, such as representing those missing-shape areas as buffered centroids, but these approaches are also associated with the inclusion of potential bias in the analysis (Visconti et al. 2013).

Under Target 11, governments have committed to expand the terrestrial PA coverage by 4% (i.e., from 13% to 17%) (Venter et al. 2014). Consequently, we ranked cells based on their expected forest loss levels or based on their expected loss of aggregate species habitat and selected the 4% of cells that had the highest rank under the 2 alternative strategies. We thus identified cells where deforestation was predicted to be highest, cells where the loss of aggregate species habitat was highest, and cells where both conditions were satisfied. Areas within 1 of the first 2 categories represent trade-offs between targets, and their protection would potentially maximize forest conservation (Target 5) or forest species conservation (Target 12), but not both. Areas in the third category represent synergies; their protection would potentially maximize both forest conservation and forest species conservation. We also tested the use of a different proportional PA expansion figure (2%, i.e., half the agreed upon value) to verify the sensitivity of results to alternative scenarios of proportional PA expansion.

We calculated global species richness by counting the number of forest vertebrate species in each 1 km grid cell. We then calculated the average richness of species in areas with highest forest loss and highest loss of aggregate

species habitat. We calculated the total carbon (Target 15) stored in areas facing the highest forest loss or the highest loss of aggregate species habitat with global data on carbon stocks (Global Soil Data Task Group 2000; Ruesch & Gibbs 2008). In this case, we calculated the total amount of stored carbon estimated to occur in the two spatial aggregations.

## Results

Expanding the PA network to address deforestation or to maximize conservation of forest vertebrates resulted in two partially distinct configurations (Fig. 1 & Supporting Information). The 4% of cells with highest rates of forest loss overlapped by approximately 73% with cells with the highest loss of aggregate species habitat, after excluding areas that had already lost more than half of their original forest cover. The figure was 72% when areas that had lost over one-third of their forest cover were excluded. This means that the remaining 27% of additional PA extent required to meet Target 11 terrestrially could be chosen in areas with either the highest rate of forest loss or the highest loss of aggregate species habitat. The values were not dependent on the threshold used to represent proportional PAs expansion; in fact, when assuming a 2% PA expansion, the results were the same (73% solutions overlap).

The spatial pattern of synergies and trade-offs between targets varied by geographic region. In tropical regions (i.e., those most rich in terrestrial and threatened vertebrates), areas with the highest forest loss did not always have the highest loss of aggregate species habitat. For example, areas with the highest loss of aggregate species habitat in the Congo basin did not have the highest deforestation rates, whereas areas with highest deforestation rates in Sumatra did not have the highest loss of aggregate species habitat. As expected, species richness was particularly high in the tropics (Fig. 2). Areas with the highest loss of aggregate species habitat had higher species richness (mean [SD] = 120 species/grid cell [111]) than areas with the highest deforestation (mean = 80 [83]) and than existing PAs (mean = 86 [146]).

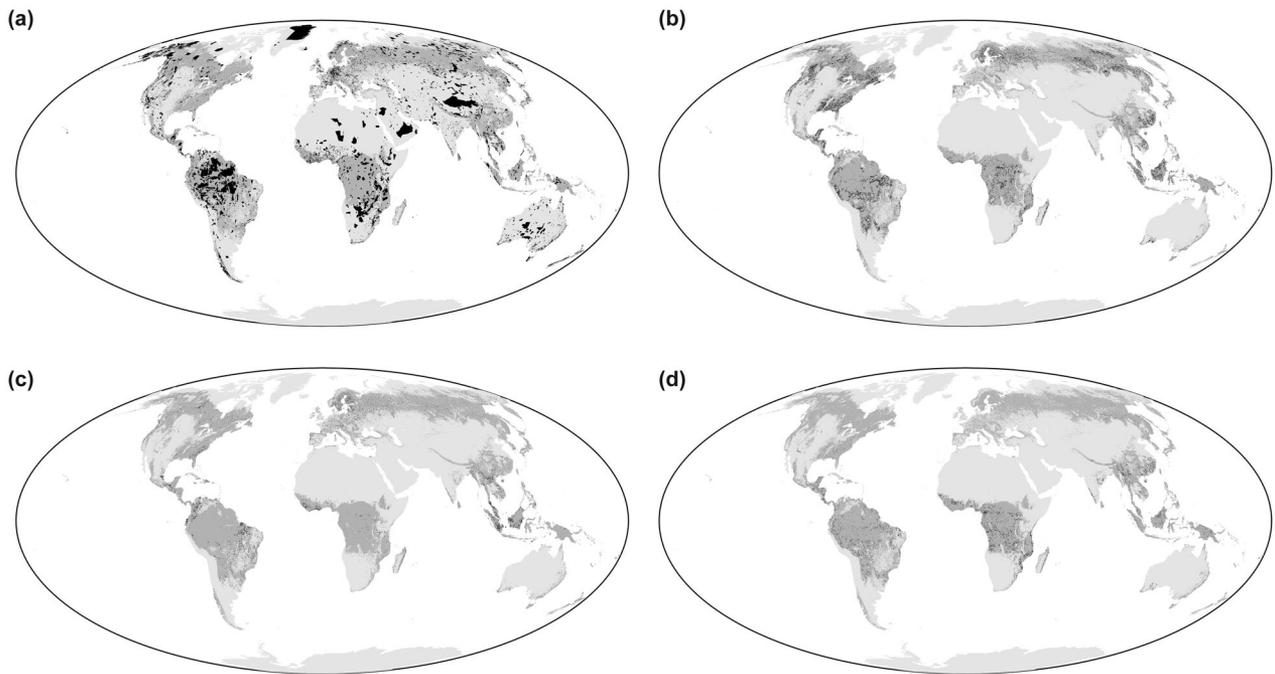
The alternative configurations, one that maximizes the potential contribution to meeting Target 5 and the other that maximizes the contribution to Target 12, had different implications for meeting Target 15 on carbon storage. Expanding PAs to encompass places with the highest risk of loss of aggregate species habitat would result in 30% more stored carbon being covered by PAs (approximately  $5.74 \times 10^{12}$  t) than expanding PAs to encompass places with highest risk of deforestation (approximately  $4.58 \times 10^{12}$  t). Thus, maximizing the potential benefit of PA expansion (Target 11) to forest species conservation (Target 12), rather than using PA expansion to address high deforestation (Target 5), would contribute more to the protection of carbon stocks (Target 15).

