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CONSERVAÇÃO E EVOLUÇÃO: DA ECOLOGIA POPULACIONAL A POLÍTICAS PÚBLICAS

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Orientador: Profa. Dra. Marina Corrêa Côrtes

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TÍTULO DA TESE: **Conservação e evolução: da ecologia populacional a políticas públicas**

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Resumo:

A fragmentação dos ambientes naturais pode gerar consequências negativas para a diversidade genética, a evolução e a conservação da biodiversidade. Esses efeitos podem se tornar ameaças à relevância dos ecossistemas para conservação da biodiversidade ao longo prazo e podem impulsionar a ocorrência de fenômenos evolutivos como a adaptação local em populações isoladas. Consequências negativas resultantes da fragmentação podem ser amplificadas por outras pressões negativas comuns em ambientes isolados, incluindo a poluição por metais pesados. A primeira parte desta tese avalia importantes mecanismos evolutivos que promovem a adaptação de plantas a solos contaminados por metais pesados. Informações sobre ecologia populacional, genômica e identificação de genes importantes para adaptação à alta concentração de elementos tóxicos, incluindo Fe, Pb, Cu, Al e Zn, foram usadas para testar mecanismos evolutivos. O estudo revela estratégias ecológicas e genes importantes para o crescimento de *Cattleya liliputana* em solos contaminados.

Melhores ferramentas para a gestão da paisagem e maior integração de áreas protegidas e paisagens produtivas são importantes para reverter a tendência global de fragmentação e uso insustentável dos recursos naturais. A segunda parte da tese fornece ferramentas e análises para promover a conectividade, a integração e o manejo efetivo da paisagem. No segundo capítulo, uma ferramenta de análise espacial de fácil utilização para apoiar projetos com objetivo de implementação de zonas de amortecimento em torno de áreas protegidas foi desenvolvida com objetivo de facilitar o planejamento e gestão de áreas protegidas no Brasil. O terceiro capítulo da tese atualiza os principais progressos para cumprimento da Meta 11 de Aichi no grupo dos países megadiversos, incluindo Brasil, e propõe alternativas para acelerar o avanço para conservação efetiva de áreas protegidas. No quarto capítulo, uma análise da contribuição das Paisagens de Produção Sócio-ecológica (SEPLS, do ingês) para alcançar a Meta 11 de Aichi foi conduzida em colaboração com a Secretaria da Convenção sobre Diversidade Biológica. O estudo revela uma ampla gama de sinergias entre a SEPLS, a Meta 11 e outros acordos ambientais multilaterais.

Palavras chave: Áreas protegidas, Meta 11 de Aichi, conservação, contaminação por metal pesado

Abstract:

The fragmentation of natural environments has pervasive consequences to genetic diversity, evolution and the conservation of biodiversity. These effects are important threats to the long-term relevance of ecosystems, and may drive evolutionary responses such as the local adaptation of isolated populations. Negative consequences resulting from fragmentation can be amplified by other common negative pressures in isolated environments, including pollution by heavy metals. Species that survive after contamination play an important role for restoration but face strong selective pressure for adaptation to the contaminants within an isolated environment. The first part of the thesis shed light on important evolutionary mechanisms that drive plant adaptation to soils contaminated by heavy metals. Information regarding population ecology, genomics, and identification of important genes for adaptation to the high concentration of toxic elements, including Fe, Pb, Cu, Al and Zn were used to test major evolutionary mechanisms. The study revealed ecological strategies and genes important for *Cattleya liliputana* adaptation to contaminated soils.

Better tools for landscape management and enhanced integration of protected areas and production landscapes are important strategies to counter the global trend on fragmentation and unsustainable use of natural resources. The second part of the thesis provides tools and analysis to promote connectivity, integration and effective landscape management. In the second chapter, a user-friendly GIS tool to support the design and implementation of buffer zones around protected areas was developed and mainstreamed, contributing to improve management plans of protected areas in Brazil. The third chapter updates the progress to achieve Aichi Biodiversity Target 11 in the group of Like-minded Megadiverse Countries and suggest strategies to accelerate the effective conservation of protected areas. In the fourth chapter, an analysis of the contribution of Socio-ecological Production Landscapes and Seascapes (SEPLS) to achieving Aichi Biodiversity Target 11 was conducted in collaboration with the Secretariat of the Convention on Biological Diversity. The study revealed a wide range of synergies among SEPLS, Target 11 and other multilateral environmental agreements.

Key words: Protected areas, Aichi Target 11,conservação, heavy metal contamination

Sumário

Introdução:

O Brasil é um dos países com maior cobertura vegetal no mundo, com 62% do território nacional, ou, cerca de 530 milhões de hectares (Mha) cobertos por vegetação nativa(MMA 2017). Desse total, 40% se encontram em áreas de conservação de domínio público ou em terras indígenas, sendo que 91% dessa fração se concentram na Amazônia. Os 60% restantes estão em propriedades privadas ou terras públicas ainda sem designação (MMA 2017). O grande patrimônio natural Brasileiro implica em grandes oportunidades de desenvolvimento econômico e tecnológico nos setores agropecuário, extrativista, biotecnológico e de turismo. A grande biodiversidade permite também pesquisas e desenvolvimento de produtos alimentícios, fármacos e fitoterápicos. Entretanto, é grande a necessidade de esforços de conservação dos remanescentes de vegetação nativa que se encontram, a cada ano, mais dispersos em fragmentos isolados e de pequeno tamanho (Ribeiro et al. 2009, Tabarelli et al. 2010, Lewis et al. 2015, Santini et al. 2016).

A biodiversidade é um recurso com valor estratégico, econômico, social e tecnológico, o que torna sua conservação um instrumento na defesa do bem-estar e da segurança dos recursos naturais dos quais dependemos para o futuro. Dada a importância da conservação e do uso sustentável de seu grande patrimônio natural, o Brasil assumiu compromissos por meio da adesão a tratados internacionais, como a Convenção sobre Diversidade Biológica (CDB). Esses compromissos demandam não somente a preservação e conservação de áreas naturais existentes, mas também a recuperação de ecossistemas degradados.

Os impactos associados à perda de habitat causada por pressões antrópicas e mudanças globais do clima têm reflexos sobre os processos ecológicos e evolutivos, afetando diretamente ações para conservação da biodiversidade a longo prazo (Johnson et al. 2017). A perda de biodiversidade e seu isolamento em áreas protegidas cercadas por uma matriz de uso intensivo do solo tem crescido ao longo da última década no Brasil e em outros países de economia emergente, detentores de grande biodiversidade na região tropical (Defries et al. 2005, Lewis et al. 2015, Arroyo-Rodríguez et al. 2017). O rápido crescimento econômico e populacional observado em países megadiversos expõe um grande desafio - conciliar o desenvolvimento econômico com a conservação da biodiversidade. Esse desafio tem sido reconhecido pelos governos do Brasil e de outros países do Grupo de Países Megadiversos[1] e motivado o desenvolvimento de estratégias, planos de ação e

[1]O grupo de países megadiversos é um grupo politicamente alinhado em relação à agenda da biodiversidade e meio ambiente em fóruns internacionais. São membros do grupo: Bolívia, Brasil, China Colômbia, Costa Rica, República

ferramentas de cooperação internacional para facilitar o cumprimento de Metas Nacionais de Biodiversidade (MNBs) e das Metas de Aichi propostas pela Convenção sobre Diversidade Biológica.

A conectividade de paisagens tem sido apontada como uma estratégia importante para gestão territorial e um instrumento para regulação de aspectos ecológicos e evolutivos dos fragmentos de vegetação nativa com objetivo de garantir a conservação da biodiversidade no longo prazo (MMA 2018). A integração de remanescentes de vegetação nativa na paisagem e a melhora de sua conectividade com outros fragmentos oferece ganhos potenciais para manutenção de diversidade genética, adaptação e mitigação a mudanças climáticas e pode também promover desenvolvimento socioeconômico local. O objetivo de ações para conectividade é permitir o estabelecimento de fluxos biológicos essenciais entre as Unidades de Conservação, remanescentes de vegetação nativa e demais áreas que envolvam formas de proteção do território, facilitando a dispersão de espécies e a recolonização de áreas degradadas, e garantindo intercâmbio genético entre as populações de animais e plantas para manutenção de suas populações e continuidade dos processos ecológicos e evolutivos.

Efeitos ecológicos e evolutivos do isolamento

A perda de conectividade pela fragmentação de habitats é comumente associada a outras pressões seletivas como defaunação, variação climática, efeito de borda e alterações em processos de interação entre espécies (por exemplo: Fleury and Galetti 2006, Valladares et al. 2006, Galetti et al. 2013, Liu and Slik 2014, Haddad et al. 2015, Bovendorp et al. 2018).No entanto, o efeito da fragmentação da paisagem *per se*(sem perda de área) pode gerar efeitos positivos em índices de diversidade de espécies e dispersão do risco de extinção, apesar de não se saber ao certo se os ecossistemas fragmentados se mantém estáveis por muito tempo (Fahrig et al. 2019). A ocorrência de pressões seletivas contrastantes entre populações isoladas é um fenômeno esperado após a fragmentação de origem antrópica. Esse fenômeno pode decorrer do isolamento de populações que antes se encontravam dispersas em um gradiente ambiental ou por meio da influência antrópica localizada, por exemplo por poluição, com características distintas entre fragmentos isolados. A redução do fluxo gênico e tamanho populacional desencadeada pelo isolamento pode resultar em respostas adaptativas e alterar os processos evolutivos e ecológicos das espécies (Rossetto et al.

Democrática do Congo, Equador, Etiópia, Guatemala, Índia, Indonésia, Iran, Quênia, Madagascar, Malásia, México, Peru, Filipinas, África do Sul, e Venezuela.

2011, Papadopulos et al. 2014, Da Silva Carvalho et al. 2015). É esperado que esses fenômenos desempenhem um papel cada vez mais importante para definição da diversidade genética, funcional e de espécies quanto mais fragmentados os ecossistemas se encontrarem podendo alterar a adaptabilidade de populações a médio e longo prazo. No entanto, os mecanismos relacionados à evolução dos processos adaptativos ainda são pouco conhecidos, principalmente em relação a espécies tropicais (Savolainen et al. 2007,Hoeksema and Forde 2008, Anderson et al. 2011).

Respostas evolutivas desencadeadas por efeitos antrópicos podem levar tempo para serem observadas. As respostas evolutivas às características do ambiente local são mais prováveis em ambientes com pressões seletivas fortes e pouco fluxo gênico (Fig. 1). Para ocorrência de adaptação local, é esperado que a pressão seletiva seja mais forte que o fluxo gênico entre populações em ambientes distintos (Fig. 1). Nesse contexto, ambientes montanhosos têm se revelado como importantes modelos naturais para a elucidação de mecanismos evolutivos associados ao isolamento e à seleção de adaptabilidades locais (Antonelli *et al.*, 2010; Palma-Silva *et al.*, 2011; Caro *et al.*, 2013; Pinheiro *et al.*, 2014). Ambientes montanhosos apresentam descontinuidades do relevo resultantes de variações geomorfológicas e altitudinais. Esses ambientes também são caracterizados por condições estremas, muitas vezes associadas a pressões evolutivas fortes, como alta exposição à radiação UV, grande variação térmica diária, evapotranspiração elevada, baixa retenção hídrica, solos pobres e, às vezes, com grande concentração de elementos tóxicos (Porembski & Barthlott, 2000; Scarano, 2002; Porembski, 2007). Essas características variam descontinuamente como um mosaico ao longo do relevo e criam uma estrutura espacial de paisagem similar ao que é observado após fragmentação de origem antrópica. Essa estrutura de paisagem, portanto, propicia a ocorrência de adaptação local (Brady et al. 2005, Wright 2007, Turner et al. 2010), apesar dos fatores envolvidos nesses processos serem pouco compreendidos.

A consolidação de informações sobre os principais mecanismos relacionados à adaptação a condições locais como solo, clima e interações entre espécies é um importante instrumento para guiar os projetos de restauração e conservação dos ecossistemas. Ações visando manter adaptações e variedades genéticas locais devem ser ponderadas em relação à ações com objetivo de favorecer o fluxo gênico entre populações isoladas sob o contexto das projeções futuras para o clima e para a mudança do uso do solo. Esse conhecimento tem grande potencial de contribuir para o sucesso a longo prazo de iniciativas para conservação da biodiversidade.

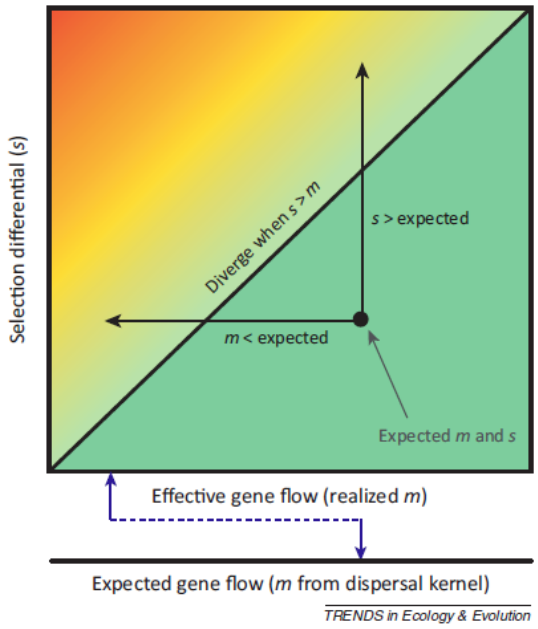

FIGURA 1. RELAÇÃO TEÓRICA ENTRE FLUXO GÊNICO E SELEÇÃO DIFERENCIAL PARA FAVORECIMENTO DA OCORRÊNCIA DE ADAPTAÇÃO LOCAL. A LINHA DIAGONAL REPRESENTA INTENSIDADES IGUAIS ENTRE SELEÇÃO DIFERENCIAL E FLUXO GÊNICO. DIVERGÊNCIA NÃO É ESPERADA NA REGIÃO ABAIXO DA LINHA DIAGONAL, EM VERDE. ACIMA DA LINHA, O AUMENTO DA DIVERGÊNCIA DE CARACTERES OCORRERÁ EM RAZÃO DA PRESSÃO EXERCIDA PELA SELEÇÃO EXCEDER O FLUXO GÊNICO. CORES QUENTES EVIDENCIAM MAIOR PROBABILIDADE DE DIVERGÊNCIA DE CARACTERES E ADAPTAÇÃO LOCAL. MODIFICADO DE RICHARDSON *ET AL.,* 2014.

Nesta tese, apresentamos no Capítulo 1 um estudo sobre a variação de caracteres ecológicos e mecanismos de adaptação em populações da orquídea *Cattleya liliputana* ocorrentes em ambientes com grande contraste em relação a presença de elementos tóxicos. Neste trabalho, avaliamos como o isolamento de populações em ambientes com altas concentrações de metais pesados promove respostas ecológicas adaptativas em populações da espécie. Os ambientes ocupados pela espécie, apesar de naturais, apresentam características similares a ambientes contaminados por metais pesados. Mostramos que *Cattleya liliputana* apresenta adaptação ao crescimento sob altas concentrações de metais pesados por meio de hipertolerância, associada com a acumulação de metais em tecidos de armazenamento. Além disso, descrevemos uma biblioteca de genes candidatos para o processo de adaptação com o objetivo de facilitar projetos futuros para investigação dos mecanismos moleculares dos processos adaptativos.

Políticas públicas para conectividade

Os efeitos deletérios da fragmentação de ecossistemas têm sido reconhecidos internacionalmente (Leadley et al. 2013, CBD 2016b, a). Nos fóruns globais de discussão de políticas

para biodiversidade, questões relativas ao isolamento e fragmentação de ecossistemas têm sido trabalhadas com maior intensidade no contexto das Metas de Aichi para Biodiversidade (Leadley et al., 2013), principalmente em relação à Meta 11 - associada ao planejamento e gestão de áreas protegidas. Em menor escala, o tema também é abordado em conjunto com propostas de restauração da vegetação nativa associada às metas 14 e 15.

A Meta 11 de Aichi internaliza os conceitos de conectividade e integração na paisagem do entorno como elementos essenciais para conservação de áreas protegidas. No entanto, a meta não define o conceito de conectividade em relação a conectividade estrutural ou funcional e não define parâmetros para avaliação da conectividade. Ações propostas para as metas 14 e 15 são focadas em restauração de vegetação nativa como principal ferramenta para a recuperação e manutenção de serviços ecossistêmicos, ganho de resiliência aos efeitos da mudança climática e aumento de estoques de carbono (Tabela 1). O ganho gerada por ações de restauração podem contribuir diretamente para a melhora da conectividade de paisagens em sinergia com os objetivos da Meta 11.

Tabela 1. Comparação entre redação das Metas 11, 14 e 15 de Aichi e Metas Nacionais de Biodiversidade.

Metas de Aichi		**Metas Nacionais de Biodiversidade (Brasil)**
	**Target 11** By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.	**Meta Nacional 11** Até 2020, serão conservadas, por meio de unidades de conservação previstas na Lei do SNUC e outras categorias de áreas oficialmente protegidas, como APPs, reservas legais e terras indígenas com vegetação nativa, pelo menos 30% da Amazônia, 17% de cada um dos demais biomas terrestres e 10% de áreas marinhas e costeiras, principalmente áreas de especial importância para biodiversidade e serviços ecossistêmicos, assegurada e respeitada a demarcação, regularização e a gestão efetiva e equitativa, visando garantir a interligação, integração e representação ecológica em paisagens terrestres e marinhas mais amplas.

	**Target 14** By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.	**Meta Nacional 14** Até 2020, ecossistemas provedores de serviços essenciais, inclusive serviços relativos à água e que contribuem à saúde, meios de vida e bem-estar, terão sido restaurados e preservados, levando em conta as necessidades das mulheres, povos e comunidades tradicionais, povos indígenas e comunidades locais, e de pobres e vulneráveis.
	**Target 15** By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.	**Meta Nacional 15** Até 2020, a resiliência de ecossistemas e a contribuição da biodiversidade para estoques de carbono terão sido aumentadas através de ações de conservação e recuperação, inclusive por meio da recuperação de pelo menos 15% dos ecossistemas degradados, priorizando biomas, bacias hidrográficas e ecorregiões mais devastados, contribuindo para mitigação e adaptação à mudança climática e para o combate à desertificação.

Áreas protegidas têm sido um dos principais instrumentos utilizados por governos para definição de estratégias de conectividade (Ervin et al. 2010). Em parte, isso se deve ao fato de áreas protegidas representarem uma porção cada vez mais importante dos remanescentes de vegetação nativa a serem conectados. No Brasil, no entanto, além das unidades de conservação, destaca-se também a importância das terras indígenas, reservas legais (RL) e áreas de proteção permanente (APP) como parte de uma rede de remanescentes de vegetação nativa na escala de paisagem. A redação da Meta Nacional 11 brasileira inclui essas categorias de áreas protegidas como instrumentos para cumprimento da meta, além dos diferentes tipos de Unidade de Conservação definidos pela Lei do SNUC (Tabela 1). O Brasil atualmente apresenta índices de conectividade média de áreas protegidas entre 17% e 25%, medidos pela metodologia "Protected Connected land" (Fig. 2) considerando apenas UCs e terras indígenas, mas grande heterogeneidade entre regiões e biomas (Saura et al. 2017; Saura et al. 2018).

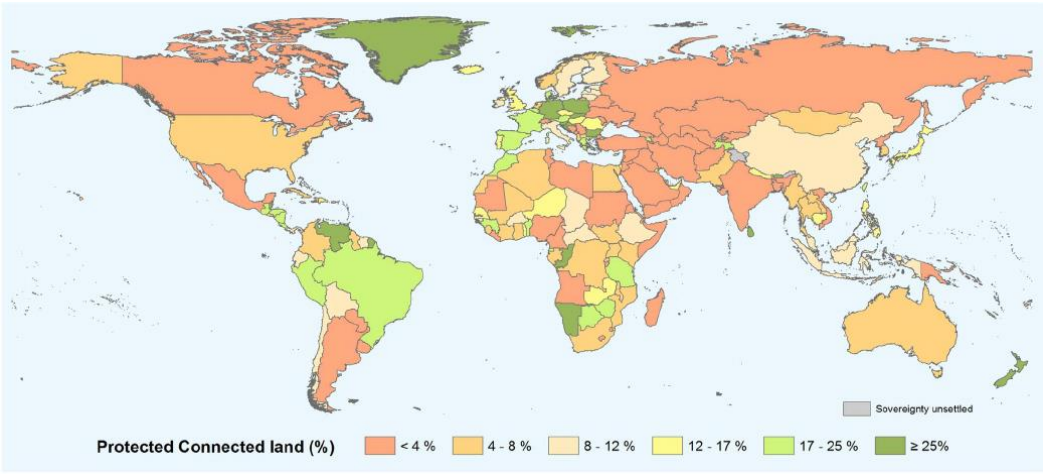

FIGURA 2. ÁREA PROTEGIDA CONECTADA PARA UMA DISTÂNCIA MÉDIA DE DISPERSÃO DE 10KM DE ACORDO COM ÍNDICE PROTCONN. MODIFICADO DE SAURA *ET AL.*, 2018.

Em meados de 2017 o Brasil submeteu para a CDB sua Estratégia e Plano de Ação Nacionais para a Biodiversidade (EPANB) contendo um conjunto de políticas públicas e projetos para melhoria do estado de conservação da biodiversidade, incluindo propostas para conectividade. Em conjunto com o plano de ação, o governo brasileiro lançou nos últimos anos importantes programas para melhoria da conectividade, incluindo o Plano Nacional de Recuperação da Vegetação Nativa - PLANAVEG, Decreto no 8.972, de 23 de janeiro de 2017 (MMA 2017), e o Programa Nacional de Conectividade de Paisagens – CONECTA, instituído pela Portaria MMA nº 75, de 26 de março de 2018 (MMA 2018).

O objetivo do PLANAVEG é fomentar políticas públicas, e outras medidas necessárias para a recuperação da vegetação nativa em aproximadamente 12 milhões de hectares até 2030. Esforços para restauração estão planejados para ocorrer principalmente em áreas de APP, RL, e áreas degradadas com baixa produtividade (MMA 2017). O mapa de estimativa do déficit de APP e Reserva Legal em propriedades privadas revela uma grande oportunidade para melhoria da conectividade nas regiões Sul e Sudeste envolvendo, principalmente, os biomas Cerrado e Mata Atlântica (Fig. 3). O Programa CONECTA, lançado pelo Ministério do Meio Ambiente tem como objetivo o desenvolvimento territorial sustentável por meio da melhoria do estado de conservação de áreas protegidas e promoção da conectividade entre essas áreas com outras áreas de importância na paisagem (MMA 2018). Os programas PLANAVEG e CONECTA destacam a importância da recuperação da vegetação nativa e gestão integrada da paisagem no entorno das unidades de conservação como estratégias importantes para o avanço da conectividade e redução das pressões antrópicas sobre áreas protegidas.

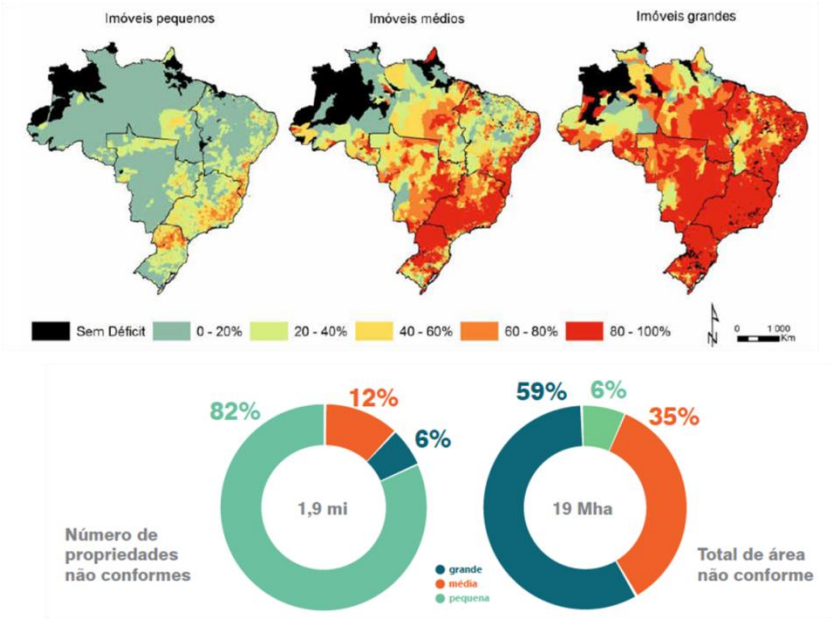

FIGURA 3. DÉFICIT DE APP E RESERVA LEGAL POR CLASSE DE TAMANHO DOS IMÓVEIS (PROPRIEDADES). PROPORÇÃO DE IMÓVEIS E ÁREA EM CONFORMIDADE DE ACORDO COM AS REQUISIÇÕES DO CÓDIGO FLORESTAL. MODIFICADO DE IMAFLORA – SUSTENTABILIDADE EM DEBATE NO. 5.

Houve ao longo das últimas décadas um expressivo avanço na criação de unidades de conservação e desenvolvimento de planos de manejo no Brasil. A legislação brasileira define que as unidades de conservação, com exceção de APAs, devem designar e manejar apropriadamente zonas de amortecimento ao redor de sua área de proteção. Apesar de presente na legislação, a eficácia da gestão integrada de unidades de conservação com o restante da paisagem tem se mostrado um desafio. O progresso para integração de áreas protegidas com atores relevantes do entorno e a promoção do manejo em escala de paisagem são grandes desafios para melhoria da conectividade e efetividade das unidades de conservação. Nesse contexto, a identificação de oportunidades e capacitação para resolução de conflitos na gestão territorial de áreas privadas no entorno de áreas protegidas é um dos maiores gargalos para melhoria da efetividade da integração e conectividade de unidades de conservação na paisagem.