## Discussion

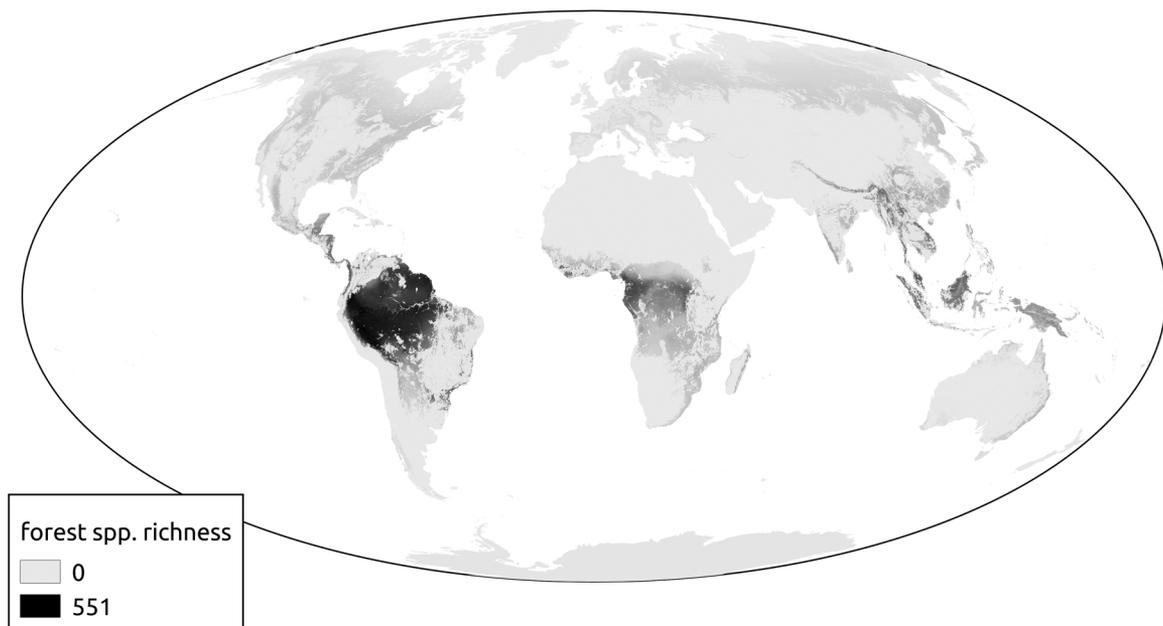
We found a 73% overlap between areas facing the highest forest loss and areas facing the highest loss of aggregate species habitat. Consequently, the remaining 27% of areas had either the highest deforestation or the highest level of species habitat loss, which represents a conservation trade-off for expanding the global PA coverage. The relatively high level of solution overlap we have found could be explained by the fact that we used the rate of forest change to measure both the loss of forest cover and the loss of aggregate species habitat. Thus, even if species richness and forest cover are distributed with some degree of independence at a global scale (e.g., with higher concordance in the tropics and lower concordance elsewhere), areas with very high rates of forest loss would be more likely characterized by both rapid decline in aggregate species habitat and rapid decline in forest cover.

We also found that areas with the highest loss of aggregate species habitat contributed more to safeguarding carbon stocks, if protected, than areas with the highest forest loss. The relationship between species and carbon at a global scale suggests that overall species diversity increases as availability of stored carbon increases (Strassburg et al. 2010; Buchanan et al. 2011). This suggests an interesting and potentially valuable surrogacy effect between protection of biodiversity at the frontier of habitat loss and maintenance of fundamental ecosystem services, such as climate change mitigation (Canadell & Raupach 2008). However, Murray et al. (2015) found a weak or negative relationship between species richness and stored carbon at the national and sub-national scale in Indonesia. This implies that further research is needed to understand the existence and magnitude of a biodiversity-carbon surrogacy in different biogeographical contexts and at different spatial scales.