No Capítulo 2 desta tese apresentamos uma ferramenta desenvolvida com intuito de facilitar análises espaciais do entorno de unidades de conservação com objetivo de identificar oportunidades para melhoria da gestão territorial de zonas de amortecimento, facilitando a manutenção das principais vias de conexão entre UCs e paisagem do entorno e evitando conflito com outros setores produtivos e comunidades locais.

Meta 11 de Aichi e conectividade de paisagens

A melhoria da conectividade e integração de áreas protegidas na paisagem são objetivos capturados pelo texto da Meta 11, apesar de muita discussão ter sido necessária para interpretação das diretrizes da meta, incluindo a definição do conceito de *outras medidas efetivas de conservação baseadas em área*. O conceito para o termo foi proposto em 2017, trabalhado durante o primeiro semestre de 2018 e recentemente aprovado pela 14º Reunião da Conferência das Partes para Convenção sobre Diversidade Biológica, em Novembro 2018 (CBD 2018).

A Meta 11 de Aichi propõe dois objetivos quantitativos de proteção territorial baseados em área e sete elementos qualificadores das áreas, como conectividade, manejo adequado, integração, equidade, entre outros (Tabela 1). A Meta 11 apresenta algumas características importantes:

1) A meta se refere a áreas protegidas de todas as categorias adotadas por países membros da Convenção de Diversidade Biológica em conjunto com outras medidas efetivas de conservação baseadas em área.

2) Não existe ainda um padrão internacionalmente reconhecido de critérios para interpretar o que pode ou deve ser incluído pelos país como parte de seu esforço de implementação da Meta de Aichi 11 e seus equivalentes nacionais e regionais.

3) Os elementos da Meta 11 aplicam-se a todas as categorias de áreas protegidas e de outras medidas efetivas de conservação baseadas em área, tanto em áreas terrestres (continentais ou insulares), como em áreas costeiras e marinhas.

4) A exigência de que a conservação se dê por meio de gestão efetiva e equitativa resultado em uma rede de proteção conectada aplica-se aos sistemas de áreas protegidas e de outras medidas efetivas de conservação baseadas em área, tanto para cada área individualmente como para o conjunto das áreas que constituem sistemas nacionais ou regionais de áreas protegidas incluindo outras medidas efetivas de conservação baseadas em área.

O conceito de conectividade incluído na meta simboliza uma abordagem alternativa às formas convencionais de conservação, sendo abrangente, descentralizado e participativo. Nesse contexto, duas ferramentas têm sido propostas para promover a conectividade de paisagens: corredores ecológicos e paisagens sustentáveis.

Corredores ecológicos são áreas onde se destacam grande quantidade de vegetação nativa e ações coordenadas envolvendo o fortalecimento, a expansão e a conexão de áreas protegidas

dentro do corredor. Essas características requerem, para sua implementação, alto grau de envolvimento e cooperação de instituições e de interessados de diversos setores (Ervin et al. 2010).

Paisagens sustentáveis são estratégias de gestão territorial integrada onde a maior parte do território é utilizada por setores econômicos para produção, mas de modo a facilitar a conectividade e a conservação da biodiversidade. Paisagens sustentáveis tem grande potencial para contribuir para a melhoria da conservação do meio ambiente em áreas degradas e melhorar práticas de produção de vários setores como agricultura, extrativismo e pecuária (Gu &Subramanian, 2014; O'Farrell & Anderson, 2010).

Paisagens sustentáveis podem integrar ações que vão além da conservação da biodiversidade, resultando, por exemplo, em desenvolvimento socioeconômico como a criação de cadeia produtivas sustentáveis que favorecem o cumprimento de objetivos específicos do manejo de áreas protegidas ou áreas de importância para conservação na passagem.

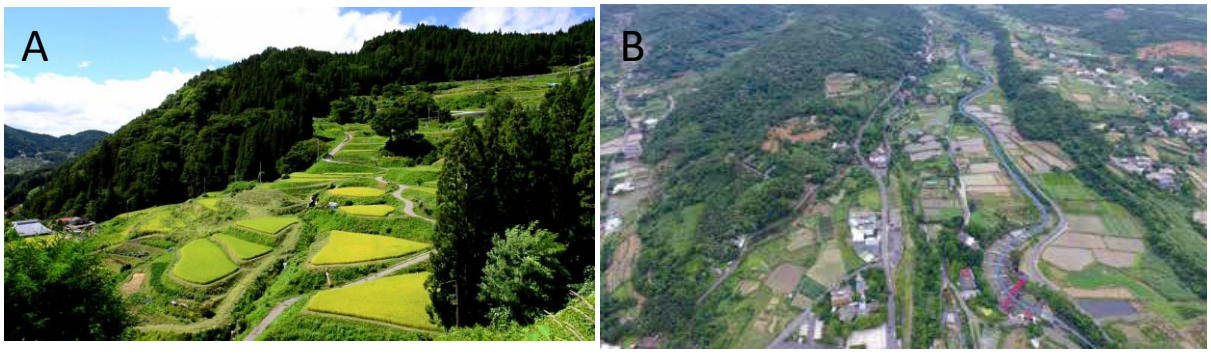

FIGURA 4. EXEMPLOS DE PAISAGEM SUSTENTÁVEL NO JAPÃO (A) E EM TAIWAN (B). MODIFICADO DE CHAO ET AL. 2018.

Paisagens sustentáveis tem o potencial de gerar múltiplos benefícios para a comunidade local e para gestão integrada da paisagem. A gestão integrada de paisagens visando conectividade tem como objetivo o fortalecimento do manejo de florestas em paisagens agrícolas mediante ações de produção sustentável, recuperação de áreas degradadas e promoção de mecanismos inovadores de financiamento da cadeia produtiva local. Essas ações têm sido estimuladas por iniciativas internacionais como Iniciativa Satoyama(Fig. 5). A Iniciativa Satoyama tem implementado projetos de maneira integrada ao planejamento territorial com objetivo de abordar grandes desafios de conservação em escala regional e nacional.

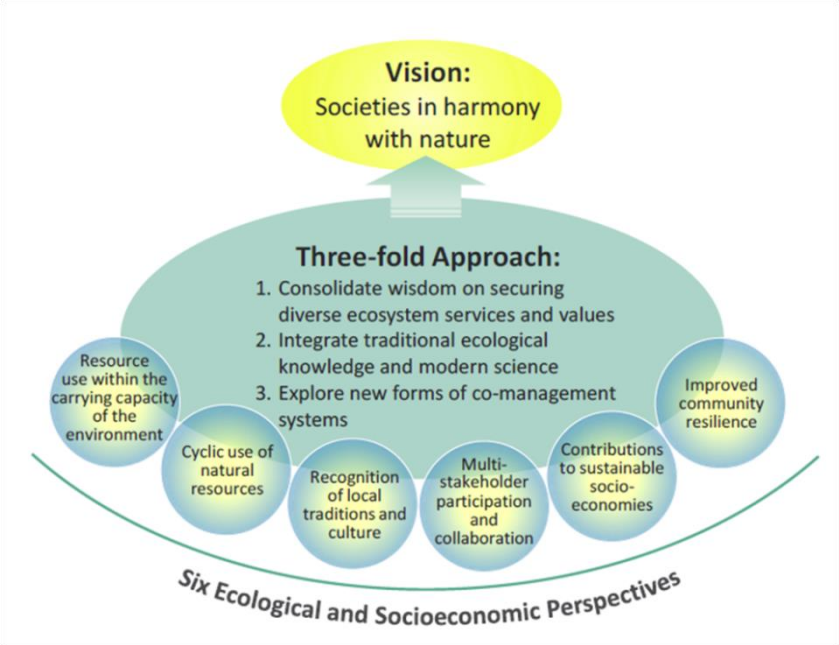

FIGURA 5. QUADRO CONCEITUAL DE PAISAGENS SUSTENTÁVEIS PROMOVIDOS PELA INICIATIVA SATOYAMA.

Nos capítulos 3 e 4 desta tese apresento uma atualização do estado da Meta 11 no grupo de países Like-Minded Megadiverse Countries (LMMCs) e uma análise do grau de sinergia entre os compromissos assumidos pelos 20 países do LMMCs para a Meta 11 de Aichi e a Iniciativa Satoyama. Essescapítulos foram desenvolvidos em colaboração com o Secretariado da Convenção de Diversidade Biológica com o objetivo de subsidiar negociações para o avanço de políticas públicas e cooperação internacional para o cumprimento da Meta 11. O Capítulo 3 apresenta um panorama do atual estado da Meta 11 nos países do grupo LMMC e as perspectivas para o alcance da meta em 2020. O Capítulo 4 apresenta os principais benefícios da implementação de paisagens sustentáveis para o cumprimento da Meta 11 no LMMCs e discute possíveis vias fomento de parcerias e captação de recursos para implementação de paisagens sustentáveis.

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Capítulo 1

Metal tolerance and accumulation drive adaptation to soil type in a Neotropical orchid

Manuscrito formatado para submissão para revista *Plant and Soil*

Metal tolerance and accumulation drive adaptation to soil type in a Neotropical orchid

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Abstract

Ecological discontinuity can impose strong natural selection. Plant adaptation to different soil environment is an evidence of the strong selective pressure driven by soil discontinuity and contrasting soil properties that result in sharp ecosystem differences even over small spatial scales. In this study, we tested whether high concentrations of toxic elements in the soil drives ecological, physiological and morphological adaptation of the orchid *Cattleya liliputana* in a Neotropical mountain range. We used a combination of demographic and genetic data to evaluate the extent to which populations are adapted to local environment and whether this adaptation involves hyperaccumulation or hypertolerance to toxic metals. Results suggest that *C. liliputana*hypertolerates metal concentrations in non-photosyntheticallytissues up to six times higher when growing in metal-rich soils. Leaves, however, do not accumulated toxic metals. Hypertolerance was associated with dwarfism,higher growth rate and reproductive success. Additionally, transcriptome sequencing and identification of candidate genes for metal adaptation are provided to support further analysis of molecular mechanisms of soil adaptive process in Neotropical orchids.

Introduction

Special nutritional pathways and other biological traits associated with coping with infertile soils and high concentration of heavy metals are expected to occur in plants inhabiting serpentine-like soils, especially when selective pressure is geographically localized and antagonistic and populations are genetically isolated (Richardson et al. 2014). Isolation due to environmental discontinuity can enhance the effects of selection and population divergence favouring the occurrence of local adaptive radiation. Traits driving adaptation and the genetic components of the plant-soil adaptation process, however, have only recently begun to be understood (Krämer 2010, Ricachenevsky et al. 2013, Halimaa et al. 2014, Daghino et al. 2015).

Adaptation to cope with high concentration of toxic elements involves two main strategies: mechanisms leading to exclusion of excess metal (avoidance), or mechanism promoting the transport associated with plant structures which can detoxify and/or sequester the excess of toxic ions inside the cells (Maestri et al. 2010). Metal hypertolerant/hyperaccumulator plants are able to accumulate from one to four orders of magnitude higher metal concentrations in their aboveground biomass compared to other plants growing in the same environment. Hyperaccumulators change metal partitioning between roots and shoots. In non-hyperaccumulators, metal shoot-to-root ratio is below unity, whereas in hyperaccumulators it is generally above (Krämer et al. 2007, Hanikenne and Nouet 2011, Ricachenevsky et al. 2013). Both hyperaccumulation and hypertolerance result from changes in physiological processes, including: (1) root metal uptake; (2) enhanced xylem loading for root-to-shoot metal translocation; and (3) enhanced metal sequestration and detoxification in shoots (Hanikenne and Nouet 2011).

Studies of population genomics have identified genes transcribing ion transporters such as MRS2-2, MTPc3, CAX7 and CAX8, Ferric-chelate reductase and transcriptional factors as important genes conferring adaptation to high metal concentration in *Arabidopsis lyrata(Turner et al. 2010).*Excess metal can also serve as substrates for a range of membrane transporters in plants, including the metal tolerance proteins (MTPs). MTP proteins were reported to act as Metal2+ (Me2+)/H+ antiporters, with a few exceptions (Ricachenevsky et al. 2013). Identifying the molecular basis of edaphic adaptation in divergent lineages is an essential step towards understanding adaptation in natural populations. The genomic resources produced with NGS can contribute to the identification of candidate genes for adaptation and the formulation and testing of evolutionary hypotheses regarding the genetic basis of the adaptation processes. Furthermore, the use of in silico analyses, including conserved protein domain and phylogenetic analyses, helps the identification and annotation of important genes from transcriptomes in many

nonmodelspecies(Guzman et al. 2014, Parween et al. 2015, Yang et al. 2015, Zhang et al. 2015) improving the gene library available for development of genetic marker targeting specific genes. These resources are especially important for the highly diverse taxa such as Neotropical orchids, which lacks much of genomic resources available for other model systems and comparatively similar temperate species.

In this study, we have tested the hypothesis that high concentrations of toxic elements in the soil drives ecological, physiological and morphological adaptation of the orchid *Cattleya liliputana*in a Neotropical montane outcrops.We used a combination of demographic and genetic data to evaluate the extent to which populations are adapted to local environment and whether this adaptation involves hyperaccumulation or hypertolerance to toxic metals. Additionally, RNA sequencing and *de novo* assembly of *Cattleya liliputana*transcriptomes were performed to produce an expression data set to facilitate further population and functional genomic analyses.

Material and Methods

Study area

Studied populations were monitored in the mountain ranges of the Iron Quadrangle (IQ) in Brazil. The populations of *C. liliputana*studied are found in iron and quartzite rock outcrops from 1483 to 2055 m a.s.l. Five populations (CAL, MOE, OBR, CAP, and GAN) are found around the Rio das Velhas river valley having a U-shaped distribution (Supplementary Figure 1). This region is characterised by large iron ore deposits and intensive mining activities. Populations grow predominantly on iron outcrops and are rarely found on small quartzite outcrops embedded in iron deposits. Two other populations (CRP and PSL) are located in a peripheral mountain range named Serra do Caraça. This region is characterized by the absence of iron outcrops and occurrence of large quartzite outcrops reaching the highest altitudes of the IQ mountains .

Study species

Cattleya liliputana (Pabst) van den Berg (van den Berg 2014) is a rupiculous orchid that has a microendemic distribution restricted to the Iron Quadrangle. The species is found in cracks and rugosities of iron and quartzite rocks. Soil usually accumulates around and beneath the roots or around the individuals in cracks. Individuals produce usually 1–5 inflorescences bearing 1–3 flowers from July to October. Flowers are pollinated by deception and usually last for several days. Fruits open between November and December, and seeds are dispersed by the wind.

Measurement of plant traits and population demography

Populations of *C. liliputana* were identified at Iron Quadrangle. One transect of 5X30 meters was extended at the center of the populations. Six additional plots of 5X4 meters were randomly distributed across the population area up to a maximum radius of 50 meters from the center. Demographic sampling consisted of marking, counting, measuring and classifying all individual within the transect and plots. Individuals were identified as a group of pseudobulbs physically attached together and physically separated from other units. Individuals were measured by counting the number of pseudobulbs and classified according to the development stage based on Borba et al.(Borba et al. 2007) as follows: 1- seedlings, plants withup to five pseudobulbs, 2- immature, plants with more than five pseudobulbs and without signs of reproduction, and 3- mature, plants with signs of reproduction . One pseudobulbs and leaves of all flowering individuals were collected and measured using an electronic paquimeter. Maximum length and width from mature pseudobulbs

and leaves were obtained from each collected sample. A minimum distance of 5 meters between individuals was used do avoid pseudoreplication.

Flower pollination and fruiting

Rates of pollination were assed in random collected flowers. Flowering pseudobulbs were collected in the field and preserved in 70% ethanol. Flowers were dissected under a stereo microscope and observed to assess whether the flower´s pollinarium was removed and/or a pollinia was delivered to the stigma. Fruiting rates were assessed in marked individuals within plots after the flowering season. Aborted fruits were not considered.

Chemical analyses of soil and plant material

Samples of soil beneath *C. liliputana individuals* were collected from GAN and PSL populations in January 2017 and stored in plastic bags. For plant tissue, individuals were collected, washed from excess sediment in water and kept alive. After reaching the laboratory, plant samples were washed in distillated water and dissected. Soil and plant samples were dried at 60°C until constant weight. Soil samples were sieved to pass a 2 mm nylon mesh. Plant and soil samples were grounded to fine powder using a mortar and shipped to the University of Montreal for chemical analysis.

For the analysis of trace elements in the plant samples, approximately 0.25 g of root, pseudobulb and leaf tissues were digested (digestorDigiPrepMS) in a 15-mL polyethylene tube with a mixture of concentrated ultrapure nitric acid (65%, 3.5 mL) and H_2O_2 (30%, 0.5 mL). The digestion was proceeded overnight or until the material was converted into a transparent and homogeneous solution. The tubes were completed up to 12 mL with Milli-Q water and stored prior to analysis by ICP-MS following a further 1:10 dilution with Milli-Q water, or until the solutions reached an acidity of 1%.

Soil samples were digested in a microwave system according to the method EPA 3051A, which consisted of using 1 g of the solid samples, 9 mL of concentrated ultrapure nitric acid (65%) and 1 mL of hydrochloric acid. After the digestion, the solutions were transferred to a 50-mL Falcon tube, which were completed up to 40 mL with Mili-Q water. Prior to the analysis, the samples were further diluted until the solutions reached an acidity of 1%.

Plastic materials and glassware were kept in 2% HNO_3 for at least 24 hours and subsequently washed with MilliQ-water seven times. Blanks, standard reference materials and triplicate samples were used for quality control during the analytical process. For each digestion cycle of plants, two vegetable standards (SRM 1515 and SRM 1573a) were digested. In the case of the soils, three standards were digested (NIST 2710, NIST 2711A, NIST 8704).

The trace metals were determined using inductively coupled plasma mass spectrometry (ICP-MS, Perkin Elmer). Concentrations were expressed in milligram of element per kilogram (mg kg^{-1}, dry weight). The limits of detection of the trace metals in the plants ranged from 0.021 to 3.78 µg kg^{-1}. For the soils, the limits of detection ranged from 0.014 to 2.53 µg kg^{-1}.

The recoveries of the trace elements for the soil reference material ranged from 82% (Ba) to 110% (Cd). For the plants, the recoveries of the trace elements ranged from 86% (U) to 107% (Cr).

Plant material and RNA extraction

Two individuals at each site (iron and quartzite) were sampled in their natural population. Leaves, pseudobulbs and root were collected, frozen immediately in liquid nitrogen and stored at -80° C until RNA extraction. RNA was extracted from each tissue and individual separately using TRIzol reagent according to the manufacturer's instructions (Invitrogen). Total RNA concentration was determined using UV spectrophotometry. Total RNA quality was checked by resolution in a 1% agarose gel. RNA integrity was evaluated using the Agilent 2100 Bioanalyzer (Agilent Technologies, CA, USA) with a minimum RNA integrity number value of 8. After RNA normalization, samples of the same population were pooled to generate two cDNA libraries to be sequenced. cDNA library construction and sequencing Library preparation and Illumina RNA sequencing were conducted at Macrogen Inc. (Seoul, Korea) following the TruSeq Stranded sample preparation protocol. The two cDNA libraries were individually barcoded and sequenced together. Paired-end (2 9 100 bp) strand-specific sequencing was performed in one lane on an Illumina platform (HiSeqTM2000) following the supplier-provided protocols (Illumina Inc., San Diego, CA, USA).

Data processingand de novo assembly

The FASTQ files for each library containing the raw cDNA sequencing reads were analyzed using the FASTQC (Andrews 2010) quality control tool. Raw reads were preprocessed discarding low-quality reads (Phred value<20). For each library separately, the resulting high-quality cleaned reads were assembled de novo into contigs using Trinity (Grabherr et al. 2011) with the parameter 'min_kmer_cov 2' following the method described by Haas et al. (2013). The use of this parameter increases the stringency for reads being assembled together (Chapman2015); thus, only kmers that occur more than once are considered for contigs, and the default is that all kmers are considered (Johnson 2013).

Functional annotation

BLAST2GO (Conesa et al. 2005) software was used to annotate the unigenes for each library. A BLASTX search was performed with an E-value of 1e-06 against the NCBI non- redundant protein

database (NR), followed by attribution of Gene Ontology (GO) terms, Enzyme Commission (EC), InterProScan domains and mapping of annotations to the Kyoto Encyclopedia of Genes and Genomes (KEGG) Database.

Results

Soil fertility and metal content

Cattleya liliputana inhabits rock outcrops where soils are scarce, although most individuals are able to retain organic and inorganic sediment around the roots and usually grow in areas where the sediments accumulate resulting in very shallow soils of 0.3 to 1.0 cm. The quantification of nutrients in soil samples around *C. liliputana*individuals showed minor differences between iron and quartzite soils (Fig. 1 A-E). Quartzite soils presented higher concentration of phosphorus than iron soils, but no significant difference was found for major nutrients such as nitrogen and potassium or the overall concentration of organic matter.

The concentration of toxic metals, however, was markedly different between iron and quartzite sites. Iron sites showed high concentration of iron, aluminum, plumb, cupper and manganese (Fig 1 F-L). Zinc was the only metal that did not differ among sites (Fig 1 J).

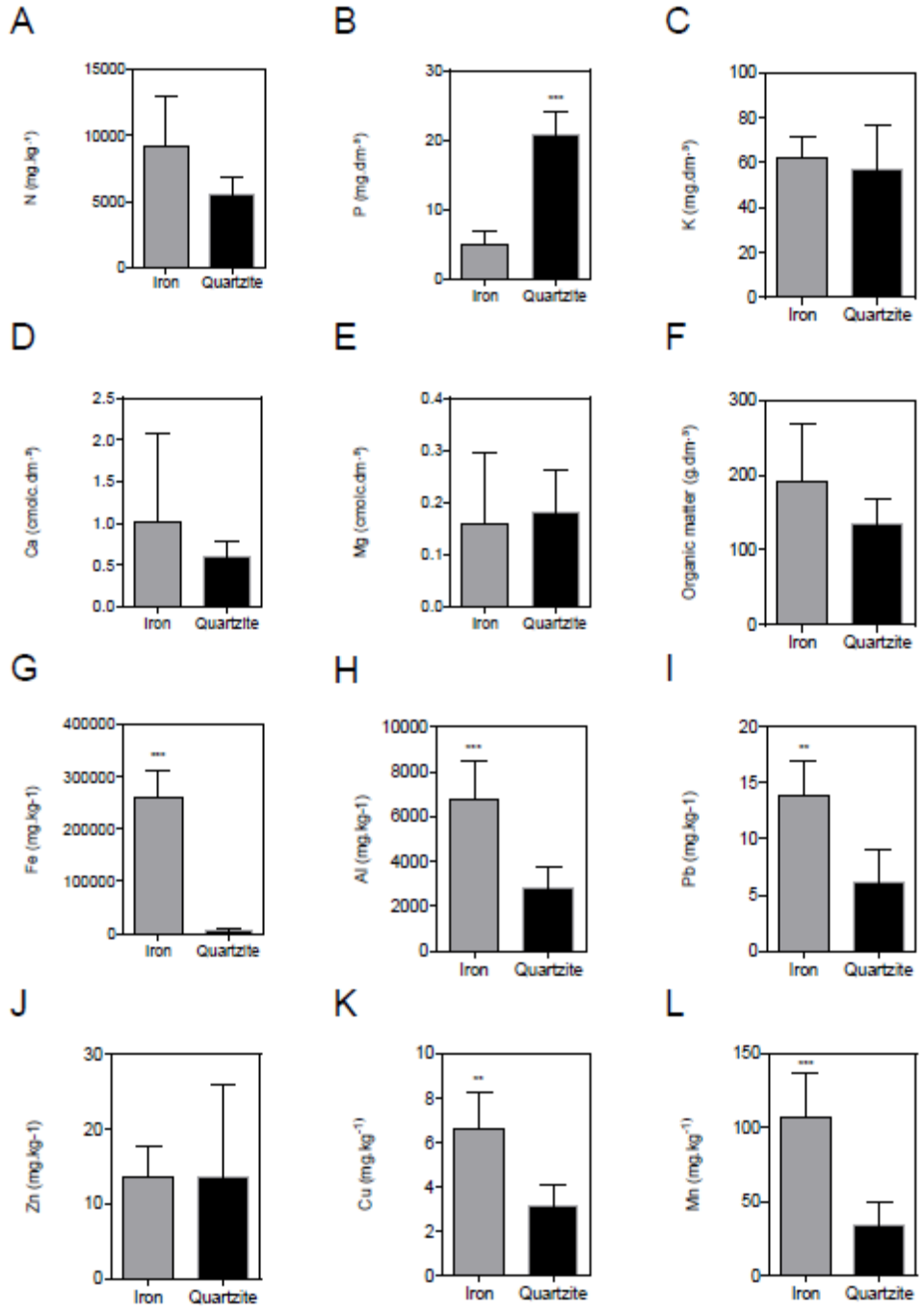

FIGURE 1. ***QUANTIFICATION OF NUTRIENTS AND HEAVY METALS IN IRON AND QUARTZITE SOILS. QUANTIFICATION OF NITROGEN (A), PHOSPHOROUS (B), POTASSIUM (C), CALCIUM (D), MAGNESIUM (E), ORGANIC MATTER (F), IRON (G), ALUMINUM (H), PLUMB (I), ZINC (J), CUPPER (K) MANGANESE (L). **P<0,01; ***P<0.001 FOR STUDENT T TEST.***

Population structure

C. liliputana population structure and morphological traits differ according to soil type. Individuals growing in iron outcrops were larger, with almost three times more pseudobulbs that plants in quartzite sites (Iron: 160.0 ± 17.05 N=137, Quartzite: 56.89 ± 8.973 N=87) (Fig. 2). Despite the high concentration of toxic elements, *C.liliputana*was found to grow well in the iron sites. Demographic analysis of population showed a higher proportion of seedling and immature individuals at iron sites (Fig. 3), suggesting higher rates of reproduction.

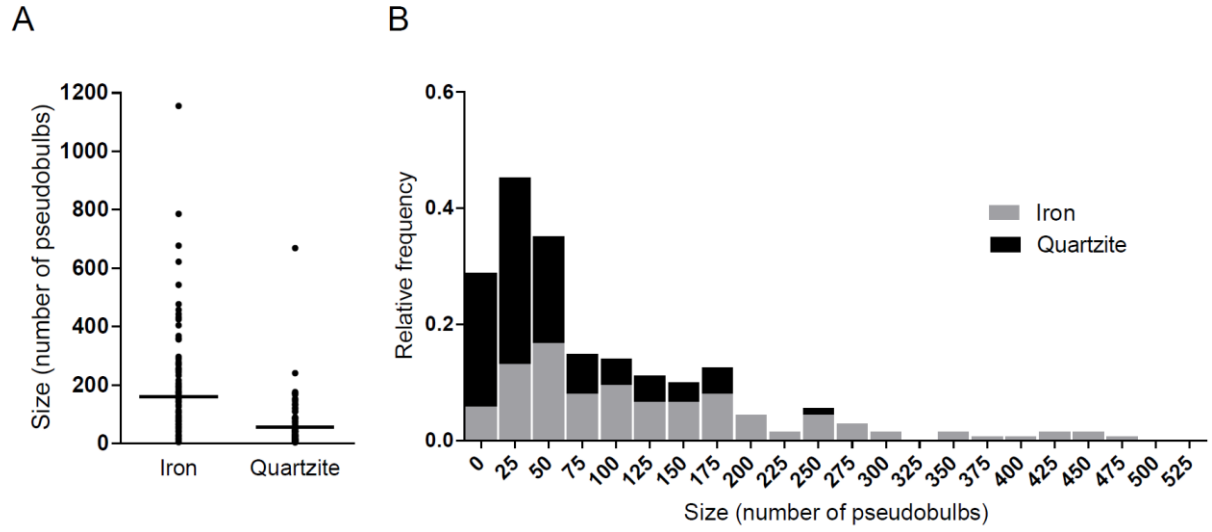

*FIGURE 2.**VARIATION IN SIZE OF* **CATTLEYA LILIPUTANA***INDIVIDUALS IN IRON AND QUARTZITE OUTCROPS. (A) MEAN SIZE AND DISTRIBUTION OF SIZE OF* **C. LILIPUTANA***INDIVIDUALS ACCORDING TO SOIL TYPE. (B) HISTOGRAM OF RELATIVE FREQUENCY OF SIZE CLASSES OF* **C. LILIPUTANA** *INDIVIDUALS ACCORDING TO SOIL TYPE.*

Pollination and fruiting were evaluated in order to quantify reproductive rates. Rates of removed pollinarium or delivered pollinia to flowers were not different between iron and quartzite populations (Fig. 4A and B). However, percentage of fruiting individuals were significantly smaller for quartzite populations suggesting a lower capacity to invest in the production of fruits.

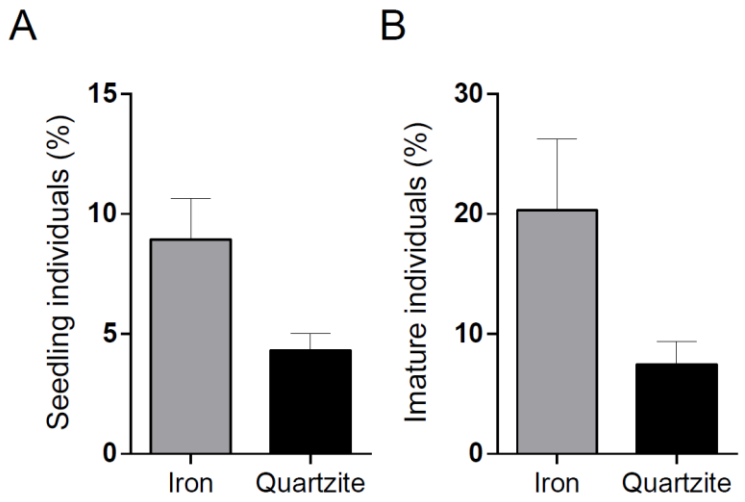

FIGURE 3. ***DEMOGRAPHIC STRUCTURE OF CATTLEYA LILIPUTANA POPULATIONS IN IRON AND QUARTZITE OUTCROPS. (A) PERCENTAGE OF SEEDLING INDIVIDUALS IN THE POPULATION ACCORDING TO SOIL TYPE. (B) PERCENTAGE OF IMMATURE INDIVIDUALS IN POPULATION ACCORDING TO SOIL TYPE. *P<.05 FOR STUDENT T TEST.***

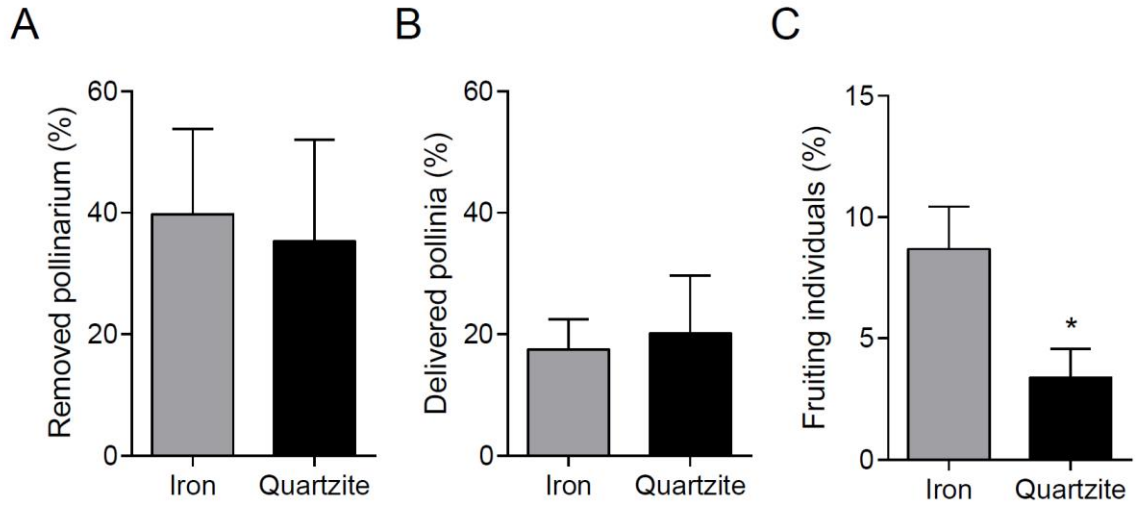

FIGURE 4. POLLINATION AND FRUITING RATES OF CATTLEYA LILIPUTANA POPULATIONS IN IRON AND QUARTZITE OUTCROPS. (A) PERCENTAGE OF FLOWERS WITH REMOVED POLLINARIUM ACCORDING TO SOIL TYPE. (B) PERCENTAGE OF FLOWERS WITH DELIVERED POLLINIA ACCORDING TO SOIL TYPE. (C) PERCENTAGE OF FRUITING INDIVIDUALS ACCORDING TO SOIL TYPE. *P,0.05

Measurements of pseudobulbs and leaves, major structures for resource allocation, suggest that individuals growing in iron outcrops have smaller sized pseudobulbs and invest less resources

on pseudobulbs than quartzite plants (Fig. 5). However, the larger number of pseudobulbs per individuals may compensate the smaller resource allocated in each pseudobulb for reproductive investment.

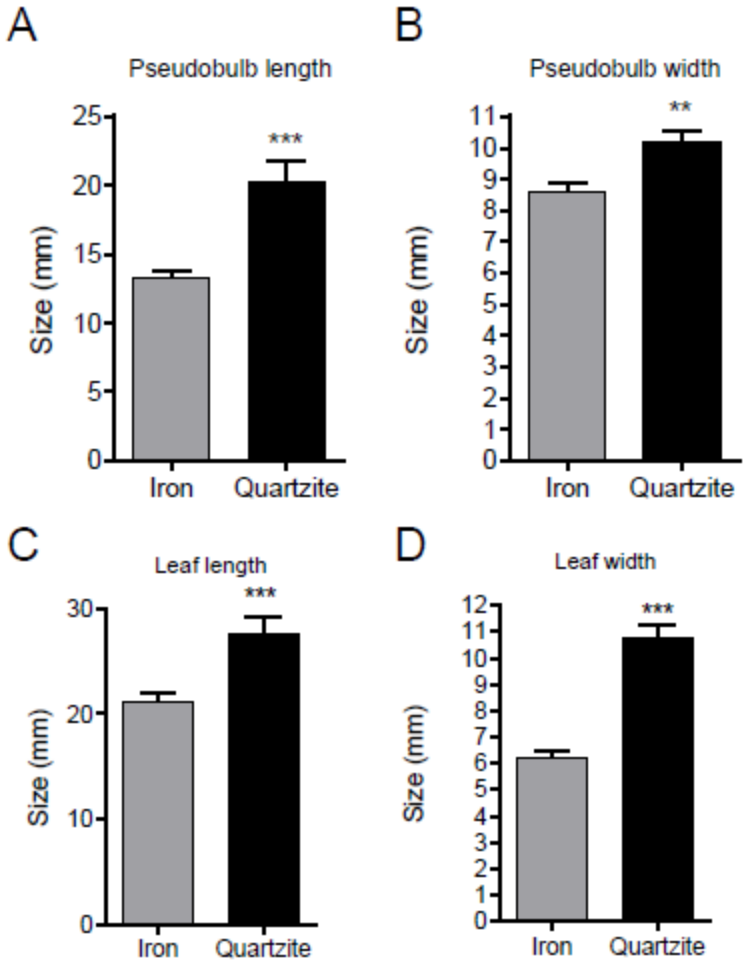

FIGURE 5. ***VARIATION IN RESOURCE ALLOCATION OF INDIVIDUALS OF* CATTLEYA LILIPUTANA *GROWING IN IRON AND QUARTZITE OUTCROPS. (A) PSEUDOBULB LENGTH, (B) AND WIDTH, (C) LEAF LENGTH, (D) AND WIDTH.**P<0.01; ***P<0.001 FOR STUDENT T TEST.***

Dwarfism has been documented to be an adaptive response to heavy metal adaptation. The smaller size of individuals growing at iron outcrops, suggest the hypothesis that *C. liliputana* evolved local adaptation mechanisms to cope with high concentrations of toxic elements.

Heavy metal accumulation

Root tissues of individuals growing in iron outcrops presented concentrations of Fe, Al and Pb from two to six times higher than individuals growing in quartzite. Pseudobulb tissue followed a similar pattern but with concentrations smaller than roots. Zinc, an element that did not vary in concentration between soil types, had also similar concentrations in tissues. The higher concentration of heavy metal according to their presence in the soil suggest that *C. liliputana*hyper accumulates toxic elements at iron sites in the roots and pseudobulb.

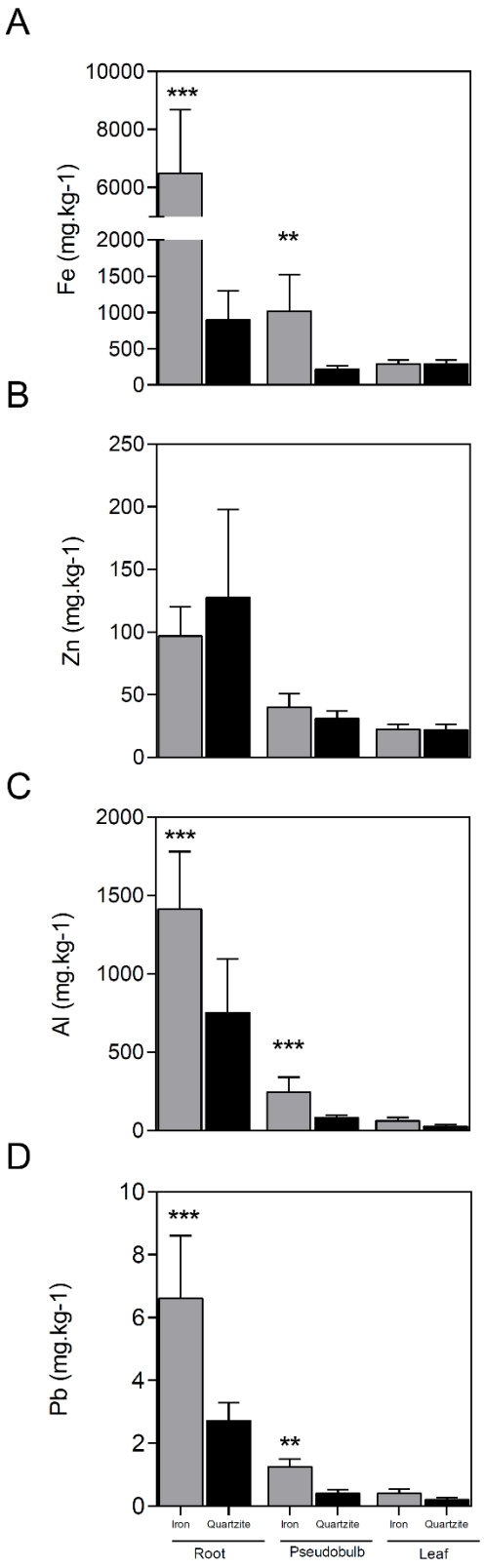

FIGURE 7. METAL HYPER ACCUMULATION IN* CATTLEYA LILIPUTANA *TISSUE. QUANTIFICATION OF IRON (A), ZINC (B), ALUMINUM (C), AND PLUMB (D) IN ROOT, PSEUDOBULB AND LEAF OF* C. LILIPUTANA *INDIVIDUALS GROWING IN IRON (GREY) AND QUARTZITE (BLACK) ROCK OUTCROPS. P<0.001; **P<0.01 FOR STUDENT T TEST.***

Identification of candidate genes for heavy metal adaptation

We sequenced approximately 8 Gbp of data and 100 000 000 raw sequencing reads of good quality (Phred>20) from two normalized cDNA libraries (Supplemental Table 1). The two libraries were prepared using RNA from leaves, pseudobulb and root of two *C. liliputana* populations. The *de novo* assembler Trinity (Grabherr et al. 2011) produced 143 963 contigs that clustered into 111 8046 nonredundant transcripts (unigenes) for IRN library and 210 553 contigs that clustered into 173 2916 nonredundant transcripts for QTZ library. The mean size of the unigenes was 572.28 bp for IRN and 483.82 for QTZ (Supplemental Table 1).

All unigenes were annotated using sequence similarity searches against the public NCBI nonredundant (nr) database using the BLASTX algorithm with an E-value threshold of 1e-06. The results showed that 88 301 unigenes had at least one significant hit to existing genes in the database (Supplementary Fig. 2). The remaining 203 036 sequences did not match any known sequences and may be considered novel transcripts, untranslated regions, noncoding RNA or short sequences not containing a protein domain. The species distribution of the top hits against the NR database showed that the majority matched with *Phoenix dactylifera*, *Elaeisguineensis*and *Vitis vinifera* (Supplementary Fig. 3). Transcripts showed sequence matches with orchid species such as *Phalaenopsis equestris*, *P*. hybrid cultivar, *P. aphrodite*, *P. amabilis*, *Dendrobium catenatum*, *D. chrysotoxum* (ranging from 0.87% to 0.09). Possible functions of transcripts with significant BLAST hits were classified for three main Gene Ontology terms (GO level 2): biological process (104 813 unigenes), cellular component (53 176) and molecular function (81 293). Figure 2 shows the level 2 GO classification of the transcriptomes of each soil type. Among the biological process terms, most of the unigenes were assigned to metabolic processes and molecular function (Supplemental Fig. 3).

Candidate genes for metal adaptation

We have selected 35 candidate genes based in physiological and genetic studies of plant adaptation to metal-rich environments (Supplemental table 3). These genes include a range of membrane transporters in plants with important roles for homeostasis of metal elements, including the metal tolerance proteins (MTPs), iron-tranporters, the calcium-proton antiporters (CAXs), magnesium transporter (MRS2) and others. Even though we were not able to assign the role of these genes in the adaptation process of *C. liliputana*, the genomic database open the possibility for future genetic studies on the mechanism of soil adaptation in Neotropical orchids.

Discussion

Ecological discontinuity can impose strong natural selection (Turner et al. 2010, Leinonen et al. 2011, Sexton et al. 2014). Plant adaptation to different soil environment is an evidence of the strong selective pressure driven by soil discontinuity and contrasting soil properties that result in sharp ecosystem differences even over small spatial scales (Brady et al. 2005, Sambatti and Rice 2006). Among such examples of edaphic specialization, plant adaptation to metal-rich soils has been used to test evolutionary and ecological hypothesis addressing mechanistic questions of adaptive evolution in natural and contaminated environments (Krämer et al. 2007, Hong-Bo et al. 2010, Hanikenne and Nouet 2011, Daghino et al. 2015, Mandáková et al. 2015).

The edaphic factor of metal-rich soils is multifaceted, involving chemical, physical, and biotic components. Arguably, the most influential factor on plant adaptation in these sites is the chemical one (Brady et al. 2005). Metal-rich sites, such as serpetine soils, frequently contain elevated levels of heavy metals, such as iron, nickel, chromium, and cobalt, which are toxic to most plants. Additionally, serpentine soils are often deficient in essential plant nutrients such as nitrogen, potassium, and phosphorus and are characterized by low calcium-to-magnesium ratios with Ca at significantly lower concentrations relative to surrounding areas.

Soil discontinuity in the Iron Quadrangle impose sharp contrast in the concentration of toxic elements similar to what is observed in serpetine soils. The analysis of outcrop soils where *C. liliputana* is found suggested that soils proprieties differ markedly but is different to the expected proprieties of serpentine soils. For example, no significant difference was found between soil types for major nutrients such as N, K, CA, Mg and organic matter, with exception of phosphorous. Iron soils reported here do not have a low calcium-to-magnesium ratio, a common feature in serpentine soils. This result suggest that nutritional proprieties of iron and quartzite soils are not significantly different. However, concentration of toxic elements found here differed markedly between soil types in accordance with (Cristina et al. 2013). For example, concentration of Fe was 45x higher in iron outcrops. Concentrations of Al, Pb, Cu and Mn were also significantly higher in iron outcrops. These results suggest that concentration of toxic elements may be the major source of selective pressures between soil types.

High concentration of toxic elements can impact survival and growth, resulting in the divergence of demographic and morphological traits of populations (Gardner and Macnair 2000, Sambatti and Rice 2006, Kazakou et al. 2010). Metal-rich soils are expected to be stressful environments for plant growth. Therefore, we tested the hypothesis that demographic structure of

populations in iron outcrops have signs of low growth and reproduction. In contrast, we found that *C. liliputana* is well adapted to environmental conditions at the iron outcrops. Individuals growing in iron outcrops had larger number of pseudobulbs and leaves and higher reproductive rate. On the other hand, individuals growing in quartzite outcrops were found to have higher resource allocation in leaves and pseudobulbs, although the mean number of pseudobulbs and leaves per individuals is smaller.

Adaptation to local environment is the result of natural selection caused by the abiotic and biotic factors present locally. If gene flow occurs frequently across habitats, local adaptation is less likely to occur, unless selection pressures are extremely strong (Holt and Gomulkiewicz 1997, Lenormand 2002). It is generally assumed that the scale of local adaptation reflects the scale of environmental heterogeneity (Galloway and Fenster 2000, Hoeksema and Forde 2008, Hereford 2009). However, a meta-analysis showed that environmental divergence explained only a small part of the variation in the magnitude of local adaptation (Hereford 2009). Therefore, adaptation over small spatial scales, as the one occurring by soil discontinuity, may be hindered by gene flow across habitats. Genetic isolation associated with divergence of reproductive characters was previously reported for *C. liliputana*(Leles et al. 2015). Approximate Bayesian Computation models also supported low gene flow between soil types and signs of demographic instability supporting the low reproductive rates found for quartzite populations (Leles et al., in prep).

Adaptation to high concentration of metals usually involves the exclusion strategy by which metals are stored in root cell wall and vacuoles, and thus kept sequestered away from photosynthetically active tissues. In contrast, a small number of plant species that evolved on naturally or anthropogenically metal-contaminated soils possess the ability to accumulate and tolerate high metal concentrations in above-ground tissues (Krämer 2010, Maestri et al. 2010). We detected high concentrations of metals in root and pseudobulb, but not in the leaf of *C. liliputana*, suggesting a tolerance mechanisms for high concentration of metal in non-photosynthetically tissues.

We were able to detect in transcriptome sequences major cation membrane transporters including Vacuolar Iron Transporter homolog 1-like, Metal Tolerance Protein 2 (MTP2), Magnesium transporter MRS2-I-like and metal binding proteins able to chelate ions including Annexin and Iron Ion Binding Protein isoform X1 (Supplemental Table 2). Although we cannot test the direct role of these proteins in the adaptation process, transcripts can be used to produce molecular markers for expression studies to shed light in the molecular mechanisms driving hypertolerance in *C. liliputana.*

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Supplementary Material

Figure Legends

Figure S1. Fig 1. Sampled populations of *Cattleya liliputana* occurring in the Iron Quadrangle.(a) Espinhaço Range Region above 1,000 m a.s.l. in eastern tropical South America. (b) Altitude map of the Iron Quadrangle showing the *Cattleya liliputana* populations analyzed in the study. Modified from Leles et al., 2015.

Figure S2. Statistic of sequence annotation of assembled unigenes per soil type.

Figure S3. Functional annotation and comparison of the second-level GO terms among iron and quartzite transcriptome sequences of *Cattleya liliputana*.

Figure S1.