We examined synergies and trade-offs between Aichi targets and focused on forests because they are rich in biodiversity and have been well mapped through the use of remote sensing technology (Hansen et al. 2013). However, the actual PA expansion figure in forests will likely be lower than what we considered here because other habitat types will also be protected (e.g., grassland, shrubland). We compared 2 scenarios of PA expansion, one targeting the maximum reduction in deforestation and the other targeting the maximum reduction in habitat loss for forest species. Yet, PAs expansion is not the only tool that can be used to reduce species' extinction risk or habitat loss. Reducing species extinction risk can be achieved through a number of conservation actions, other than PA expansion, including translocation of individuals (Seddon et al. 2014), eradication of invasive species (Howald et al. 2007), and management of wildlife trade (CITES 1973). Similarly, the reduction in global deforestation rates can be achieved through, for example, incentives from the United Nations' program on Reducing Emissions from Deforestation and Forest Degradation



**Figure 1.** Current protected areas and areas with highest levels of biodiversity loss. In all panels, dark grey areas represent forest extent in 2000, here reported as habitats with >15% tree cover. Black areas represent: (a) extent of the protected area network in 2014; (b) areas where the highest forest loss corresponds to the highest habitat loss aggregated across species (i.e., areas of synergy); (c) areas facing the highest forest loss, but not the highest loss of aggregate species habitat (i.e., areas of forest trade-off); (d) areas facing the highest loss of aggregate species habitat, but not the highest forest loss (i.e., areas of species trade-off). See Supporting Information for a color version of the map.



**Figure 2.** Global richness of forest vertebrate species (amphibians, birds, and mammals).

(REDD) (Agrawal et al. 2011) and certifications of sustainable forest management (Auld et al. 2008), such as those offered through the Forest Stewardship Council.

Considering all the various conservation tools available to achieve species and forest conservation would likely result in more complex interactions between multiple biodiversity targets. Further investigations of the synergies and trade-offs between targets, along the lines of our tests with PAs, would be needed to shed light on these complex interactions. However, given that habitat loss is the factor threatening the greatest number of species (Hoffmann et al. 2010) and that human pressure plays a key role in shaping species geographic distribution (Di Marco & Santini 2015), habitat conservation remains the action that benefits the most species. Thus, the expansion of PAs remains among the most effective strategies both for biodiversity conservation and for halting the conversion of natural areas (Bruner et al. 2001; Maiorano et al. 2008).

We sought to highlight spatial synergies and trade-offs between global biodiversity targets, rather than to identify specific spatial priorities for PA expansion. The latter requires consideration of additional factors, such as the cost of establishing and managing protected areas, level of connectivity in the protected area network, potential impact on local economies, etc. (Margules & Pressey 2000). Researchers have investigated global priorities for terrestrial PA expansion under Aichi Target 11, focusing wholly (Pouzols et al. 2014; Venter et al. 2014) or largely (Butchart et al. 2015) on vertebrate species. These works show that the contribution of Target 11 to Target 12 (reducing species' extinction risk) is highly dependent on the consideration of trade-offs between biodiversity value and agricultural opportunity cost (Venter et al. 2014) or between biodiversity value and projected changes in land use (Pouzols et al. 2014). Moreover it is unlikely that meeting Target 11 will suffice as a stand-alone strategy to achieving Target 12 (Butchart et al. 2015).

The achievement of global conservation targets is subject to the decisions governments make at the national scale. Strategies for PA establishment or expansion in particular are subject to national governments' allocation of resources, which makes the achievement of global biodiversity targets less cost-efficient than it would be under a globally coordinated strategy (Dobrovolski et al. 2014; Pouzols et al. 2014; Venter et al. 2014). For this reason, it is important to consider how the interaction between global biodiversity targets can also affect national or regional-level targets, such as those established by the European 2020 Biodiversity strategy (European Commission 2011). In this case, an approach similar to ours could be adopted, with the use of more detailed data on species distribution and area protection mechanisms (Santini et al. 2014), which would allow for more accurate prediction of the impact of habitat loss on biodiversity.

We have discussed a few examples of the trade-offs between some Aichi targets, but many other targets interactions exist and could be quantitatively investigated following our framework. For example, Marques et al. (2014) argue that efforts to halt habitat loss (Target 5), reduce overexploitation (Targets 6, 7), eradicate invasive non-native species (Target 9), and mitigate climate change (Targets 10 and 15) can all potentially contribute to species conservation (Target 12). A lack of strategic thinking contributed to the failure to achieve the 2010 global biodiversity targets (Butchart et al. 2010), and progress so far in meeting the more ambitious Aichi 2020 is insufficient (Tittensor et al. 2014). Governments must recognize the existence of both synergies and trade-offs between targets and define conservation strategies that maximize co-benefits and minimize conflicts between them. Quantifying and securing synergies between targets is a urgent priority, before the options for co-benefits are reduced by human pressures.

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## Supporting Information

A color map of areas with highest deforestation and highest loss of aggregate species habitat (Appendix S1) is available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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