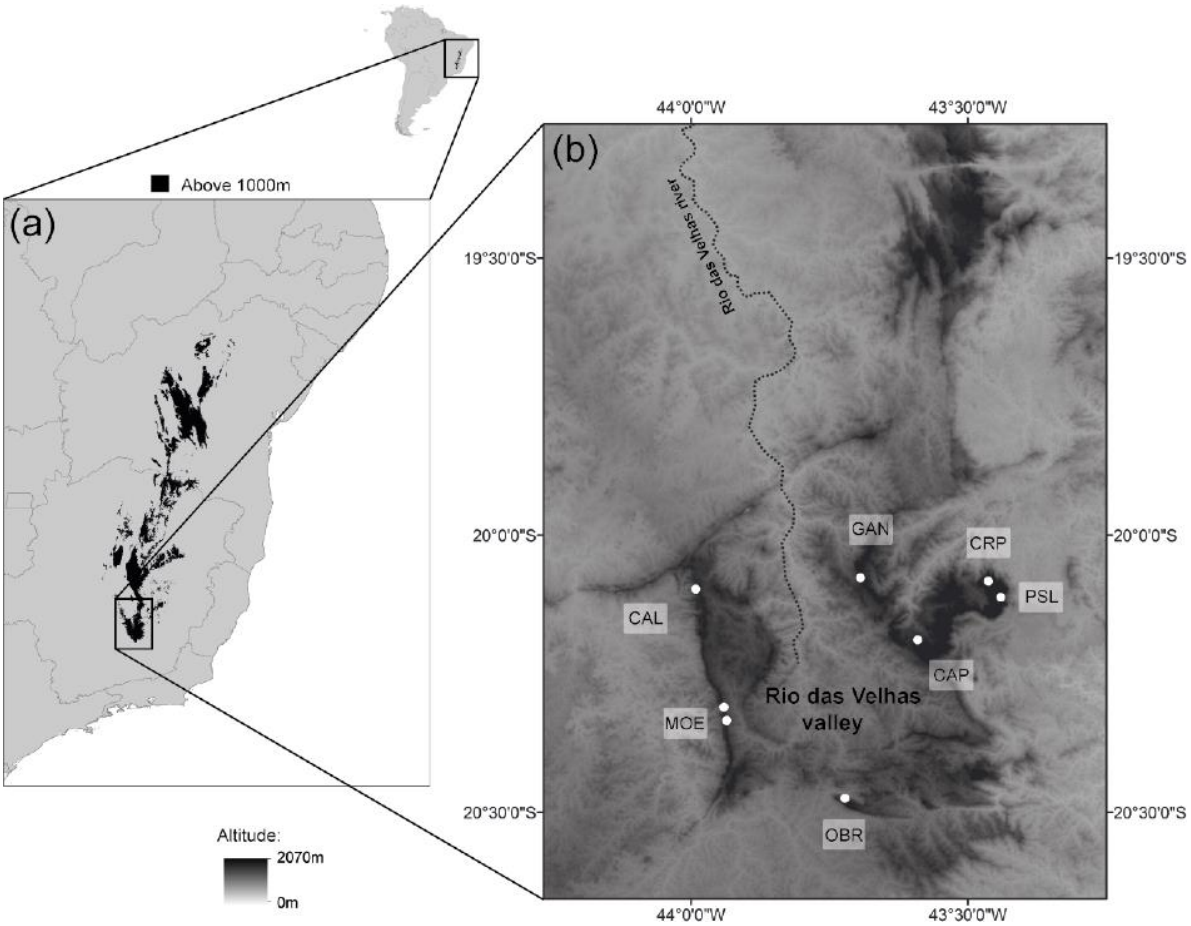
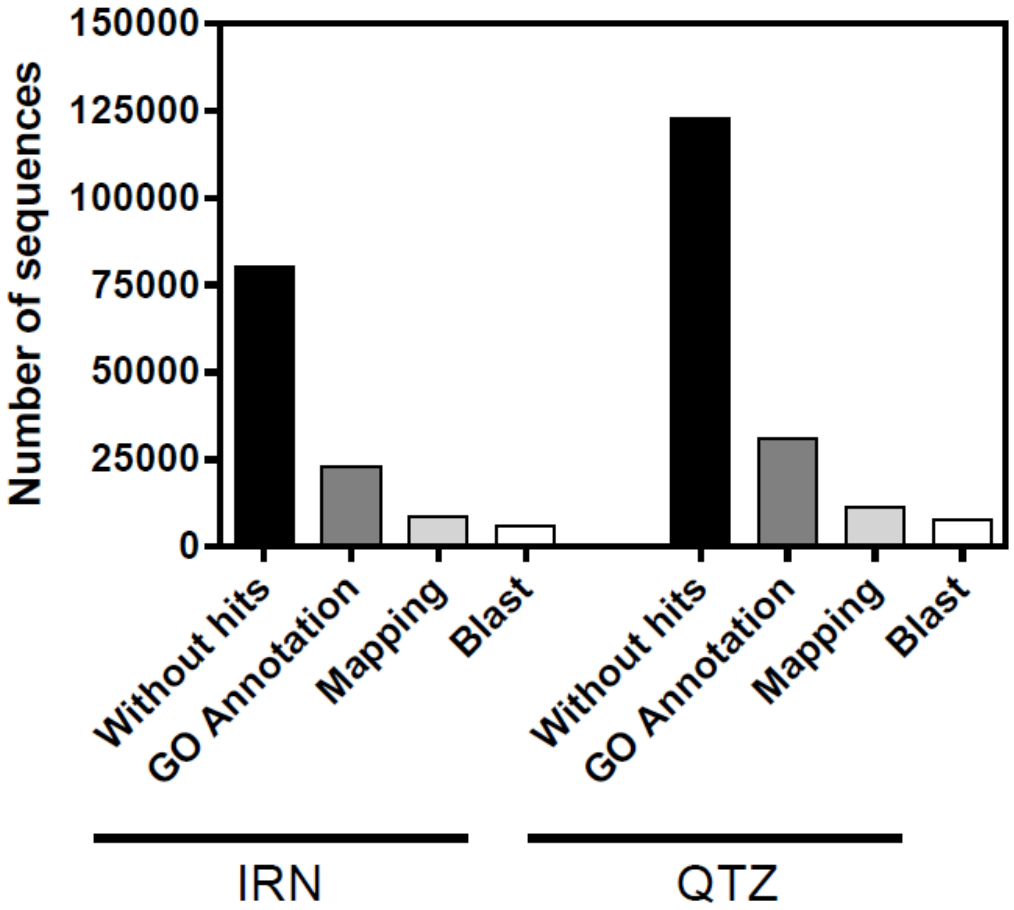

Above 1000m
(a)
Altitude:
2070m
0m
(b)
44°0'0"W
43°30'0"W
19°30'0"S
20°0'0"S
20°30'0"S
Rio das Velhas River
GAN
CRP
PSL
CAL
CAP
Rio das Velhas valley
MOE
OBR

Figure S2.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GO Annotation
Mapping
Blast
Without hits
GO Annotation
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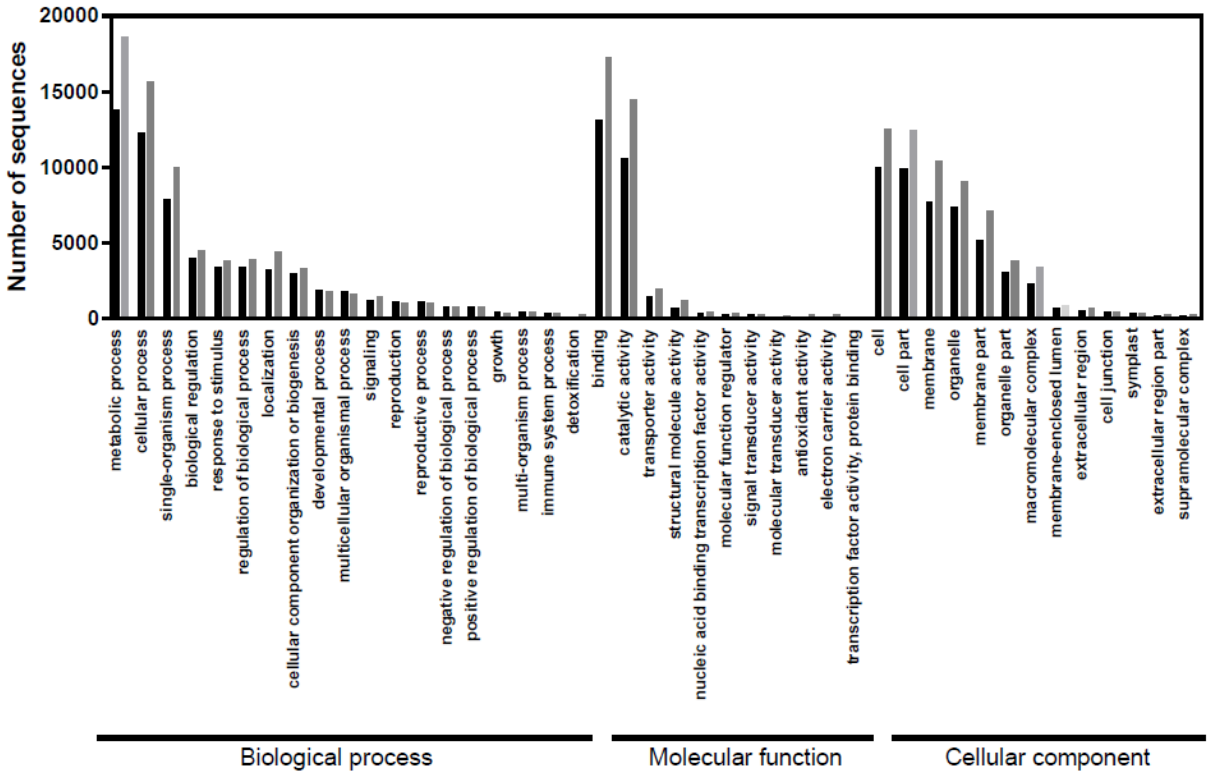
IRN
QTZ

Figure S3.


Number of sequences
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15000
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cellular process
single-organism process
biological regulation
response to stimulus
regulation of biological process
localization
cellular component organization or biogenesis
developmental process
multicellular organismal process
signaling
reproduction
reproductive process
negative regulation of biological process
positive regulation of biological process
growth
multi-organism process
immune system process
detoxification
binding
catalytic activity
transporter activity
structural molecule activity
nucleic acid binding transcription factor activity
molecular function regulator
signal transducer activity
molecular transducer activity
antioxidant activity
electron carrier activity
transcription factor activity, protein binding
cell
cell part
membrane
organelle
membrane part
organelle part
macromolecular complex
membrane-enclosed lumen
extracellular region
cell junction
symplast
extracellular region part
supramolecular complex
Biological process
Molecular function
Cellular component

Supplemental Table1. Statistical summary of cDNA sequences of *Cattleya liliputana* obtained for each sequenced soil type.

	Iron	Quartzite
Total bases	81 201 374	120 495 756
Number of reads	50 990 750	49 248 642
GC (%)	51.69	47.98
Q 20 (%)	95.2	95.5
Q 30 (%)	88.84	89.57
Number of contigs	143963	210553
Average lenth of contigs (bp)	564.04	572.28
Number of unigenes	118046	173291
Average lenth of unigenes (bp)	490.91	483.82

Supplemental Table 2. Candidate genes for metal adaptation in *Cattleya liliputana*.

Gene Class	Gene name	Sequence ID	Seq. Length	Similarity	Blast Top Hit	Taxonomy Name	Mapping GO Term	Annotation GO Term
MTP	MTP2 metal tolerance protein 2	Unigene_026056	1534	78.05%	gi|720043104|	Nelumbo nucifera	response to zinc ion-IBA;transmembranetransport-IEA;cationtransport-ISS;cation transport-IEA	efflux transmembrane transporter activity;regulation of sequestering of zinc ion;zinc II ion transmembrane transport
Ion transporter	ABC transporter B family member 1, partial	Unigene_034337	616	92.25%	gi|659134217|	Cucumis melo	auxin influx-IEA;anthocyanin accumulation in tissues in response to UV light-IEA;auxin polar transport-IEA;membrane-IEA	trichome morphogenesis;vernalizationresponse;metabolicprocess;regulation of cell size
MRS2 -1	Magnesium transporter MRS2-I-like	Unigene_035296	2035	86.50%	gi|743774477|	Elaeisguineensis	transmembrane transport-IEA;metal ion transmembrane transporter activity-IEA;magnesium ion transmembrane transport-IBA	magnesium ion transmembrane transporter activity;magnesium ion transport

CC1	two pore calcium channel protein 1 isoform X1	Unigene_102191	2643	85.20%	gi|743795741|	Elaeisguineensis	calcium ion transport-IBA;calcium ion transport-IEA;	membrane depolarization during action potential;vacuoleorganization;regulation of ion transmembrane transport
Iron transport	vacuolar iron transporter 1.1	Unigene_003817	1245	86.25%	gi|695043888|	Musa acuminata subsp. malaccensis	manganese ion transmembrane transport-IBA;iron ion transmembrane transport-IMP;iron ion transmembrane transport-IBA	cellular manganese ion homeostasis;iron ion transmembrane transporter activity;vacuolar membrane;iron ion transmembrane transport;intracellular sequestering of iron ion
Iron transport	vacuolar iron transporter homolog 1-like	Unigene_017428	800	77.75%	gi|743899096|	Populuseuphratica	manganese ion transmembrane transport-IBA;iron ion transmembrane transporter activity-IBA;intracellular sequestering of iron ion-IBA;cellular response to iron ion-IBA;cellular	cellular manganese ion homeostasis;iron ion transmembrane transporter activity;iron ion transmembrane transport;intracellular sequestering of iron ion

							manganese ion homeostasis-IBA	
Iron transport	zinc/iron regulated transporter-like protein 1	Unigene_039748	1267	78.80%	gi|700367850|	Dendrobium catenatum	transmembrane transport-IEA;oxidoreductase activity-IEA;2-alkenal reductase [NAD(P)] activity-IEA;metal ion transmembrane transporter activity-IEA;zinc ion transmembrane transporter activity-IEA	zinc II ion transmembrane transport;zinc ion transmembrane transporter activity;oxidoreductaseactivity;integral component of membrane
YSL12	probable metal-nicotianamine transporter YSL12	Unigene_056433	1423	82.85%	gi|743852231|	Elaeisguineensis	transmembrane transport-IEA;membrane-IEA;integral component of membrane-IEA	transmembrane transport;integral component of membrane

Iron binding	iron ion binding protein isoform X1	Unigene_098909	1246	88.00%	gi|223944829|	Zea mays	iron ion binding-IEA;oxidoreductaseactivity-IEA;metal ion binding-IEA;oxidation-reduction process-IEA	iron ion binding;oxidation-reductionprocess;oxidoreductase activity
Cax	CAX-interacting protein 4	Unigene_006439	1329	84.10%	gi|743818575|	Elaeisguineensis	lithium ion transport-IEA;protein import into peroxisome matrix-IEA;lipidtransport-IEA;zinc ion binding-IEA;intra-Golgi vesicle-mediated transport-IEA;calcium ion transport-IEA;positive regulation of calcium ion transport-IEA	;calcium ion transport;lithium ion transport;nucleic acid binding;lipidtransport;positive regulation of calcium ion transport;;zinc ion binding
Cax	Cation/calcium exchanger 4	Unigene_012818	976	71.35%	gi|587879059|	Morusnotabilis	transmembrane transport-IEA;membrane-IEA;integral component of membrane-IEA	membrane

Cax	Cax7, partial	Unigene_113472	406	80.80%	gi|171194117|	Arabidopsis lyrata	transmembrane transport-IEA;cationtransport-ISS;cation transmembrane transport-NAS;integral component of membrane-IEA;sodium ion transmembrane transport-ISS;cation:cationantiporter activity-NAS;cation:cation antiporter activity-ISS;calcium:sodium antiporter activity-ISS	sodium ion transmembrane transport;para-aminobenzoic acid metabolic process;animal organ senescence;calcium:sodium antiporter activity;integral component of membrane
Annexin	annexin-like protein RJ4	Unigene_028703	1215	76.30%	gi|743821249|	Elaeisguineensis	calcium ion binding-IEA;calcium-dependent phospholipid binding-IEA	ion binding
Annexin	annexin ANNAT3, partial	Unigene_030119	1317	73.00%	gi|700255161|	Iris japonica	calcium ion binding-IEA;calcium-dependent phospholipid binding-IEA	calcium-dependent phospholipid binding;calcium ion binding

Annexin	annexin protein	D2-like	Unigene_040320	1424	83.60%	gi|725827541|	Ornithogalum longebracteatum	response to oxidative stress-IEA;copper ion binding-IEA;calcium ion transport-IEA;calcium ion binding-IEA;cellular cation homeostasis-IEA;potassium ion export-IEA;calcium ion transmembrane transport-IEA;zinc ion binding-IEA;divalentmetal ion transport-IEA;chromatin assembly or disassembly-IEA;response to desiccation-IEA;vacuolar membrane-IEA	Golgi organization;copper ion binding;cellular oxidant detoxification;calcium ion binding;cellular cation homeostasis;potassium ion export;ATPbinding;zinc ion binding;response to desiccation;

Annexin	annexin D4	Unigene_047220	1513	69.65%	gi|743845459|	Elaeisguineensis	membrane-IEA;integral component of membrane-IEA;calcium ion binding-IEA;response to osmotic stress-IEA;calcium-dependent phospholipid binding-IEA;response to abscisic acid-IEA;plasmodesma-IEA	ion binding;response to stimulus
Annexin	annexin D1-like	Unigene_084036	1230	80.80%	gi|672110289|	Phoenix dactylifera	calcium ion binding-IEA;calcium-dependent phospholipid binding-IEA	calcium-dependent phospholipid binding;calcium ion binding

CIPK	CBL-interacting serine/threonine-protein kinase 12-like	Unigene_095806	1790	83.35%	gi|659078449|	Cucumis melo	protein binding-IPI;nucleotide binding-IEA;membrane-IEA;integral component of membrane-IEA;phosphorylation-IEA;transferaseactivity-IEA;kinaseactivity-ISS;kinaseactivity-IEA;signaltransduction-IEA;protein kinase activity-IEA;protein serine/threonine kinase activity-IEA;ATP binding-IEA;proteinphosphorylation-IEA;plasma membrane-ISM	protein serine/threonine kinase activity;plasmamembrane;signaltransduction;proteinphosphorylation;integral component of membrane;proteinbinding;ATP binding

CIPK	CBL-interacting protein kinase 19-like isoform X1	Unigene_099273	1137	78.75%	gi|672131616|	Phoenix dactylifera	nucleotide binding-IEA;signaltransduction-IEA;membrane-IEA;integral component of membrane-IEA;phosphorylation-IEA;transferaseactivity-IEA;protein kinase activity-IEA;kinaseactivity-IEA;protein serine/threonine kinase activity-IEA;ATP binding-IEA;proteinphosphorylation-IEA;plastid-RCA	plastid;membrane;protein kinase activity;phosphorylation; nucleotide binding
KUP	potassium transporter 7	Unigene_009843	2118	89.90%	gi|960459473|	Brachypodiumdistachyon	potassium ion transmembrane transport-IEA;potassium ion transport-IEA;potassium ion transmembrane transporter activity-IBA;potassium ion transmembrane transporter activity-IEA;membrane-IBA;membrane-RCA;membrane-	cytoplasmic vesicle;potassium ion transmembrane transporter activity;potassium ion transmembrane transport;cellular response to phosphate starvation;glucosinolate biosynthetic process;integral component of membrane;galactolipid biosynthetic process

							IEA;glucosinolate biosynthetic process-IEA;integral component of membrane-IEA;galactolipid biosynthetic process-IEA;cytoplasmicvesicle-RCA;cellular response to phosphate starvation-IEA;transport-IEA;ion transport-IEA	
KUP	probable potassium transporter 17 isoform X1	Unigene_026683	2950	83.45%	gi|672136312|	Phoenix dactylifera	potassiumiontransmembranetransport-IEA;potassiumiontransport-IEA;potassiumiontransmembranetransporteractivity-IBA;potassiumiontransmembranetransporteractivity-IEA;membrane-IBA;membrane-RCA;membrane-IEA;integralcomponentofmembrane-IEA;transport-IEA;iontransport-IEA	potassium ion transmembrane transporter activity;potassium ion transmembrane transport;integral component of membrane

KUP	probable potassium transporter 11	Unigene_053263	2396	85.95%	gi|672157048|	Phoenix dactylifera	potassiumiontransmembranetransport-IEA;potassiumiontransport-IEA;potassiumiontransmembranetransporteractivity-IBA;potassiumiontransmembranetransporteractivity-IEA;membrane-IBA;membrane-IEA;integralcomponentofmembrane-IEA;iontransport-IEA	potassium ion transmembrane transporter activity;potassium ion transmembrane transport;integral component of membrane
KUP	putative potassium transporter 8	Unigene_056153	2358	85.30%	gi|743782352|	Elaeisguineensis	regulation of meristem growth-IEA;methionine biosynthetic process-IEA;potassium ion transmembrane transport-IEA;potassium ion transport-IEA;potassium ion transmembrane transporter activity-IBA;potassium ion transmembrane transporter activity-IEA;RNA splicing, via	RNA splicing, via endonucleolytic cleavage and ligation;plasmamembrane;potassium ion transmembrane transporter activity;potassium ion transmembrane transport;regulation of meristem growth;integral component of membrane;methionine biosynthetic process

								endonucleolytic cleavage and ligation-IEA;membrane-IEA;integral component of membrane-IEA;iontransport-IEA;plasma membrane-IBA	
KUP	potassium transporter 10-like	Unigene_071899	2766	86.75%	gi|743857727|	Elaeisguineensis	potassiumiontransmembranetransport-IEA;potassiumiontransport-IEA;potassiumiontransmembranetransporteractivity-IBA;potassiumiontransmembranetransporteractivity-IEA;membrane-IBA;membrane-IEA;integralc	potassium ion transmembrane transporter activity;potassium ion transmembrane transport;integral component of membrane

							omponentof membrane-IEA;iontransport-IEA	
KUP	potassium transporter 10-like	Unigene_093560	1563	85.30%	gi|743857727|	Elaeisguineensis	potassiumiontransmembranetransport-IEA;potassiumiontransport-IEA;potassiumiontransmembranetransporteractivity-IBA;potassiumiontransmembranetransporteractivity-IEA;membrane-IBA;membrane-IEA;integralcomponentofmembrane-IEA;iontransport-IEA	potassium ion transmembrane transporter activity;potassium ion transmembrane transport;integral component of membrane
KUP	probable potassium transporter 11	Unigene_115009	3400	86.35%	gi|672157048|	Phoenix dactylifera	potassium ion transmembrane transport-IEA;potassium ion transport-IEA;potassium ion transmembrane transporter activity-IBA	potassium ion transmembrane transporter activity;potassium ion transmembrane transport;integral component of membrane

Nitrate Transporter	protein NRT1/ PTR FAMILY 2.11-like	Unigene_009973	2350	76.20%	gi|743790946|	Elaeisguineensis	membrane-IEA;integral component of membrane-IEA;transport-IEA;transporter activity-IEA	membrane
Nitrate Transporter	probable peptide/nitrate transporter At3g43790 isoform X4	Unigene_010720	2846	81.70%	gi|672189693|	Phoenix dactylifera	transmembrane transport-IEA;membrane-IEA;integral component of membrane-IEA	transmembrane transport;integral component of membrane
Nitrate Transporter	protein NRT1/ PTR FAMILY 7.3-like isoform X1	Unigene_036023	2322	82.90%	gi|743778802|	Elaeisguineensis	nitratetransmembranetransporteractivity-IEA;membrane-IEA;integralcomponentofmembrane-IEA;nitratetransport-IEA;transport-IEA;transporteractivity-IEA	nitrate transport;integral component of membrane;nitrate transmembrane transporter activity
Nitrate Transporter	protein NRT1/ PTR FAMILY 7.2 isoform X1	Unigene_111364	2908	80.95%	gi|743862356|	Elaeisguineensis	membrane-IEA;integral component of membrane-IEA;transport-IEA;transporter activity-IEA	transporter activity;transport;integral component of membrane

Nickel Transporter	nickel transporter, partial	Unigene_004273	205	56.00%	gi|968329116|	Methylobacteriumaquaticum	NA	NA
Proton pump	proton pump-interactor 1-like isoform X1	Unigene_017314	2685	68.15%	gi|672109749|	Phoenix dactylifera	regulation of proton transport-IEA;membrane-IEA;integral component of membrane-IEA;endoplasmicreticulum-IEA;plasma membrane-IEA	membrane
Proton pump	pyrophosphate-energized vacuolar membrane proton pump	Unigene_027406	3173	92.45%	gi|672130541|	Phoenix dactylifera	auxin polar transport-IEA;inorganic diphosphatase activity-IEA;chloroplast-IEA;plant-type vacuole membrane-IEA;mitochondrion-IEA;membrane-IEA;integral component of membrane-IEA;leafdevelopment-IEA;establishment or maintenance of transmembrane electrochemical gradient-	hydrogen-translocating pyrophosphatase activity;response to water deprivation;proton transport; plant-type vacuole membrane;auxin polar transport;response to salt stress;establishment or maintenance of transmembrane electrochemical gradient;inorganic diphosphatase activity;leaf development

							IEA;metabolicprocess-IEA;transmembranetransport-IEA;protontransport-IEA;response to salt stress-IEA;response to water deprivation-IEA;plant-type vacuole-IEA	
Proton pump	V-type proton ATPase subunit C-like	Unigene_063558	1662	90.85%	gi|672112899|	Phoenix dactylifera	unidimensional cell growth-IEA;chloroplast-IEA;calcium ion transport-IEA;lignin biosynthetic process-IEA;cellulose metabolic process-IEA;cellgrowth-IEA;vacuolar proton-transporting V-type ATPase, V1 domain-IEA;root hair cell differentiation-IEA;proton-transporting ATPase activity, rotational mechanism-IEA;Golgiorganization-IEA;vacuoleorganization-IEA;hydrogen ion	regulation of carbohydrate biosynthetic process;cell tip growth;ATP hydrolysis coupled proton transport;vacuoleorganization;plasmamembrane;calcium ion transport;Golgiorganization;response to misfolded protein;Golgi vesicle transport;vacuolar proton-transporting V-type ATPase, V1 domain;plant-type vacuole

							transmembrane transporter activity-IEA;ATP hydrolysis coupled proton transport-IEA;response to salt stress-IEA;cell morphogenesis-IEA;	
Proton pump	vacuolar H+-ATP synthase 16kDa proteolipid subunit	Unigene_110427	999	98.65%	gi|6164957|	Dendrobium crumenatum	vacuolar proton-transporting V-type ATPase, V0 domain-IBA;proton-transporting ATPase activity, rotational mechanism-IBA;membrane-IEA;proton-transporting V-type ATPase, V0 domain-IEA;hydrolaseactivity-IEA;metabolicprocess-IEA;protontransport-IEA;hydrogen ion transmembrane transporter activity-IEA;ATP hydrolysis coupled proton transport-	ATP hydrolysis coupled proton transport;proton-transporting ATPase activity, rotational mechanism;vacuolaracidification;metabolicprocess; integral component of membrane;vacuolar proton-transporting V-type ATPase, V0 domain

			IEA;vacuolaracidification-IBA;vacuole-IEA;transport-IEA;iontransport-IEA;vacuolar membrane-IEA

Capítulo 2

The importance of multi-scale spatial analyses for the delimitation and management of protected area buffer zones

Manuscrito formatado para revista *Conservation Biology*

The importance of multi-scale spatial analyses for the delimitation and management of protected area buffer zones

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Introduction

The concept of buffer zones in PA management was initially proposed in the 1930s but rose to prominence as a conservation instrument in the 1970s when it became an integral part of UNESCO's Man and Biosphere Programme(UNESCO 1974, 1995). The prime purpose of a buffer zone is to insulate core areas where biodiversity conservation is the primary objective from potentially damaging external influences in the wider area, and promote the integration of core areas into the wider land- or seascape. In principle, this function allows a range of sustainable activities to take place in the buffer area (Bennett and Mulongoy 2006), whilst maintaining "pristine" core zones which are more likely to be insulated from activities which are prevalent in the wider landscape matrix, reducing the propagule pressure from invasive species and access to potentially unsustainable use.

Although the concept of a buffer zone may be straightforward, its design and implementation raise many political and social challenges. Buffer zones can be viewed as a restriction to current practices of agricultural production, mining, urban development, and land use which are often the main economic components of emerging economies. In this context, adequately understanding the interaction between human activities, biodiversity conservation and the resulting dynamics under an eco-social framework is important to achieve desired conservation outcomes.

Countries working on the implementation of buffer zones and integration of PAs into the wider landscape struggle to overcome the debate from the restriction of land use around PAs. For example, Brazilian legislation requires that PAs, with few exceptions, must delimit buffer zones and regulate land use in the buffer area in order to promote long-term conservation of local biodiversity (Law Nº 9.985). However, the majority of PAs in Brazil lack the delimitation or effective management of buffer zones in part due to the inability to implement these actions driven the constant conflicts of interest regarding land use restrictions. In addition, most of the buffer zones propositions lack a

multi-scale analysis, meaning no knowledge on how to appropriately scale a buffer to maximise the effectiveness per unit area currently exists, and such scalability is essential, especially in complex landscapes where various dynamics in terms of costs and benefits should be accounted for and communicated to local stakeholders. The understanding of the relative trade-offs in terms of conservation gained by implementing buffer zones, relative to direct changes in revenue and increases in cost and other forms of pressure from economic sectors will increase the transparency and help to make decisions which secure local sustainable livelihoods and best mitigate the impacts of landscape-level infrastructural developments on protected areas.

We propose a multi-scale landscape approach easily implemented by non-experts and provide a free and open-source user-friendly tool, Multi-Scale Buffer (MSBuffer), in order to evaluate the landscape structure around PAs and explore the effects of changing buffer dimensions on the conservation outcomes (Fig. 1). This approach can be used to provide data of ecological threats, conservation priorities and possible sources of conflicts to guide the integration of PAs into the landscape. In order to show the data obtained by the multi-scale approach, we used the Brazilian state park "Parque EstadualTurístico do Alto Ribeira" (PETAR) as a case study. We show how multi-scale approaches can help decision makers to evaluate the landscape attributes and the effect of buffer size for conservation, increasing the transparency and avoiding conflicts during the establishment of buffer zones and management strategies.

The program requires that users upload a map file, an ecological relevant variable to be analyzed (forest cover, land use, species occurrence, ecologically valuable sites, etc) and set the multiple scales of interest. As an output, the user obtains a spatial calculation of the variable of interest according to the buffer scales, as well as maps corresponding to each buffer size. MSBuffer can be run as ArcGIS toolbox and is available at https://github.com/LEEClab/MSBuffer. The tutorial and explanation of MSBuffer analysis can be found in Supplemental Material 1.

Multi-scale analysis to support integration and connectivity of protected areas

The process of integrating PAs into the wider landscape requires assessing the broader context of the PA in order to provide information for stakeholders and decision makers. Assessing the broader context includes: (i) assessing the key biodiversity, setting goals and assessing connectivity gaps; (ii) assessing the socio-economical context; (iii) identifying sectors and policies, their constraints and opportunities; (iv) identifying major ecological threats to be buffered and gathering spatial information of how these variables are distributed in the landscape; and (v) putting it all together by aligning gaps and opportunities and creating scenarios (Ervin et al. 2010).

In our example, the PA is located at the border of a large Atlantic Forest remnant within a karst formation that harbours high density of cavities and calcareous outcrops. The PA area is large (35,772ha) and well connected to forest fragments in the landscape, constituting part of the largest Atlantic Forest fragment (Fig 1). The main biodiversity goal of the buffer zone is to protect forest remnants that promote connectivity, cave ecosystems and the underground water bodies that provide essential ecosystems services in the region. The region is rural and agricultural and mining are the main sectors in the region. Major threats to biodiversity include deforestation, fire and mining.

In order to map and quantify the occurrence of informative variables, we used the MSBuffer tool and publically available environmental monitoring data (links to the database can be found in the Supplemental Material 2).

Brief description of results from multi-scale analysis

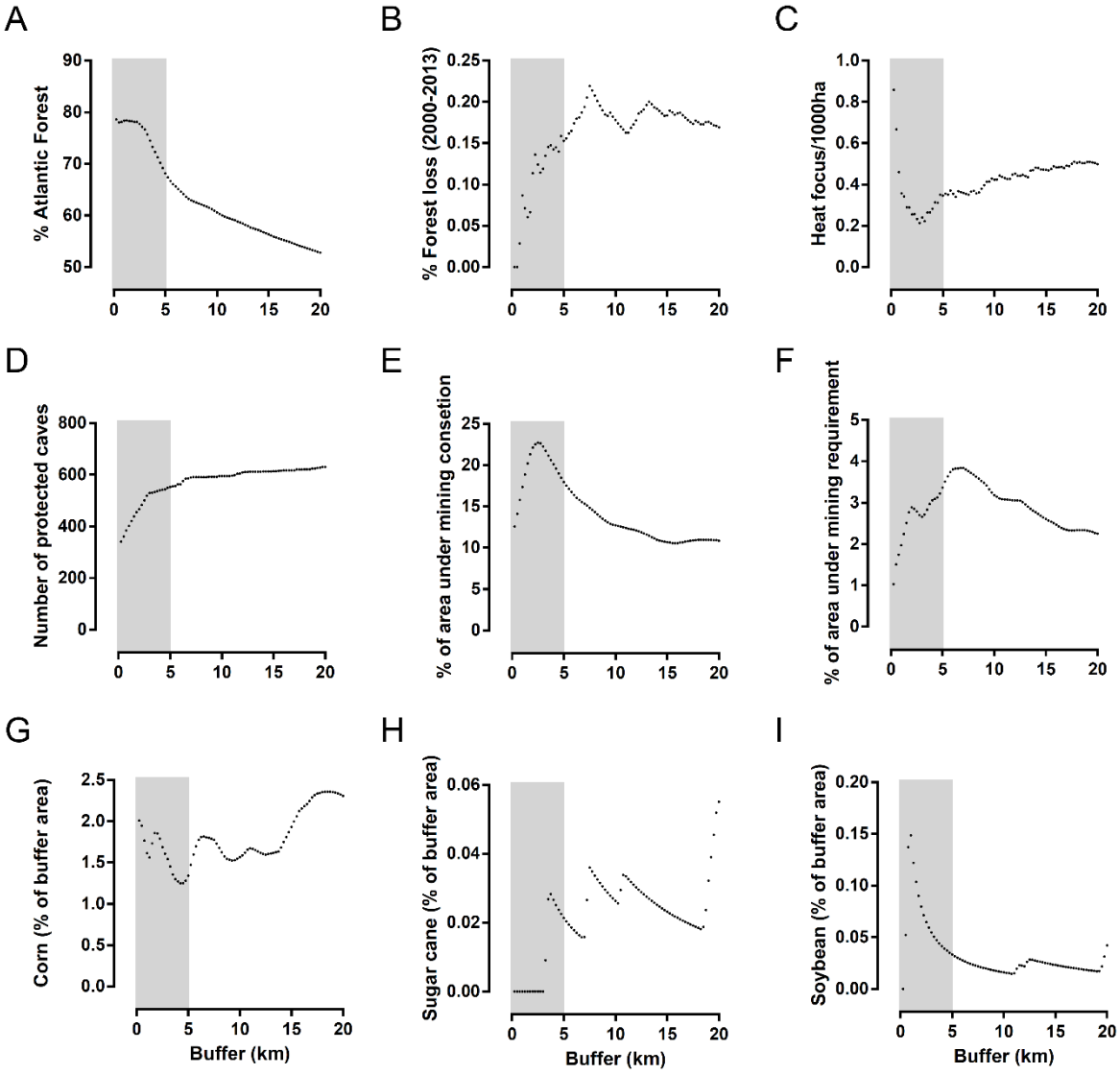
As expected, most of remaining Atlantic Forest fragments outside the PA was found close to the park borders. Interestingly, the density of Atlantic Forest remnants within the buffer zones was

found to be high up to a distance of 5 km and decrease rapidly for larger buffer sizes, where buffer reaches more anthropogenic landscapes and urban areas (Fig. 2A).

In order to measure the change in forest cover, we used the INPE satellite data based on Atlantic Forest remnants and looked for changes in forest cover between 2000 and 2013 ("SOS Mata Atlântica" 2014). Twenty nine deforested areas were found, totalling 323.08ha within 20km distance. Suppression sites were predominantly at the border of large fragments in contact with anthropogenic land uses, but decreased steeply towards the PA border, especially below 5km distance, suggesting the natural forest belt around the PA prevents deforestation within the core area (Fig. 2B). Heat focus, a proxy for fire occurrence, detected by the INPE fire monitoring program from 2014 to 2016 occurred predominantly in modified landscape close to agricultural and urban sites, and highlighting the value of the buffer in reducing the likelihood of fire in forested areas where it may drive changes in community structure. High density of heat focus was observed close to the border of the PA, suggesting a resilient pressure of fire usage (Fig. 2C).

The majority of caves in the region were located close to the park border. The number of caves increased steeply with buffer size until around 5km (Fig. 2D). Occurrence of caves was found to be accompanied by strong pressure for mining. The area under mining concession reached over 20% under 5km distance (Fig. 2E), co-occurring with most of the caves outside the PA border. The areas under mining requirement were shifted to distances over 5km (Fig. 2F), suggesting that mining pressure is still spreading in the landscape.

Maize was the major crop produced in the region with over 8.000ha in total, around 2% of buffer area (Fig. 2G). Other crops such as soybean and sugar cane were sparse, reaching around 0.05% of buffer area (Figs. 2H and I). The result suggests that decision makers should not be majorly concerned regarding impacts on agricultural production by possible buffer restrictions.



Putting all together

The multi-scale analysis of buffer size shows a well preserved natural forest belt of 5km around the PA which includes the majority of cave formations not included within the PA borders. The result suggests that this region should be the core buffer zone for the park. This scenario would protect around 50,000 ha of Atlantic Rainforest and 231 caves, with the minimal restriction of already established other land use types. The analysis of ecological threats also suggests that major conflicts for buffer delimitation is from mining companies, as high density of non-active mining titles was found in the area. The data produced by the multi-scale analysis can be used by decision makers

to recommend other buffer sizes, including larger buffers that integrate the PA with economical sectors to promote sustainable development taking into account strategies not considered here.

The importance of multi-scale approach:

The fast exploitation of natural resources has driven increasing concern on the long term conservation of biodiversity and effectiveness of protected areas worldwide (Lovejoy 2006, SCBD (Secretariat of the Convention on Biological Diversity) 2014). In the 2014 midterm assessment of progress towards the implementation of the Strategic Plan for Biodiversity 2011-2020, all elements of Aichi Biodiversity Target 11 showed progress, though only the 17% target for the conservation of terrestrial and inland waters was expected to be met by 2020 if current trends continued (Leadley et al. 2013, SCBD (Secretariat of the Convention on Biological Diversity) 2014). Between September 2015 and July 2016, the Secretariat of the Convention on Biological Diversity carried out regional capacity-building workshops on achieving Targets 11, which aimed, among other goals, to provide a platform for discussing various topics related to protected area and assist Parties to the Convention to identify their national priority actions that will be undertaken over the following four years. Actions targeting buffer zones were reported by Parties in road maps to implementation of national priority actions to Target 11 and in the National Biodiversity Strategies and Action Plans. For example, seven out of the 20 countries from the group of Like-Minded Megadiverse Countries explicitly reports the intent to implement actions to create buffer zones around protected areas. In addition, the Conference of the Parties to the Convention on Biological Diversity have invited all Parties to give due consideration to areas that increase connectivity and promote integration of PAs into the wider land- and seascape in establishing new or expanding existing PAs (CBD 2016).

However, the lack of multi-scale analysis of land cover and use around PAs means that the best conservation options for implementation of buffer zones have not been considered and

consequently the possible conflicts and costs of the options available are unknown. DeFries et al. (2010) suggested the greatest limitation to implementing a science-based approach to managing land uses surrounding protected areas is likely engagement between park managers and policy makers responsible for these decisions. This problem has restricted the implementation of the best conservation practices recommended by the United Nations and reduces the probability of achieving the Aichi Biodiversity Target 11. Our simple framework and a user friendly tool aims to allow park managers, researchers, decision-makers and other stakeholders to calculate and visualize how important variables are distributed in the landscape surrounding PAs and evaluate multiple size alternatives around PAs in order to implement the most appropriate buffer size and managing strategy.

We recommend that buffer studies should take into account the effect of multiple size alternatives across the landscape structure, and discuss the relative trade-offs in using buffers of different sizes. This approach will help to increase the transparency of decisions and allow a straightforward discussion of costs and benefits of multiple alternatives.

We believe that scientific community and society would benefit from more transparent decision-making in PAs buffer delimitations which optimise the effectiveness of buffers and better account for associated costs. By providing a scalable way to calculate and visualize the data we expect to facilitate implementation of buffer zones which can be applied to any protected area and account for any quantifiable information which is relevant to conservation. The use of MSbuffer can help researchers and managers anywhere to maximise the effectiveness of their reserves and plan the integration of PAs into the wider land and seascape.

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Figure legends:

Figure 1. Representative rationale of multi-scale analysis for the delimitation and management of protected area buffer zones. (A) Representative buffer zones, Atlantic Forest remnants (in green) and the localization of protected area PETAR. (B) Multi-scale approach of landscape distribution of variables of interest within buffers. Left, illustration of ring buffers around an area of interest used to extract landscape metrics; superposition of buffers with variables of interest such as mining titles (middle-right), deforestation sites (middle-left) and heat focus (right). (C) Proposed graph showing the distribution of the variable of interest obtained by the multi-scale analysis plotted against the buffer size.

Figure 2. Multi-scale analysis of buffer size obtained by the MSBuffer tool in the landscape around PETAR state park. (A) Percentage of Atlantic Forest cover within buffer, (B) Percentage of forest loss from 2000 to 2013, (C) distribution of satellite-detected heat focus, (D) number of cavities granted protection by the buffer zones, (E) percentage of buffer area under mining concession, (E) percentage of buffer area under mining requirement, (F) percentage of the buffer area occupied by maize plantations, (G) percentage of the buffer area occupied by sugar cane plantations, and (I) percentage of the buffer area occupied by soybean plantations.

Figure 1.

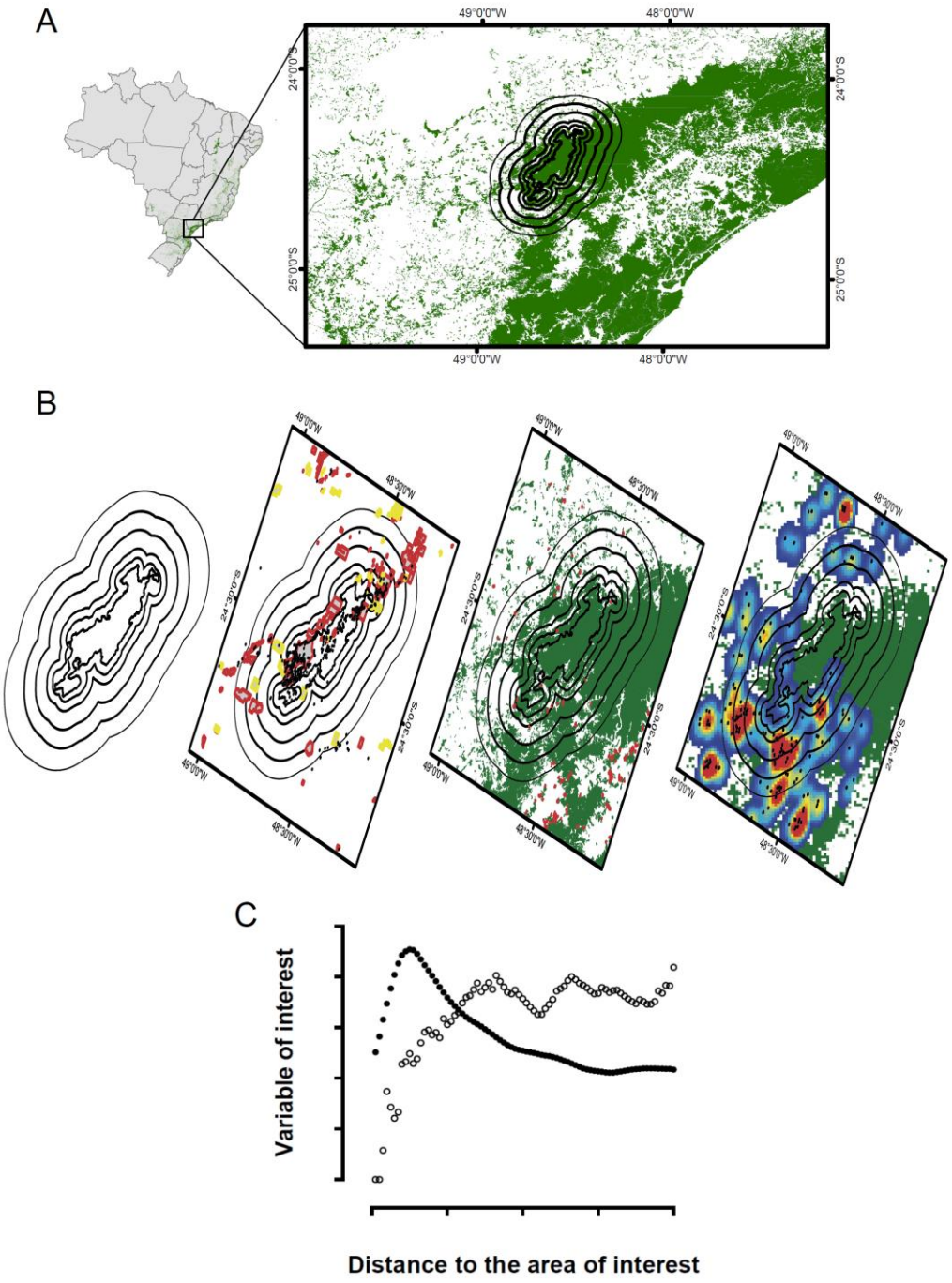
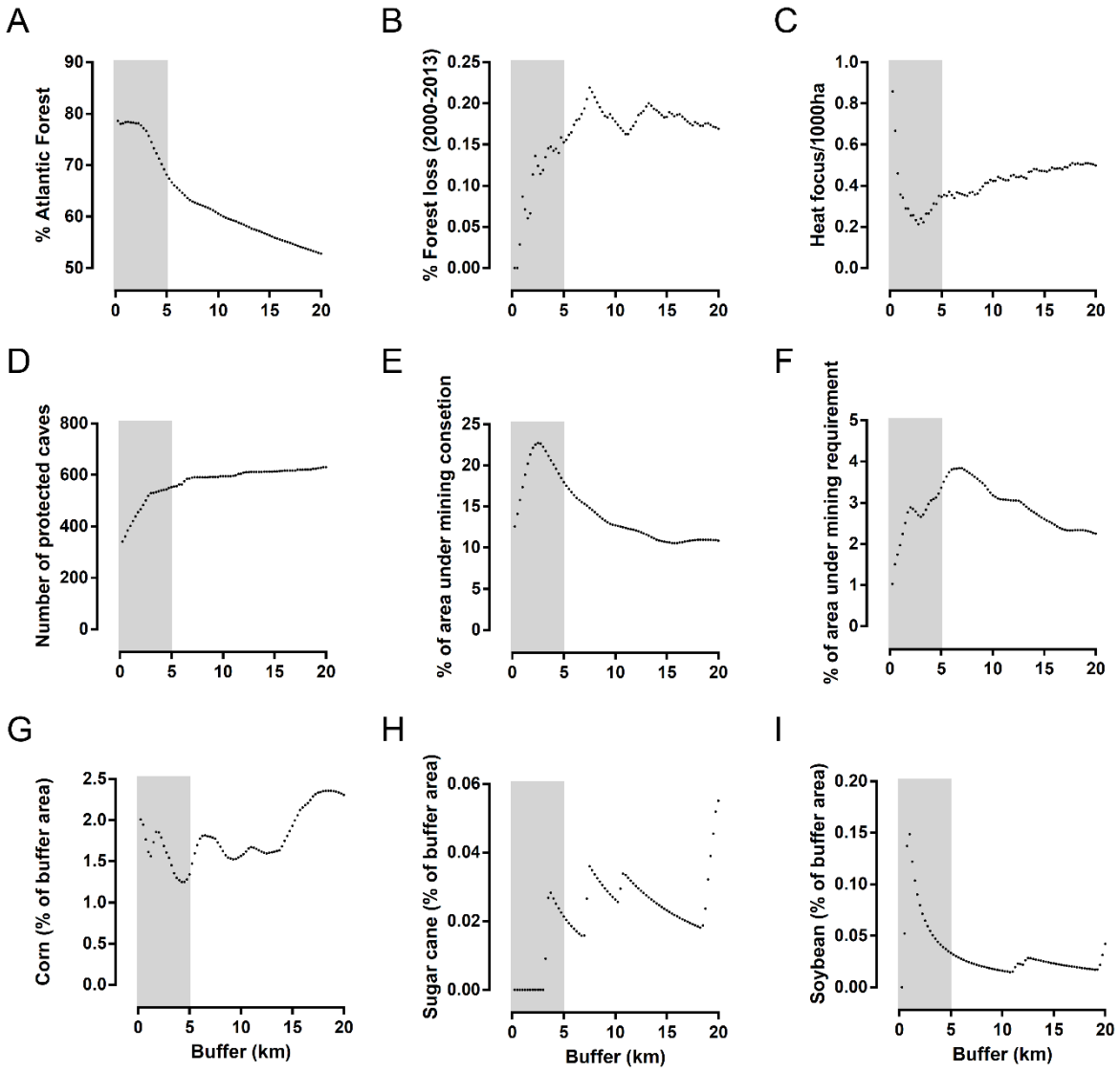

A
49°0'0"W
48°0'0"W
24°0'0"S
25°0'0"S
B
C
Variable of interest
Distance to the area of interest

Figure 2.


A
% Atlantic Forest
90
80
70
60
50
0 5 10 15 20
B
% Forest loss (2000-2013)
0.25
0.20
0.15
0.10
0.05
0.00
0 5 10 15 20
C
Heat focus/1000ha
1.0
0.8
0.6
0.4
0.2
0.0
0 5 10 15 20
D
Number of protected caves
800
600
400
200
0
0 5 10 15 20
E
% of area under mining consetion
25
20
15
10
5
0
0 5 10 15 20
F
% of area under mining requirement
5
4
3
2
1
0
0 5 10 15 20
G
Corn (% of buffer area)
2.5
2.0
1.5
1.0
0.5
0.0
0 5 10 15 20
Buffer (km)
H
Sugar cane (% of buffer area)
0.06
0.04
0.02
0.00
0 5 10 15 20
Buffer (km)
I
Soybean (% of buffer area)
0.20
0.15
0.10
0.05
0.00
0 5 10 15 20
Buffer (km)

Capítulo 3

Aichi Biodiversity Target 11 in the Like-Minded Megadiverse Countries

Manuscrito em preparação sob coordenação do Secretariado da Convenção sobre Diversidade Biológica

Abstract

The group of like-minded megadiverse countries (LMMCs) harbours a wealth of biological and cultural diversity. Through their recent actions, these countries have contributed to progress on Aichi Biodiversity Target 11, especially with respect to marine protected area expansion, where they are responsible for one-sixth of the area added in marine areas under national jurisdiction over the past two years. Here, we analyze the actions, ongoing projects, national goals, targets, strategies, and commitments proposed by the LMMCs to address the elements of Target 11. Results indicate that if implemented, actions proposed by the LMMCs will increase terrestrial and marine protected area coverage by 688,675 km^2 and 159.285 km^2 respectively. Of the 714 actions assessed for the qualitative elements of Target 11 (coverage of areas important for biodiversity and ecosystem services, ecological representation, connectivity, effective and equitable management, and integration in the wider land-and-seascape), 70% showed a strong likelihood of implementation. Based on a country-level analysis of all commitments, outstanding gaps for connectivity and integration will be addressed in at least half of the LMMCs, while significant progress towards addressing some of the gaps in effective and equitable management will be made, if commitments are implemented as proposed. This progress on the qualitative elements of Target 11 in the LMMCs will also provide benefits at the global level.

Introduction

Considerable declines in biological diversity have been measured across many ecoregions,prompting calls to significantly expand the coverage of protectedareas (Locke, 2013; Wilson, 2016; Büscher et al., 2017). As cornerstones for conservation, protected areasmay help addressthis 'biodiversity crisis' (Hoekstra et al., 2005) and avoid a sixth mass extinction (Dirzo et al., 2014; Ceballos et al., 2017).Despite challenges such as intense human pressures, gaps in effective management andequity, increased fragmentation (Jones et al., 2018; Tucker et al., 2018), protected areas remain effective tools for biodiversity conservation (Le Saout et al., 2013; Coatzee et al., 2014; Gray et al., 2016).

In 2010, the Strategic Plan for Biodiversity 2011-2020was adopted by the Conference of Parties (COP) to the Convention on Biological Diversity (CBD), with the vision that "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people" (CBD, 2010a). The Strategic Plan includes 20 headline targets (Aichi Biodiversity Targets), among which, Target11 states that, "By 2020, at least 17 per cent of terrestrial and inland water areas, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes" (CBD, 2010a).

Recent analysis shows that the growth in global protected area coverageis on track to meet or exceed the 17% and 10% coverage targets for terrestrial and marine protected areas, though gaps remain in ecological representation and the other qualitativeelements of Target 11(Gannon et al., 2017).However, for successful achievement of Target 11, all elements of the Target must be addressed in an integrated and holistic manner. Implementation of national biodiversity commitments is a key part of this effort, although the factors that facilitate implementation of national and regional commitments differ depending on local context. Some of the important factors include willingness, engagement, sustainable funding, appropriate institutional and governance framework, technical support, and capacity building, coordination and cooperation.

Towards this end, this article presents a case study of the efforts of the twenty Like-Minded Megadiverse Countries (LMMCs)[2] to accelerate implementation nationally and collectively.The group of LMMCs, developed for consultation and cooperation, was formed in 2002 to promote the three objectives of the CBD, namely conservation and sustainable use of biological diversity and the fair and equitable sharing of benefits arising from the use of genetic resources. The group initially included fourteen of the seventeen megadiverse countries, as identified by Conservation International (Mittermeier et al., 1997), along with Bolivia, Costa Rica and Kenya. Further members joined in the ensuing years, bringing the total to twenty countries when Ethiopia joined in 2016. In December 2016, the ministers and government representatives of the LMMCs adopted the Like-Minded Megadiverse Countries Carta to Achieve Aichi Biodiversity Target 11 (SCBD, 2016a). It also urgesallpartners and stakeholdersto support the implementation of commitments, including through the provision of financial resources and technical support for achieving Target 11 (SCBD, 2016a).

The 20 LMMCs together cover almost 29% of the Earth's terrestrial surface, yet contain a disproportionately large portion of its biodiversity, harbouring more than half of all currently-listed threatened species (IUCN, 2016a). The ten countries with the highest number of total bird species are all LMMCs (Birdlife International, 2016). Twenty-six of the 36 biodiversity hotspots (CEPF, 2018) occur in LMMCs, accounting for just over 50% of the total aggregate area of hotspots. LMMCs contain the majority of those botanical regions with highest levels of plant species richness and include six of the eight countries with the highest numbers of endemic flowering plant species (Pimm et al., 2014). With over half of the world's human population (UNSD, 2018), the LMMCs also contain a wealth of cultural diversity, including 14 of the 30 territories with the highest number of languages in danger (Moseley, 2010), and a high level of overall linguistic diversity (Lewis et al., 2016).

This article presents the status of Target 11 in the LMMCs as of May 2018,including progress that has occurred over the previous two years,an analysis of proposed priority actions, on-going projects, national goals, targets and commitments (hereafter national biodiversity commitments)related to Target 11, and the potential of thesecommitments and other opportunities to enhance progress towards achievement of the target at the national and global levels by 2020.The commitments and opportunities from LMMCs have implications to not only enhance the progress of Target 11, but provide benefits for stated objectives of other Aichi Biodiversity Targets and other Multilateral Environmental Agreements.

[2] Bolivia (Plurinational State of), Brazil, China, Colombia, Costa Rica, Democratic Republic of Congo, Ecuador, Ethiopia, Guatemala, India, Indonesia, Iran (Islamic Republic of), Kenya, Madagascar, Malaysia, Mexico, Peru, Philippines, South Africa, and Venezuela (Bolivarian Republic of).

Methods

Analysis of the status of Target 11 in the LMMCs

The status of elements of Target 11 for which indicators are available is presented based on information from global datasets. For the Target's quantitative elements (terrestrial and marine protected area coverage), information was obtained from the May 2018 release of the World Database on Protected Areas (WDPA) (UNEP-WCMC& IUCN, 2018). Although all CBD Parties are requested to report regularly to the WDPA, there are frequently time lags and omissions in reporting, and so this is necessarily an incomplete 'snapshot'of an extremely dynamic data set, and the trends over time are not represented in this analysis (Lewis et al., 2017).

Data in the WDPA is used as a basis for indicators of other elements. Mean percent coverage of Key Biodiversity Areas (KBAs), an indicator for the coverage of areas important for biodiversity, was analysed using the February 2018 release of the WDPA, with results available at the national, regional and global level (BirdLife International, UNEP-WCMC & IUCN, 2018). Terrestrial connectivity is assessed using the ProtConn indicator (Saura et al., 2017 & 2018), while ecological representation is assessed based on protected area coverage of terrestrial and marine ecoregions, as defined by Olson et al. (2001) and Spalding et al. (2007). These indicators are reported in the Digital Observatory for Protected Areas (DOPA) of the European Commission – Joint Research Centre (EC-JRC) based on analyses of the June 2016 and April 2018 release of the WDPA, for connectivity and ecological representation respectively (EC-JRC, 2018). Though ProtConn could be applied to marine ecoregions with some adaptations (Saura et al. 2017), this has yet to be examined. For ecological representation, data on protected area coverage of ecoregions was used to calculate the mean target achievement for each of the 20 LMMCs, following Jantke et al. (2018). Mean target achievement represents the degree to which targets are being achieved across all ecoregions, where a score of 100% would indicate all ecoregions in a given country have met the 17% or 10% conservation targets.

The only indicator for management effectiveness currently available is the completion of protected area management effectiveness (PAME) evaluations. In 2010, Parties were invited to work towards assessing 60% of the total area of their PAs by 2015 (CBD, 2010b). Completed PAME assessments are tracked in the Global Database of Protected Area Management Effectiveness, with data from May 2018 used to assess the current status (UNEP-WCMC, 2018a). Information on

governance diversity (the percentage of protected areas under different governance types) is one proxy for assessing equity aspects in protected area systems. Governance diversity was calculated using the May 2018 release of the WDPA (UNEP-WCMC and IUCN, 2018). UNESCO-MAB Biosphere Reserves and sites with a status of 'proposed' or 'not reported' were removed. Other aspects of protected areas management effectiveness (e.g. conservation outcomes) and equitable management (e.g. governance quality including equity) have not yet been assessed globally. There are no proposed indicators for assessing the integration of protected areas into the wider landscape and seascape, and no global assessments of this element have been developed.

Where relevant, the status in the LMMCs is presented in comparison to the global level. Change in the status of these elements between 2016 (the year the Carta was adopted) and 2018 is presented using the same set of indicators, both globally and within the LMMCs.

National biodiversity commitment analysis

The national biodiversity commitments of LMMCs were examined for their relevance to the quantitative and qualitative elements of Target 11. The sources of these commitments included: Parties' national priority actions (including questionnaire responses) collected through a series of regional capacity-building workshops; approved Global Environment Facility, GEF-5 and GEF-6 protected area related biodiversity projects; and relevant targets, strategies, actions and measures from National Biodiversity Strategies and Action Plans (NBSAPs). For the quantitative elements of the target, commitments made during the 2017 UN Oceans Conference and those made through regional initiatives (Micronesia Challenge and Caribbean Challenge Initiative) were also included. This information was used to estimate progress for the quantitative elements of Target 11 based on the extent of proposed new or expanded protected areas.

For the six qualitative elements of Target 11, the information was used to rankeach commitment according to the likelihood of its implementation, using a three-point scale (Table 1), where higher scores are meant to indicate greater chances of success.Commitments included two parts: the type of action (e.g., restoration, protection, and sustainable use) and anaction statement (e.g., develop a plan, conduct research, and strengthen governance).Following the ranking of all commitments, a comparison of commitment scores between elements was made, to address which elements may be lagging and still require further efforts. A comparison of commitment scores between sources (GEF, NBSAP, National priority actions) was also performed. In both cases, this was

done using a Kruskal–Wallis test, followed by a Dunn's test for multiple comparisons with Bonferroni correction, using R, version 3.5.1 (R Core Team 2018).

Table 1: Ranking applied to individual biodiversity commitments

Score	Scoring for each commitment
1	Commitment recognizes the need for action on the element in question; however there is little elaboration and/or no action plan developed
2	Commitment addresses the element with a developed list of actions and/or supporting legal framework; however no plan for implementing these actions is proposed
3	Commitment is supported by a specific and detailed plan to implement the proposed action(s) for the Target 11 element in question

The commitments identified in different sources were then aggregated for each element within each country. The aggregated commitments were used to assign an overall country score for each qualitative elementusing a five-point scale (Table 2). This country-level scoring was used to determine overall progress towards the qualitative elements of Target 11. Progress was assessed against gaps that were identified by the CBD Secretariat in 2016 (SCBD, 2016b), as a guide for what achievement of each element could entail (Table 3), recognising that several elements lack proper indicators or benchmarks for successful achievement. A score of four indicates that the commitments for an element of Target 11, if implemented as proposed by 2020, are likely adequate to meet the gap identified for that element.

Table 2: Country-level scoring for the qualitative elements of Target 11

Score	Country-level scoring for each element
0	No commitments were provided for the element in question
1	Country mentions the element in their documents; the need for actions is recognized however there is no designed action plan.
2	Country has a legal framework addressing the element and/or has developed a list of actions that address the element, however no plan for how to implement these is proposed.

3	Country has developed a specific plan(s) for how they will implement the proposed action(s), though taken together the actions are not sufficient to meet the target of the element, as outlined in Table 3
4	Country has multiple developed action plans, and has put the element as a priority in developing comprehensive implementation plans thatwill likely meet or surpass the requirements for the element, as outlined in Table 3

Table 3: Suggested gaps to advance progress on the qualitative elements of Target 11

Element of Target 11	**Suggested gap to be addressed by 2020**
Ecologically representative	Increased coverage of terrestrial and marine ecoregions, to reach 17% and 10% coverage targets
Areas important for biodiversity and ecosystem services	Increased coverage for all areas important for biodiversity, such as KBAs; identification and mapping of areas important for ecosystem services
Well-connected	Develop at least one corridor or connectivity conservation initiative
Effectively managed	Increased completion of management effectiveness evaluations; improved quality of management in existing sites; connection between management inputs and conservation outcomes
Equitably managed	Report governance type for all existing sites; increased number of co-managed and Indigenous Peoples and Local Communities (IPLC) governed sites; recognition of rights of IPLCs; mechanisms for equitable distribution of benefits and mitigation of costs; completion of governance and social assessments
Integrated into the wider land-and-seascapes	Begin to integrate protected and conserved areas into local, regional, and national spatial planning and into important sectors

Results

Status of the elements of Target 11 in the LMMCs as of 2018

A summary of the status of various elements of Target 11in the LMMCs as of May 2018is shown in Figure1.

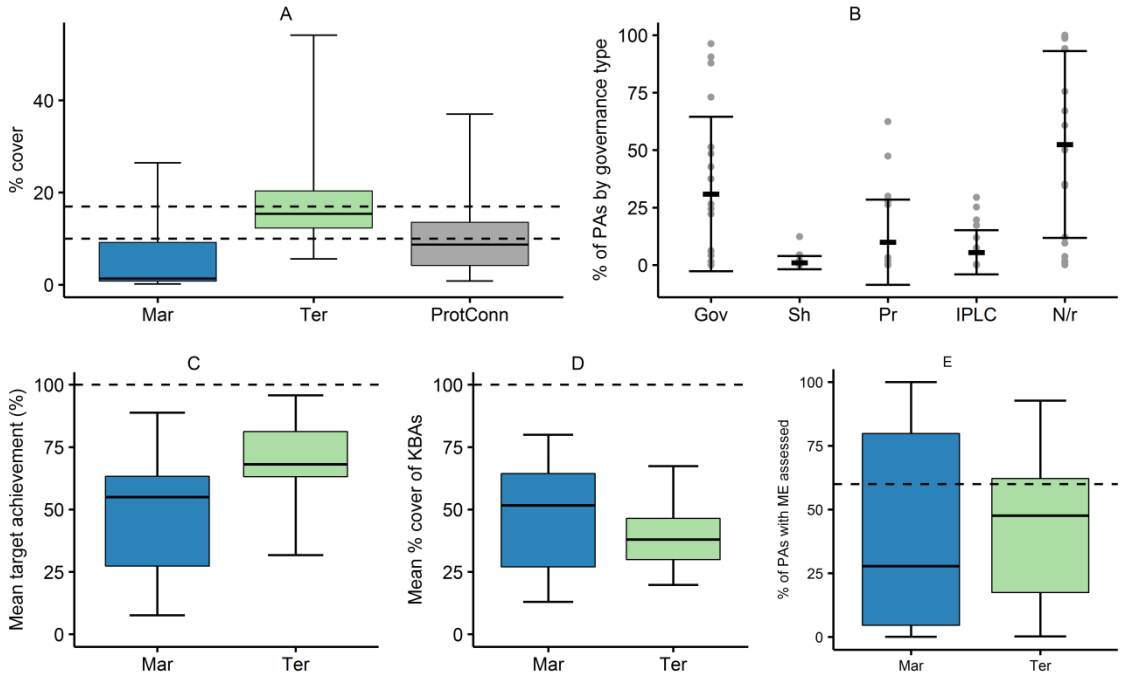


Figure 1: Current status of elements of Target 11 in the LMMCs as of 2018: Percent protected area coverage andpercent cover of Protected-connected lands(A); proportional breakdown of protected areas by governance type (Gov =Government, Sh =Shared, Pr =Private (Pr), IPLC = Indigenous Peoples and Local Communities, N/r = Not Reported), showing mean±SD, with grey dots representing individual countries (B); mean target achievement (%) for marine and terrestrial ecoregions (C); mean percentage areaof Key Biodiversity Areas (KBAs) covered by protected areas (D); percent of protected areas with reported management assessments (E). All boxplots show median, inter-quartile range, maximum and minimum, with dashed lines showing the target for the element. Mar = marine, and Ter = terrestrial.

Protected area coverage

As of May 2018, marineprotected area coverageacross all LMMCs was 9.5%, which compares to 16.8% globally, for marine areas under national jurisdiction and 7.3% for the entire ocean (UNEP-

WCMC, 2018b). For terrestrial protected areas,18.4%of the area of the LMMCs was covered, comparedto 14.8% at the global level (UNEP-WCMC, 2018b).

Connectivity and integration into the wider landscape and seascape

The coverage of protected-connected lands (lands that are both protected and connected, using EC-JRC's ProtConn indicator) assessed at the country-level in the LMMCs is nearly 10% (Fig. 1A), somewhat higher than the global level of 7.5% (Saura et al., 2018). Five of the 20 LMMCs have at least 17% coverage by protected-connected lands; compared to 30% of all countries which have met the target (Saura et al., 2018). No indicator is currently available for tracking the integration of protected areas into the wider land-and-seascape.

Equitably managed

Currently, the proportion of protected areas under private, shared, and Indigenous Peoples and Local Communities (IPLC) governance in the LMMCs totals 27.2%; this compares to 9.6% globally (UNEP-WCMC & IUCN, 2018). However, a large proportion of protected areas (8.9% at the global level and 23.5% in the LMMCs) still do not have their governance type reported to the WDPA (Fig. 1B). No indicator is currently available to measure or aggregate data on governance or equity at the site level.

Ecological representation

As of April 2018, mean target achievement ranges from 31.7% to 95.7% for terrestrial ecoregions and from 7.6% to 88.8% for marine ecoregions within the LMMCs (Fig. 1C). This compares to a mean target achievement of 66.6% for terrestrial ecoregions and 59.7% for marine ecoregions, at the global level. As well, 357 of 823 terrestrial and 99 of 232 marine ecoregions have reached the respective coverage targets (EC-JRC, 2018). For ecoregions with at least 90% of their area in the LMMCs, 101 of 239 terrestrial and 14 of 37 marine ecoregions have met the 17% and 10% coverage targets.

Areas important for biodiversity and ecosystem services

Based on the Key Biodiversity Areas Standard (IUCN, 2016b) as a proxy for representation of areas of particular importancefor biodiversity,average protected area coverage of KBAs in the LMMCs ranges from 13.0 to 80.0% of the area of marine KBAs, and 19.8 to 67.4% for terrestrial KBAs (Fig. 1D). Globally, the mean percentage area covered by protected areas is 44.31% for marine and 46.65% for terrestrial KBAs (BirdLife International, UNEP-WCMC, & IUCN, 2018).No indicator is available for tracking progress on the coverage of areas important for ecosystem services.

Effectively managed

Currently six of the 20 (30%) LMMCs have met the 60% target forterrestrial protected areas, while the target has been met by six of the 18 (33%) maritime countries(Fig. 1E). This compares to 21% and 16% for terrestrial and marine protected areas respectively, at the global level (UNEP-WCMC, 2018a).

Changes in the status of Target 11 from 2016 to 2018

Between April 2016 and May 2018, global protected area cover increased from 14.7% to 14.8% for terrestrial areas and from 10.2% to 16.8% for marine areas under national jurisdiction (UNEP-WCMC, 2016; UNEP-WCMC, 2018b). Coverage increased from 4.1% to 7.3% for the global ocean. Within the LMMCs, terrestrial coverage fell from 19.0% to 18.4%, while marine coverage showed a three-fold increase, from 2.9% to 9.5%. This change protected area coverage is reflected in the number of ecoregions reaching the 17% and 10% coverage targets, which increased from 351 to 359 for terrestrial ecoregions and from 84 to 99 for marine ecoregions, globally, between April 2016 and April 2018 (EC-JRC, 2018). Mean target achievement saw similar changes, increasing from 54.6% to 59.7% for marine ecoregions, and from 65.7% to 66.6% for terrestrial ecoregions. The LMMCs contributed to the increased protected area coverage of two marine ecoregions; however, there was a net decrease in the number of terrestrial ecoregions reaching the 17% target in the LMMCs. Additions from Brazil in May 2018, has increased MPA coverage for a further two marine ecoregions.

Connectivity has only been assessed for 2016 using the ProtConn indicator, so no changes can be assessed. However,looking at the longer-term trends as assessed using the Protected Area Connectedness Index, there was almost no change between 2000 and 2012 (CSIRO, 2018). Between 2012 and now, there has been only limited increases in terrestrial protected area cover, so changes in connectivity are expected to be minimal.

Mean percentage area of marine KBAs covered by protected areas showed a slight increase from 44.10% to 44.31%, globally, while there was almost no change for terrestrial KBAs (46.58% to 46.65%) (BirdLife International, UNEP-WCMC, & IUCN, 2018). Within the LMMCs, two countries showed a small increase in protected area coverage of terrestrial KBAs, and one country (Madagascar) showed an increase in coverage of marine KBAs.

When assessed in 2015, the 60% PAME assessment target was met by less than 18% of countries at the global level, and only three LMMCs (Coad et al., 2015). The 2018 status shows improvement on this element in the LMMCs and at the global level over the last three years (UNEP-WCMC, 2018a).

The number of protected areas in the WDPA under all governance types increased between 2016 and 2018, at the global level, with over 13,000 sites added during this period. The proportion of sites governed by state-actors fell from 84% to 81.5%, while the proportion under shared and private governance increased from 1.8% to 3.3% and 4.5% to 5.7%, respectively. The proportion of sitesunder IPLC governance and with their governance type not reported showed no significant change, remaining at 0.6% and 9%, respectively.In the LMMCs, over the same period, there was an increase in the proportion of sites governed by government, private actors, and IPLC; a decrease in the proportion of sites with no governance type assigned; and no change in the proportion of sites with shared governance.

Analysis of LMMCs'national biodiversity commitments

A total of 714 commitments were extracted from different sources using keywords, with the largest portionderived from GEF-5 and GEF-6 projects, followed by NBSAPsand National Priority Actions(Fig. 2). Thenumber of commitments per country varies from 15in the Democratic Republic of Congoto 70in China(Fig. 3).Neither Bolivia nor Kenya has submitted revised NBSAPs, and Malaysia did not submit national priority actions (or a response to the questionnaire) during the CBD capacity building workshop. AllLMMCs had protected areas projects under GEF-5 or GEF-6.

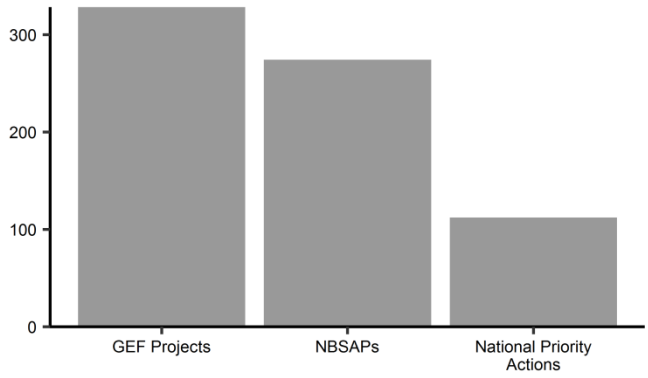


Figure 2: Number of LMMCs' national biodiversity commitments by source. National priority actions also include responses to the workshop questionnaire.

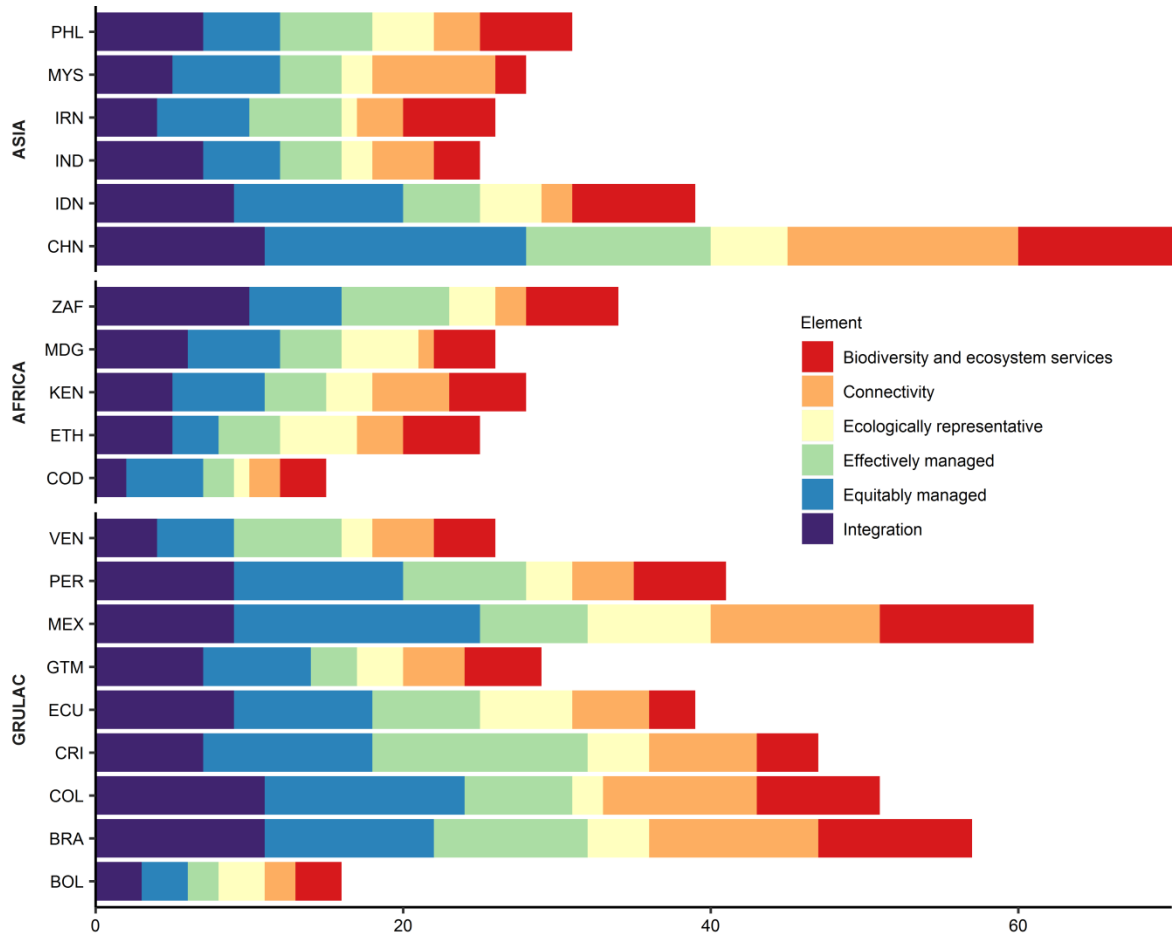


Figure 3: Number of LMMCs' commitments towards the qualitative elements of Target 11, by ISO country code.

Based on the analysis of national biodiversity commitments, the likelihood of implementation for these actions in the LMMCs is fairly strong, as 70% of the 714 commitments scored a 2 or 3, reflecting the presence of lists of actions with plans for their implementation.For commitments pooled across all LMMCs, significant differences (χ^2= 52.9, p<<0.001, df = 5) were found between commitment scores for the six qualitative elements of Target 11 (Fig. 4A), though the effect was small (ε^2 = 0.063). A post-hoc test using Dunn's test with Bonferroni correction showed that commitment scores for effective management, equitable management, and integration were significantly higher than those for biodiversity and ecosystem services, ecological representation, and connectivity (Fig 4A). Significant differences (χ^2= 185.8, p<<0.001, df = 2) were also found between commitment scores from the four different sources, and the effect was relatively strong (ε = 0.265). Actions from GEF-5 and GEF-6 protected area projects received higher scores than those from either NBSAPs or national priority actions (Fig. 4B).

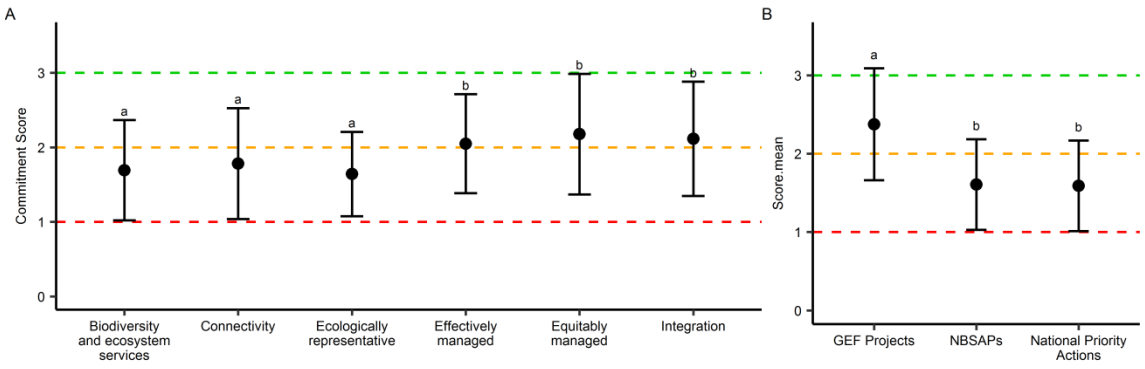


Figure 4: National biodiversity commitment scores (mean ± SD) based on the confidence that actions will be implemented by 2020, compared by element (A) and by commitment source (B). Letters "a" and "b" represent statistically significant differences in mean scores, at a 95% confidence level.

Potential contribution of LMMCs' commitments for elements of Target 11

If national biodiversity commitments for the terrestrial and marine coverage elements areimplemented as proposed,marine protected area coverage will reach10.08% across the LMMCs (an increase of 0.61% from existing coverage) and terrestrial protected area coverage will reach 20.22% (an increase of 1.82% from existing cover) (Fig. 5). With this increase, two additional LMMCs will reach the 17% target for terrestrial protected areas, while the LMMCs as a whole will reach the 10% marine target. No additional LMMCs will meet the 10% target nationally.

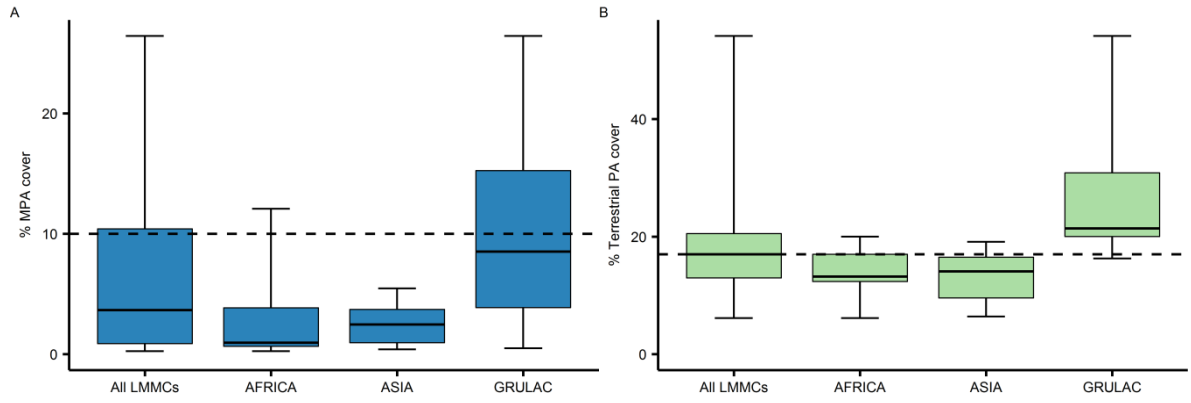


Figure 5: Potential percent protected area coverage in 2020 if all country commitments are implemented as proposed for (A) coastal and marine areas and (B) terrestrial and inland waters.

Based on the country-level analysis of national biodiversity commitments, the gaps outlined in Table 3have the highest chance of being met within the LMMCs for the elements of integration into the wider land and seascape and equitable management (relating to increasing governance diversity and completing assessments), followed by connectivity and effective management (Fig. 6). Based on the analysis of the 714 commitments for the qualitative elements of Target 11, no country would meet the target for coverage of areas important for biodiversity and ecosystem services or for ecological representation. Twelve of the LMMCs would fill the identified gap for connectivity and ten for integration,while ten would make significant advances towards filling the identified gaps for equitable management, and six for management effectiveness.

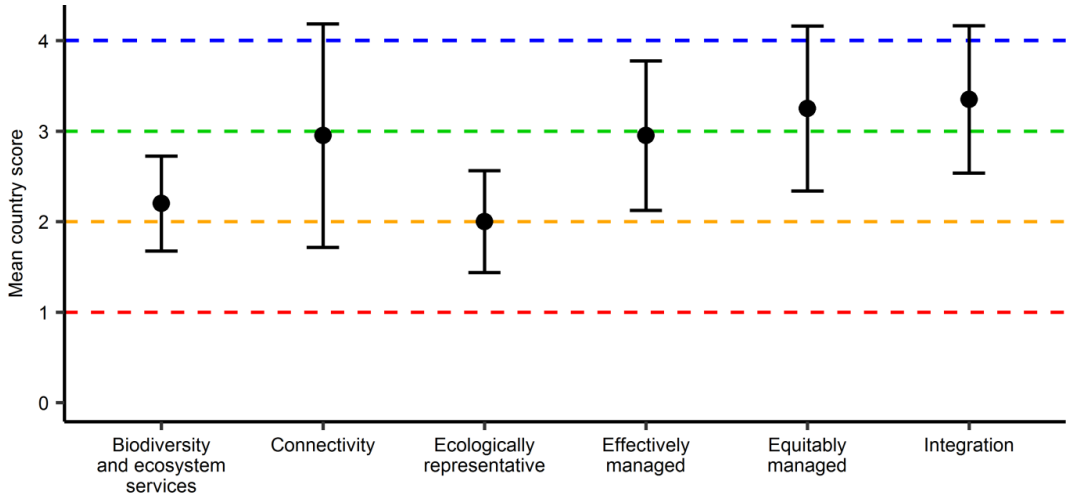


Figure 6: Mean country scores for qualitative elements of Target 11.

Discussion

Contribution to progress on Target 11 from 2016-2018 in the LMMCs

Progress on Target 11 in the LMMCs is most noticeable in the improvement from 2016 to 2018 for the protection of marine environments (MPA coverage and protection of marine ecoregions). The LMMCs contributed just over one-sixth of the more than 9 million km^2 of protected areas added to marine areas under national jurisdiction over this two-year period. For example, both Mexico and Brazil established large marine protected area networks, brining marine coverage to

more than 20% of their national waters. The LMMCs also contributed to improved coverage in two marine ecoregions, while the new marine protected areas in Brazil (added to the WDPA in May 2018) improved coverage for an additional two marine ecoregions. Of the 11 CBD Parties which have improved marine protected area coverage since 2016 to meet the 10% target, three are LMMCs (SCBD, 2018a). Conversely, over the same two-year period, one of the LMMCs decreased terrestrial protected area cover below the 17% target. Despite a net decline in terrestrial protected area coverage in the LMMCs of over 230,000 km^2, and a net decrease of two terrestrial ecoregions meeting the 17% target, there was still a slight improvement at the global level, and increased terrestrial coverage in some the LMMCs. For instance, the largest terrestrial site added to the WDPA in 2017 was Bassin de la Lufira, in Democratic Republic of Congo, with an area of 43,684km^2, bringing coverage in that country closer to the 17% target identified in their NBSAP.The decrease in terrestrial protected area cover resulted from changes in four countries: China, where most national level protected area records were temporarily removed from the WDPA for re-assessment (though they were not de-gazetted); South Africa, where a complete update of national-level records saw eight reserves re-classified as UNESCO Biosphere Reserves, which are not included in analyses of global protected area cover; Guatemala, which provided a complete update of their protected area records; and Peru, where '*Zona de Amortiguamiento*' (buffer zones for existing protected areas) were removed, as they do not meet the IUCN protected area definition. With respect to the qualitative elements of Target 11, a mosaic of conservation and sustainable livelihood initiatives was developed in Ecuador, leading to improved connectivity for a range of ecosystems. While in Costa Rica, alternative sustainable livelihood opportunities are being provided to more than 1000 families living in corridors and protected area buffer zones, to ensure the conservation of biodiversity.

Analysis of national biodiversity commitments

There was significant variation in the specificity of actions and geographic scales of the LMMCs' national biodiversity commitments. Scores of individual commitments varied depending on source (Fig. 4B), with commitments from NBSAPs and national priority actions typically phrased as shorter action statements or broader biodiversity strategies, goals or targets. However, these commitments often lack more detailed plans of actions, and on average, received lower mean scores than GEF projects. In contrast, due to the requirements of the GEF Grant Programme and co-financing, the commitments from GEF-5 and GEF-6 projects are action-oriented, have more detailed workplans, and as a result are more likely to be implemented. Despite this tendency, there was no difference in mean scores between sources for commitments on ecological representation (Fig. S1B).This may be indicative of the limited recognition of specific ecoregions in all sources of commitments, including GEF projects; the fact that few proposals for new protected areas provide

the specific areas where they will be implemented; and the fact that national frameworks for conservation prioritisation may not align with the ecoregions used for reporting at the global level.

When comparing the mean individual commitment scores between elements for all sources (Fig. 4A), the higher scores for effectively managed, equitably managed, and integrated into the wider landscapes and seascapes are likely due to more extensive action plans or proposals. Part of the difference in mean commitment scores between elements may also be attributable to the shift in focus of GEF protected area funding over the past decade (GEF, 2016). GEF funding for protected area projects has shifted towards a greater focus on integration into landscapes and seascapes and mainstreaming with productive sectors, and away from the establishment of individual protected areas. This would increase the impacts for protected area integration and management, compared to new protected areas which would benefit the representation elements of Target 11.The lower mean commitment scores for areas of importance for biodiversity and ecosystem services, ecological representation, and connectivity could be also attributed to the fact that few commitment statements identify specific ecoregions or KBAs, nor do they address specific regions, corridors, or mechanisms for connectivity. Commitments towards the quantitative elements will have impact for these elements related to the spatial arrangement of protected areas.There is also opportunity from territories and areas conserved by indigenous peoples and local communities (ICCAs) and OECMs to contribute to improvements on the status of Target 11. Mapping of these new additions may help address some of the gaps in these qualitative elements.

Contribution to progress over the next two years: 2018-2020

If all commitments are implemented as proposed, they will increase terrestrial protected area coverage by almost 700,000 km^2, which accounts for 1.82% of the terrestrial area of the LMMCs and 0.51% globally. This represents a significant proportion of proposed increases in terrestrial protected area coverage worldwide. Proposed actions will also increase marine protected area coverage by over 150,000 km^2 (0.63% of the marine territory in the LMMCs, 0.11% of global marine area under national jurisdiction, and 0.04% of the global ocean).The LMMCs will continue to contribute to progress on Target 11 at the global levelas their national biodiversity commitments continue to be implemented.

For the qualitative elements of Target 11, estimating progress that will occur from implementation of actions in the LMMCs is more difficult. However, the country-level analysis of biodiversity commitments (Fig. 6) indicates that some of the gaps remaining for the qualitative elements of Target 11 may be addressed in the LMMCs, which will invariably also provide benefits at the global level. Across the LMMCs, the identified gaps for integration and equitably managed

(particularly with regard to improving governance diversity and mechanisms to improve distributional equity followed by the completion of governance assessments) were found to have the highest likelihood of being addressed in the LMMCs, followed by connectivity and effective management. At a national level, connectivity had the most countries that will address the proposed gap, with 12 countries planning to establish new biological corridors or completing other projects to improve the connectivity of protected area.It should be noted, however, that the scale and ambition of suggested gaps that could be addressed by 2020 (Table 3) varies significantly between elements. For connectivity and integration, where at least half of the LMMCs were found to have commitments sufficient to address the gaps, these gaps are fairly simple for connectivity, and in the case of integration, the gap outlined is a somewhat general statement which may be addressed equally generally in the national biodiversity commitments.For equitably managed, the identified gap has multiple components, however the analysis of country scores did not require all of these components to be addressed in order for the gap to be considered filled, which accounts for the generally high country scores for this element.

It is unlikely, based only on these commitments, that the representation elements (coverage of ecoregions and KBAs) will be completely met by 2020. Lower mean country scores for areas important for biodiversity and ecosystem services reinforces the ongoing trend of protected areas being located away from areas with high numbers of threatened vertebrate species (Venter et al., 2018). The lower mean scores for ecological representation reflect the lack of specific plans or actions for the conservation of ecoregions. Only one country provided specific targets for ecological representation (Brazil), but provided no specific actions to address the targets. Country scores for elements of Target 11 showed a moderate correlation with the number of commitments received per element (r_s = 0.56, $p<0.001$) as well as the likelihood of implementation (r_s = 0.52, $p<0.001$). Integration and equitable management were the elements with the largest number of commitments (Fig. 2). This difference was most noticeable for GEF projects (which showed the highest likelihood of implementation), where these two elements accounted for more than half of all commitments recorded.

Additional opportunities for improved progress: OECMs and ICCAs

Further enhancement of the elements of Target 11 may come from the inclusion of OECMs (Dudley et al., 2018). A definition of OECMs and criteria for their identification was recently adopted (CBD, 2018a), and it is now up to Parties to begin mapping and reporting these sites. This will allow for their inclusion in the WDPA and their consequence for elements of Target 11 to be assessed. This additional area will have a positive impact on both quantitative and qualitative elements of Target

11.The integration of indigenous lands (as OECMs or ICCAs) into protected and conserved areas frameworks warrants the employment of necessary safeguards relating rights of Indigenous Peoples and Local Communities (IPLCs). The contributions of IPLCs to biodiversity conservation are varied and indigenous peoples' territories are managed and held in a diversity of contexts. Therefore, it cannot be assumed that these areas are *de facto* protected areas, or OECMs. However, OECMs may be a more appropriate designation to recognise the conservation being carried out by IPLCs. Subject to important caveats, OECMs may also offer an important opportunity to increase recognition and support for ICCAs (Jonas et al., 2017).

Of the 38 million km^2 of land reported to be managed by or under the tenure rights of indigenous peoples globally approximately one-third (10.6 million km^2)is located in the LMMCs (Garnett et al., 2018). This includes both lands that are found within current protected areas (3.4 million km^2), and those that are outside of reported protected area networks (7.2 million km^2). Garnett et al. (2018) estimate that globally, indigenous lands account for 37% of all remaining natural lands (based on the calculation of Human Footprint), and that a higher proportion (67%) of indigenous lands can be classified as natural, compared with 44% of lands under other forms of tenure. Human footprint measures the extent of human impact on landscapes, where a high human footprint would refer to areas where "anthropogenic land conversion has occurred to an extent that the land can be considered human-dominated and can no longer be considered 'natural'" (Watson et al., 2016). At least 2 million km^2 of the unprotected indigenous lands in the LMMCs can be estimated to have a low human footprint (Garnett et al., 2018). Some of these natural lands under the tenure of IPLCs may contribute to Target 11, although the specific extent has yet to be determined. Any of these areas included as OECMs or ICCAs will contribute to improvements for the quantitative and some of the qualitative elements.

Broader implications, gaps remaining, and next steps

The commitments and opportunities from LMMCs have significant potential to not only enhance progress on Target 11, but to also contributeto the stated requirements of other Aichi Biodiversity Targets and Multilateral Environmental Agreements (MEAs). To understand these contributions, an ongoing analysis is investigating links between the national biodiversity commitments of LMMCs and obligations under six major MEAs[3] and other Aichi Biodiversity Targets.

[3] Relevant MEAs include: the United Nations Convention to Combat Desertification (UNCCD); the World Heritage Convention (WHC); the Convention on the Conservation of Migratory Species of Wild Animals (CMS); the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); the Ramsar Convention on Wetlands; and Nationally Determined Contributions (NDCs) to the Paris Agreement from the United Nations Framework Convention on Climate Change (UNFCCC).

Initial findings indicate contributions and co-benefits of the implementation of Target 11 commitments for the countries' other international obligations. Preliminary results from an analysis of 10 LMMCs are presented in Supplementary Table 1.This analysis implies the existence of important linkages that can help simplify data gathering, monitoring and reporting. Identification of synergies may also generate information that will be relevant to leverage support for conservation investment and to make more efficient use of available funding sources (Smith et al., 2019).As an example, actions to establish forest corridors between protected areas in Brazil's GEF-5 Project (#5324, www.thegef.org) were found to support their commitments to the Paris Agreement, addressdecisions under the UNCCDto sustainably manage land and address land degradation, and address goal of the WHC Strategic Action Plan.

There are still commitment gaps remaining that will need to be addressed for elements with lower commitment scores and country scores (connectivity, ecological representation and areas important for biodiversity and ecosystem services). All three are related to the spatial arrangement of protected and conserved areas. As such, commitments to add or expand protected areas, the support and recognition of ICCAs, and the eventual inclusion of OECMs, may all have positive impacts for these elements. The next step will be to map these new additions with respect to KBAs and ecological regions, to better understand their impact. Spatial conservation prioritisation can help to ensure the effective placement of new protected areas (Moilanen, Wilson &Possingham, 2009).

It is clear that protected areas can be effective tools for conservation (Barnes et al., 2016; Gray et al., 2016), though many are facing increasing threats from human pressures (Jones et al., 2018). To date, global reporting of progress on the 'effectively managed' element of Target 11 has focused on the completion of management effectiveness assessments (Gannon et al., 2017; UNEP-WCMC & IUCN, 2016). Data from PAME evaluations, on its own, is unlikely to provide adequate information to assess the performance of protected areas (Coad et al., 2015). There is a need for more information on conservation outcomes in protected areas, and a better understanding of their relation to specific management inputs (Geldmann et al., 2018).

For the 'equitably managed' element of Target 11, progress will require improvements in the diversity, quality, effectiveness and equity of protected area governance. Although the reported diversity of protected area governance types has been increasing, this says nothing about the quality, effectiveness or equity of protected area governance. Methodologies to assess effective and good governance (including equity) at site level have been developed, and tested in several countries (Borrini-Feyerabend et al., 2013; Franks & Booker, 2018), though no global assessments of

the results are available. Over the following years, more systematic application of governance and social assessments at the site and system level would enhance progress on this element. Additionally, following the equity framework developed by Schreckenberg et al. (2016), a set of 10 indicators covering the different dimension of equity has been proposed which could provide a means to report on this element of Target 11 (Zafra-Calvo et al., 2017). The IUCN Green List of Protected and Conserved Areas is one initiative aimed at recognising sites that are effectively and equitably managed and deliver positive conservation outcomes (IUCN & WCPA, 2016). Parties have been invited to promote the IUCN Green List as a voluntary standard (CBD, 2016a) and 15 new sites were listed in November 2018. The recently adopted voluntary guidance on governance and equity in protected areas also provides a range of suggested steps that could be implemented to support effective and equitable governance models as well as supporting increased governance diversity (CBD, 2018). Guidance has also been developed to address the integration of protected areas and OECMs into wider landscapes and seascapes and their mainstreaming across sectors (CBD, 2018).Indicators for tracking progress on this element will also need to be developed.

As countries scale-up the incorporation of OECMs and ICCAs into national reporting on progress towards Target 11, it will be vital to ensure that proper safeguards are being respected. The ICCA Consortium advocates for the respect and recognition of IPLCs within existing protected areas (Stevens et al., 2016), along with IPLCs' active participation within the post-2020 global biodiversity framework. With the enormous potential of indigenous lands to complement and enhance existing protected and conserved areas networks and strategies, full participation of IPLCs must be ensured. Above all, for IPLCs, there must be free, prior, and informed consent including for the establishment, governance, planning, monitoring and reporting of protected and conserved areas on their traditional territories (lands and waters); appropriate recognition afforded to collective rights, especially pertaining to land tenure; respect for their self-determination, local and cultural institutions, and traditional knowledge; and support to their efforts to develop and maintain sustainable livelihoods. Some of these safeguards are reflected in the criteria for identification of OECMs (CBD, 2018).

Discussions regarding the potential nature of a follow-up to the Aichi Targets have already started (e.g. SCBD, 2018b) and a decision regarding the process for preparing a post-2020 global biodiversity framework was recently adopted (CBD, 2018b). Various suggestions for aspects of a post-2020 target for area-based conservation have also been proposed. Some of these include protecting all remaining intact wilderness (Watson et al., 2018), focusing specific retention targets on the minimum area needed to achieve particular goals like carbon storage or watershed

protection (Maron et al., 2018), or shifting the focus of future targets to protected area quality (Barnes et al., 2018). Other proposals are relevant for all Aichi Biodiversity Targets and include calls for the new set of targets to be simple, succinct, measurable and unambiguous (Butchart et al., 2016). Regardless of the specific nature of the post-2020 biodiversity framework, significant progress on Target 11 should provide encouragement for setting more ambitious goals for the future. Continued assessment of national biodiversity commitments and the reporting and monitoring of activities to be carried out through regional support networks could help in developing best practices for implementation based upon the lessons learned, in line with COP decision XIII/2 paragraph 9(d) which called for facilitating support networks at the regional and sub-regional level (CBD, 2016a). Going forward, this will be supported by the Global Partnership on Aichi Biodiversity Target 11, established in November 2018, with the aim to facilitate the implementation of proposed actions and commitments in all sub-regions.This is also in alignment with Sustainable Development Goal 17, which advocates for strengthening and revitalizing global partnerships for sustainable development.

Conclusions

The LMMCs contain a wealth of biological and cultural diversity, and their contribution to progress on Target 11 is noteworthy. However, the Aichi Biodiversity Targets are global in nature and will require efforts and commitments from other countries. The national biodiversity commitments in the LMMCs, if implemented as proposed, will increase terrestrial and marine protected area coverage within the LMMCs, while enhancing the statusof other elements of Target 11. This will bring marine protected area coverage for the LMMCs above the 10% target. A majority of thenational biodiversity commitments submitted by the LMMCsfor the qualitative elements of Target 11showed a strong likelihood of implementation.Based on a country-level analysis of all commitments, the elements with the highest chance of achieving significant progress within the LMMCs are integration and equitable management (with regard to some of the specific gaps identified), followed by connectivity and effective management. Opportunities for further increasing terrestrial coverage in the LMMCs may come through the recognition and support of ICCAs and the systematic collection of information on OECMs. In the LMMCs, there are at least 2 million km^2 of indigenous lands outside of current protected areas networks, with a low human footprint. Some of these areas may contribute to Target 11, although the specific extent has yet to be determined. Furthermore, national biodiversity commitments for the elements of Target 11 may provide co-benefits forother Aichi Targets and the obligations ofotherMEAs.

Going forward, the continued facilitation and support of partnerships such as the LMMCs is critical, and collaboration from all actors will be necessary in order to reverse or halt the decline of biodiversity and avert the biodiversity crisis. Addressing this crisis requires tangible implementation strategies, such as: national and regional-level commitments, sustainable funding, human and technical capacity, coordination among multiple agencies and sectors, cooperation among key stakeholders at multiple levels, and communication at all levels. Together, the LMMCs have made considerable efforts to enhance progress on Target 11, and serve as an example for collaboration, willingness, and engagement at the national and regional level. The LMMCs will further support global efforts towards the 2050 Vision for Biodiversity, conserving, valuing, and restoring biodiversity, maintaining ecosystem functions and delivering essential benefits to ensure humanity's ability to live in harmony with nature.

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Supplementary Figure 1

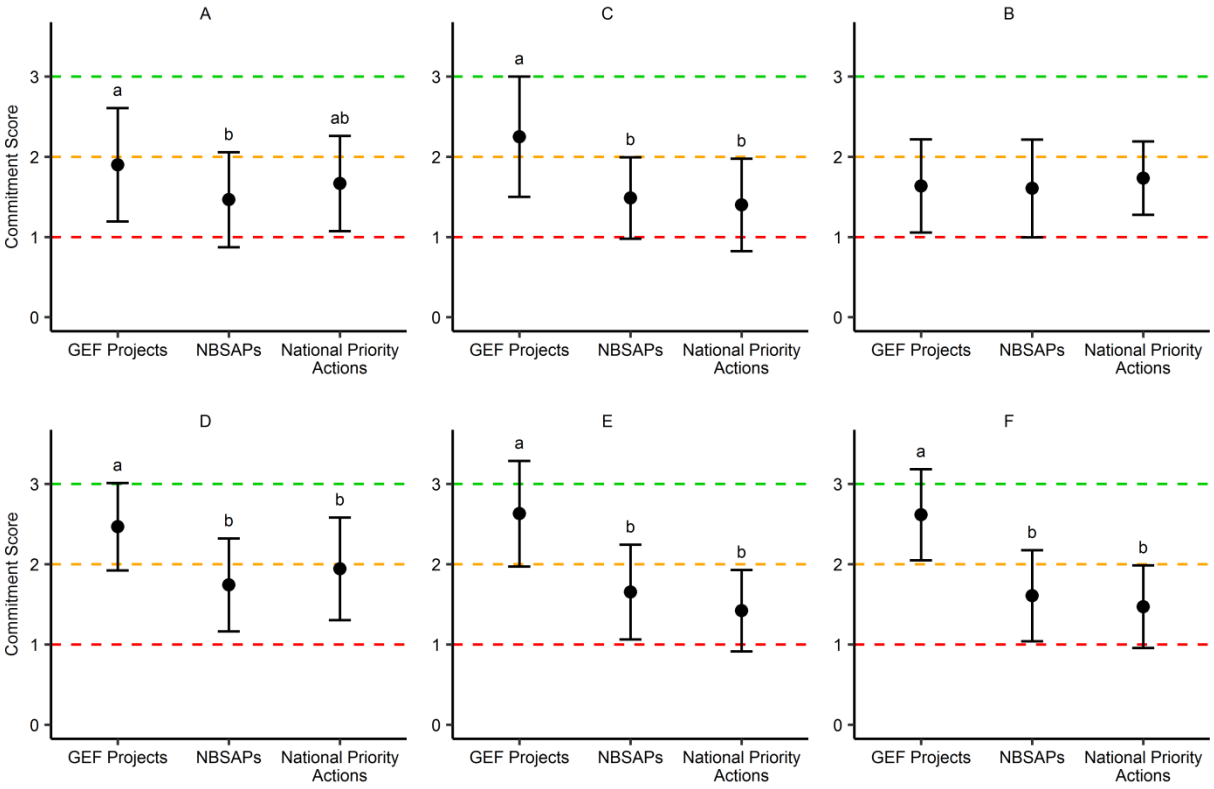

Figure S1: Differences in commitment scores from different sources, for each of the qualitative elements of Target 11: areas important for biodiversity and ecosystem services (A), ecological representation (B), connectivity (C), effectively managed (D), equitably managed (F), and integration into the wider landscape and seascape (G). Letters “a” and “b” represent statistically significant differences in means scores, at a 95% confidence level. Where no letters are present, no significant difference was found between sources.

SupplementaryTable 1.

Source	Qualitative Element of Aichi Biodiversity Target 11	UNCCD	WHC	CMS	CITES	Ramsar	NDC	Aichi Target 4	Aichi Target 5	Aichi Target 6	Aichi Target 7	Aichi Target 9	Aichi Target 10	Aichi Target 12	Aichi Target 13	Aichi Target 14	Aichi Target 15	Aichi Target 18
Approved GEF projects	Biodiversity and ecosystem services																	
	Connectivity																	
	Ecologically representative																	
	Effectively managed																	
	Equitable governance																	
	Integration																	
National biodiversity commitments	Biodiversity and ecosystem services																	
	Connectivity																	
	Ecologically representative																	
	Effectively managed																	
	Equitable governance																	
	Integration																	

This figure describes the number of synergies between the commitments to Aichi Biodiversity Target 11 qualitative elements within Global Environment Facility (GEF) biodiversity projects and national biodiversity commitments from Brazil, China, Colombia, India, Malaysia, Mexico and South Africa with language from multilateral environmental agreements (MEA) and other Aichi Biodiversity Targets (collected as count data: present = 1, absent = 0, the table above presents a summation of the seven countries per MEA). Multilateral environmental agreements: UNCCD: United Nations Convention to Combat Desertification; WHC: World Heritage Convention; CMS: Convention on the Conservation of Migratory Species of Wild Animals; CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora; Ramsar: Convention on Wetlands; National Determined Contributions (NDCs) to the Paris Agreement United Nations Framework Convention on Climate Change.	**Legend**	**0**	**1 - 14**	**15 - 24**	**25 - 49**	**> 50**

Capítulo 4

Contributions of Socio-Ecological Production Landscapes and Seascapes to the achievement of Aichi Biodiversity Target 11 in the Group of Like-Minded Megadiverse Countries

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Chapter 10

Contributions of Socio-Ecological Production Landscapes and Seascapes to the achievement of Aichi Biodiversity Target 11 in the Group of Like-Minded Megadiverse Countries

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Abstract

The maintenance of functional integrity and health of ecosystems within protected areas is dependent not only on the protection provided but also on the ecological, economic and social interactions with surrounding areas. Efforts to create pathways for achieving socio-economic development that safeguard ecosystems and biodiversity are essential for building sustainable societies. Improving the impact of societies on protected areas is a key issue in the group of Like-Minded Megadiverse Countries (LMMCs) which are home to over 50 percent of the world's population and around 70 percent of its biodiversity. In order to facilitate the achievement of Aichi Biodiversity Target 11, an analysis was performed to determine the extent to which LMMCs' commitments make use of sustainable productive strategies and whether the commitments incorporate the perspectives of the Satoyama Initiative. Commitments from the LMMCs addressing the qualitative elements of Target 11 were drawn from National Biodiversity Strategies and Action Plans, National Priority Actions, 5th National Reports and protected areas-related biodiversity projects from the fifth and sixth replenishment of the Global Environment Facility. Commitments related to Socio-Ecological Production Landscapes and Seascapes (SEPLS) were identified as those which address sustainable productive practices. The relevant text was extracted and analysed in relation to the contribution of proposed actions to enhance the elements of Target 11 and perspectives of the Satoyama Initiative.

The results indicate that a subset of LMMCs' commitments to Target 11 is aligned with the perspectives of the Satoyama Initiative. These commitments are predominantly related to integration and equitable management of protected areas, elements of Target 11 whose progress was deemed to require more action to meet the target by 2020. By embracing the network of the International Partnership for the Satoyama Initiative (IPSI) partners and making use of the SEPLS strategy, the LMMCs could gain access to valuable knowledge and funding to accelerate implementation. Considering the importance of LMMCs to biodiversity, implementation of the SEPLS-related commitments from these countries will have global impacts for biodiversity conservation, contribute to the achievement of Aichi Biodiversity Target 11and promote sustainable socio-economic development.

Keywords: protected areas, Satoyama Initiative, biodiversity conservation, CBD, sustainable development, SEPLS

1. Introduction

The functional integrity and health of ecosystems within protected areas is dependent not only on the protection provided but also on the ecological, economic and social interactions with surrounding areas (Ervin et al. 2010; Rees et al. 2017; Watson et al. 2016). Efforts to create pathways for achieving socio-economic development that safeguards ecosystems and biodiversity are essential for building a sustainable society and conserving protected areas for the long-term. This idea is embedded in the elements[1] of Aichi Biodiversity Target 11, which states that: "By 2020, at least 17 percent of terrestrial and inland water, and 10 percent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes" (CBD 2010).

However, protected areas are often viewed and managed as islands of biodiversity, separated from the surrounding landscapes and societies (Hansen & DeFries 2007). Sectors like agriculture, forestry, and fisheries often neglect the goals of protected areas, increasing the likelihood and severity of a range of threats that may compromise biodiversity conservation (Laurance, Sayer & Cassman 2014; Symes et al. 2016). Improving the impact of societies on protected areas is a key issue in the group of Like-Minded Megadiverse Countries (LMMCs[2]) which are home to over 50 percent of the world's population and about 70 percent of its biodiversity (SCBD 2016a; UN DESA 2017) (see Fig.1).

The Socio-Ecological Production Landscapes and Seascapes (SEPLS) approach of the Satoyama Initiative is a valuable model for sustainable productive practices which can support the development of a nature-harmonious society (IPSI Secretariat 2017; Takeuchi 2010). SEPLS are defined as areas with dynamic mosaics of habitats and land and sea uses where the harmonious interaction between people

Figure 1. The Like-Minded Megadiverse Countries – embracing the partnership.

and nature maintains biodiversity while providing humans with the goods and services needed for their livelihoods, survival, and well-being in a sustainable manner (Satoyama Initiative 2010). SEPLS consist of, in many cases, croplands, settlements, forests and grasslands, as well as fisheries, and embody a great deal of traditional knowledge (Bélair et al. 2010; IPSI Secretariat 2017). Hence, the SEPLS approach promotes biodiversity conservation in secondary natural environments created through interactions between human activities and nature, and contributes to improving community resilience and socio-economic development (Japan Satoyama Satoumi Assessment 2010; Takeuchi 2010).

The ecological and socio-economic perspectives of the Satoyama Initiative are to: (i) achieve sustainability through the cyclical use of natural resources and use of resources within the environment's carrying capacity; (ii) promote recognition of the value of local traditions and cultures; (iii) facilitate landscape management through multi-stakeholder participation; (iv) promote socio-economic development; and (v) improve resilience of ecosystems and communities (IPSI Secretariat 2017). These perspectives can significantly contribute to facilitating the achievement of the qualitative elements of Aichi Biodiversity Target 11 and thereby improve the livelihoods and well-being of society in general and indigenous peoples and local communities in particular. Hence, synergizing the implementation of the activities of SEPLS with the national commitments for Aichi Biodiversity Target 11 in the LMMCs could facilitate both biodiversity conservation and sustainable socio-economic development within and around protected areas, contributing to achievement of Target 11.

2. Background

In the 2014 midterm assessment of progress towards the implementation of the Strategic Plan for Biodiversity 2011-2020, all of the elements of Target 11 showed progress, though only the 17% target for the conservation of terrestrial and inland waters was expected to be met by 2020 if current trends continued (Leadley et al. 2014; SCBD 2014).

Between September 2015 and July 2016, the Secretariat of the Convention on Biological Diversity (CBD) carried out six regional capacity building workshops on achieving Aichi Biodiversity Target 11, which aimed, among other goals, to provide a platform for discussing topics related to protected areas and to assist Parties to the Convention in identifying roadmaps for national priority actions to be undertaken in the following years to achieve the target by 2020.

The results from an analysis of over 1,400 priority actions, as well as other commitments identified by the Parties to the Convention that participated in the above regional workshops, suggested that if commitments are implemented as proposed, the area-based coverage of targets for terrestrial and inland waters (at least 17%) and for coastal and marine areas (at least 10%) would both be surpassed, while significant progress would be made for ecological representation, conservation of areas important for biodiversity, and effective management (Gannon et al. 2017; SCBD 2016b). However, the equitable management (governance/equity) of protected areas and their integration into the wider landscape, seascape and various sectors were found to require more efforts to speed up progress for the achievement of Target 11. These elements requiring more efforts form the backbone for a harmonious relationship between societies and protected areas. For example, diverse and good governance can help to ensure conservation is effective, resilient and widely covered. In terms of social outcomes, enhancing governance can help ensure that protected areas positively contribute to (and do not undermine) well-being and sustainable development within landscapes and seascapes (SCBD 2018a). Protected area integration can foster the development of a connected, functional ecological network among protected areas and facilitate the mainstreaming of values, impacts and dependencies of the biodiversity and ecosystem services provided by protected areas into key sectors, such as agriculture, fisheries, forestry, mining, energy, tourism and transportation (SCBD 2018b).

LMMC CARTA TO ACHIEVE AICHI BIODIVERSITY TARGET 11

We, the ministers of environment and the senior officials of the United Mexican States, the Federation of Malaysia, the Bolivarian Republic of Venezuela, the Republic of Colombia, the Republic of the Philippines, the Republic of India, the Republic of Costa Rica, the Republic of Ecuador, the Republic of Guatemala, the Republic of Indonesia, the Republic of Kenya, the Republic of Madagascar, the Republic of South Africa, the Republic of Peru, the Democratic Republic of the Congo, the Federal Democratic Republic of Ethiopia, the Federative Republic of Brazil, the Islamic Republic of Iran, and the People's Republic of China, assembled at the margins of the high-level segment of the thirteenth meeting of the Conference of the Parties to the Convention on Biological Diversity, in Cancun, Mexico, on 3 December 2016,

Recalling that our Group of Like-minded Megadiverse Countries (LMMC) was formed in Cancun 14 years ago, in 2002, as a mechanism for consultation and cooperation to promote interests related to the conservation and sustainable use of biological diversity, and the fair and equitable sharing of benefits derived from the utilization of genetic resources, at the behest of an initiative taken by the Government of Mexico, and **recalling** also the Cancun, Cusco and New Delhi Declarations of our Group;

Recalling further the continuing support of the LMMC to the benefit-sharing provisions of the Convention and its Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization;

Noting that, with 12% of the surface of the globe, the LMMC harbour at least 70% of the planet's terrestrial biological diversity as well as rich marine biodiversity, over 45% of the population of the world, and an extraordinarily rich cultural diversity and associated traditional knowledge;

Acknowledging that protected areas and other effective area-based conservation measures, in addition to conserving ecosystems, are essential for life, support livelihoods and offer nature-based solutions for the complex challenges faced by the world today. They possess unique, ecological, socio-economic and cultural practices. They are also important vehicles for facilitating integration of biodiversity into comprehensive sustainable development policies;

Emphasizing the significance of achieving the Strategic Plan for Biodiversity 2011-2020 and its Aichi Biodiversity Targets, the United Nations 2030 Agenda for Sustainable

Figure 2. The Like-minded Megadiverse Countries Carta to Achieve Aichi Biodiversity Target 11

Improvements in the relationship between societies and protected areas and the achievement of Target 11 in its entirety are sought by the LMMCs. The meeting of the LMMCs on the margins of the high-level segment of the thirteenth meeting of the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) in 2016 resulted in the *Like-minded Megadiverse Countries Carta to Achieve Aichi Biodiversity Target 11* being welcomed by the COP (CBD 2016; SCBD 2016a). The *Carta, inter alia*, acknowledged that protected areas are "important vehicles for facilitating integration of biodiversity into comprehensive sustainable development policies", called upon "all Parties, and other countries, which have not yet identified and developed their national priority actions (roadmaps) to do so and to implement them to facilitate the achievement of Aichi Target 11 by 2020 at the global level", and urged "all partners and stakeholders to take concerted efforts to abet the implementation of roadmaps" (SCBD 2016a) (see Fig.2).

In order to facilitate the achievement of Aichi Biodiversity Target 11 and to enhance the progress of the qualitative elements[3] of the target, the present study aims to determine the extent to which LMMCs' commitments make use of sustainable productive strategies and incorporate the perspectives of the Satoyama Initiative, either implicitly or explicitly. The results highlight ways that the LMMCs and the International Partnership for the Satoyama Initiative can pool resources and efforts in a concerted manner to facilitate implementation and contribute to the achievement of Aichi Biodiversity Target 11, as well as to enact the ecological and socio-economic perspectives of the Satoyama Initiative.

3. Methodology

3.1 Data collection

Commitments from the LMMCs addressing the qualitative elements of Target 11 were drawn from: National Biodiversity Strategies and Action Plans (NBSAPs); Fifth National Reports of Parties to the CBD; Status, Gaps and Opportunities and National Priority Actions (NPAs) from the six regional workshops on protected areas; and protected area-related biodiversity projects from the fifth and sixth replenishment of the Global Environment Facility (GEF). The relevant text was extracted and compiled according to its contribution to one of the qualitative elements of Target 11.

3.2 Classification system

The excerpts, referring to commitments, from the above sources were compiled in a database and classified according to the level of confidence that the actions put forth will be implemented by 2020. A weak commitment, scoring 1, simply addresses the element of Target 11 in the document. The need for action is recognized; however, there is no designed framework or action(s) mentioned. A commitment scoring 2 includes a legal framework addressing the element and/or a list of actions that should be implemented in order to address the element. In this case, there is no explicit plan for how to implement these proposed actions. A strong commitment, scoring 3, has developed a specific plan(s) for the implementation of the proposed action for the element.

3.3 Identification of SEPLS-related commitments

From the database containing all LMMC national commitments related to the qualitative elements of Target 11, SEPLS-related commitments were identified as those which address at least one of the perspectives of the Satoyama Initiative conceptual framework. After identification of SEPLS-related national commitments, we developed a new framework linking the commitments to a set of perspectives[4] related to those in the original Satoyama Initiative framework. These perspectives include actions on: sustainability related to cyclical use of resources and use of resources within carrying capacity of the environment; traditional knowledge related to the recognition of the value of local traditions and culture; gender related to promoting the inclusive participation and recognition of the importance of women to sustainable production and biodiversity conservation; landscape management related to multi-stakeholder participation and spatial planning in the context of a broader landscape; socio-economic development related to production and benefit sharing, increase in revenue and capacity building; and resilience actions related to improving ecosystem health, adaptation to climate change and better landscape connectivity.

3.4 Data analysis

The national commitments of the LMMCs were classified according to (i) country, (ii) document from which the commitment was extracted, (iii) type of environment of the commitment (terrestrial/coastal-marine), (iv) contribution to the elements of Target 11, and (v) contribution to the set of perspectives of the Satoyama Initiative. Based on commitment score, mean scores were calculated for each perspective in order to test whether perspectives vary according to the level of confidence that actions will be implemented. The mean commitment scores were plotted and compared using a one-way ANOVA and a Tukey test of multiple comparisons.

Since one commitment may result in multiple benefits, a network of interactions between SEPLS-related national commitments and the framework of perspectives of the Satoyama Initiative was constructed to facilitate the

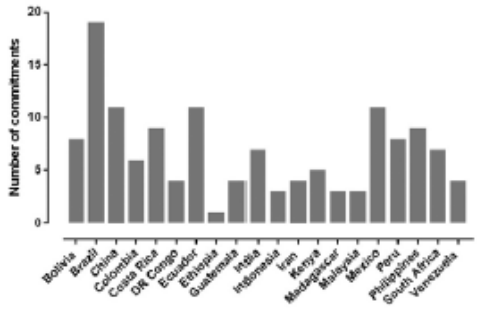

Figure 3. Number of SEPLS-related commitments by Like-Minded Megadiverse Countries.

visualization of interactions among elements of Target 11 and the modified framework of perspectives. The network was plotted in the programme R, version 3.3.0, using the package bipartite (Dormann, Gruber & Fruend 2008).

4. Results

From a database of 1,036 LMMCs' commitments addressing the qualitative elements of Aichi Biodiversity Target 11, a total of 137 commitments also address at least one of the perspectives of the Satoyama Initiative. These 137 national commitments aim to harmonize protected areas with the needs of sustainable production.

The identified SEPLS-related national commitments proposed actions to, *inter alia:* promote production landscapes and/or seascapes; promote improvements for sustainable management of biodiversity with a focus on socio-economic development; or, address improvement of production practices by local communities.

SEPLS-related commitments were identified from all LMMCs (Fig. 3). A mean of 6.85±4.15 commitments was identified per country, ranging from 1 to 19 commitments. The majority of commitments proposed actions in terrestrial ecosystems (66%) followed by commitments targeting both terrestrial and coastal and marine ecosystems (16%) (Fig. 4A). Four percent of commitments proposed actions exclusively in coastal and marine ecosystems. Fourteen percent of commitments did not specify the type of ecosystem to be targeted by the proposed actions.

Sixty percent of SEPLS-related national commitments were derived from GEF projects, 40% from GEF-5 and 20% from GEF-6 (Fig. 4B). The remaining 40% of commitments were derived from NBSAPs (32%), National Priority Actions (4%), National Reports (2%) and reports of Status, Gaps and Opportunities from the regional protected area workshops (2%). This highlights the opportunity for synergies with the GEF-5 and GEF-6 projects that are not yet completed, as well as upcoming GEF-7 projects and the various commitments of the Parties to the Convention. These synergies with the SEPLS strategies could provide for a more effective implementation of the qualitative elements of Target 11.

The identified SEPLS-related commitments spanned all qualitative elements of Target 11, namely, integration, equitable management, effective management, connectivity, conservation of areas important for biodiversity and ecosystem services, and ecological representation (Fig. 5A).

Integration and equitable management of protected areas were elements which had the highest number of SEPLS-related commitments, 50 and 37, respectively. Twenty-two SEPLS-related commitments targeted management effectiveness, and 15 targeted connectivity. Commitments to improve ecological representation and the coverage of

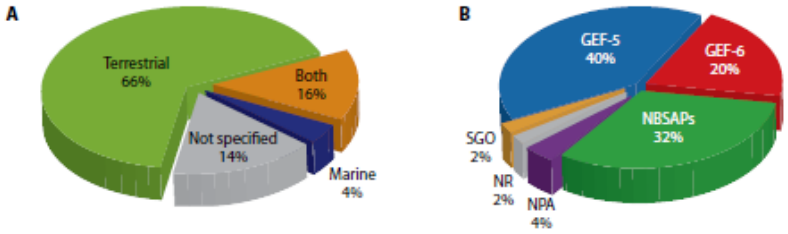

Figure 4. Distribution of SEPLS-related commitments according to the target ecosystem (terrestrial/coastal-marine) and source. (A) SEPLS-related commitments were identified as containing actions targeting exclusively terrestrial environments (green), both terrestrial and costal and marine environments (orange), exclusively costal and marine environments (blue), and commitments whose actions did not specify the type of environment targeted (grey). (B) SEPLS-related commitments were derived from GEF-5 projects (blue), GEF-6 projects (red), National Biodiversity Strategy and Action Plans (green), National Priority Actions (pink), National Reports (grey) and reports of Status, Gaps and Opportunities from regional workshops on protected areas (orange).

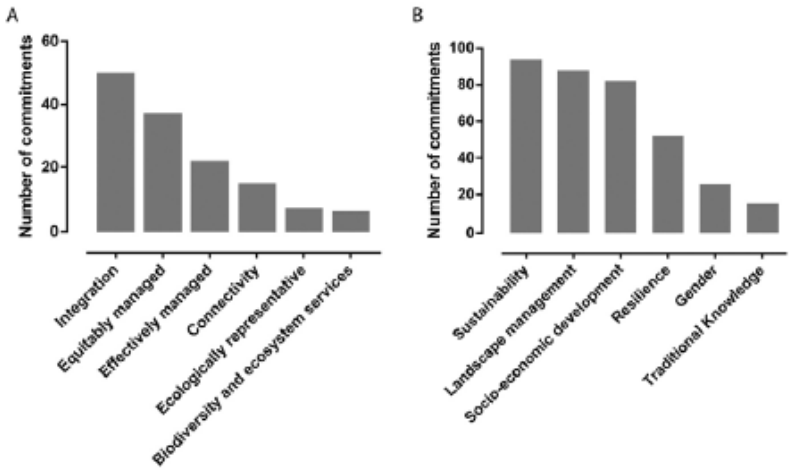

Figure 5. Distribution of SEPLS-related commitments by elements of Target 11 and by perspectives of the Satoyama Initiative. (A) Number of SEPLS-related commitments according to the elements of Target 11 to which they will contribute most if implemented. (B) Number of SEPLS-related commitments that would contribute to the perspectives of the Satoyama Initiative if implemented.

areas important for biodiversity and ecosystem services had the lowest number. Seven SEPLS-related commitments targeted under-represented ecosystems, such as montane forests, wetlands, estuaries, and mangroves. Six commitments targeted areas important for biodiversity and ecosystem services and were associated with improved conservation and wise use of wetlands and river basins to ensure maintenance of hydrological regimes.

SEPLS-related commitments were analyzed to determine whether implementation of identified actions will contribute to the achievement of the perspectives of the Satoyama Initiative (Fig. 5B). The perspectives with the highest number of identified actions were those addressing the improvement of sustainability of production practices—including both resource use within carrying capacity and cyclic use of natural resources (94 commitments), landscape management (88 commitments) and socio-economic development (82 commitments). Actions contributing to the improvement of ecosystem resilience, such as climate change adaptation and connectivity, were iterated in 52 commitments. Actions targeting gender were listed in 27 commitments, and there were 15 actions targeting the conservation of traditional knowledge.

SEPLS-related commitments were scored according to the level of confidence that the proposed actions will be implemented. Overall, mean commitment scores were moderate-high for all perspectives of the Satoyama Initiative, suggesting the majority of commitments addressing the perspectives are well-elaborated and present a framework of actions or specific plans for the implementation of the commitments (Fig. 6). Scoring differences of commitments contributing to the perspectives of the Satoyama Initiative were not statistically significant ($F_{5, 361}$=1.625, p=0.152).

SEPLS-related commitments of the LMMCs were linked to perspectives of the Satoyama Initiative in order to evaluate the structure of multiple benefits derived from the implementation of identified actions. The network resulting from the synergistic links of Target 11 national commitments of the LMMCs with the perspectives of the

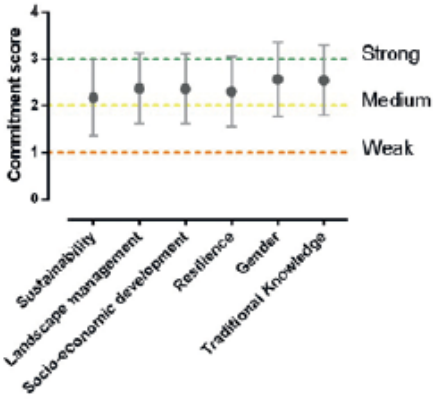

Figure 6. Score of the confidence in the implementation of SEPLS-related commitments according to the perspectives of the Satoyama Initiative to which they will contribute if implemented. Values represent mean±SD.

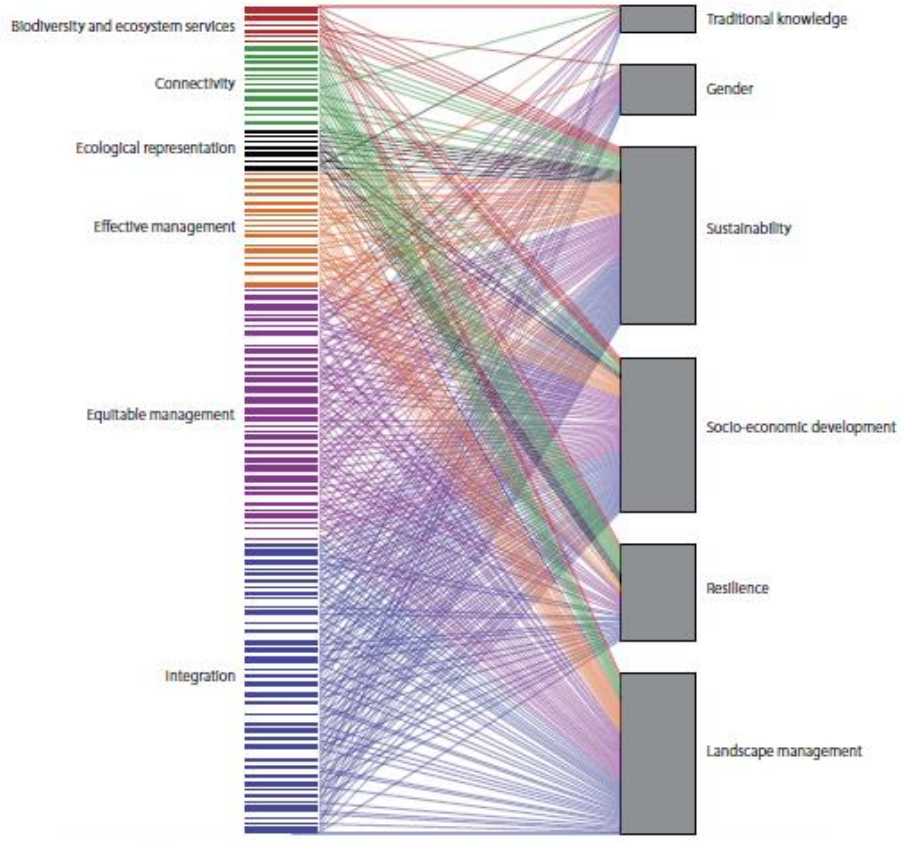

Figure 7. Bipartite network illustrating interactions between SEPLS-related commitments (left) and perspectives of the Satoyama Initiative (right). Commitments were coloured according to their contribution to the elements of Aichi Biodiversity Target 11: biodiversity and ecosystem services (red), connectivity (green), ecological representation (black), effective management (orange), equitable management (purple) and integration (blue).

Satoyama Initiative is highly interconnected (Fig. 7). This result suggests that most of the SEPLS-related national commitments incorporate multiple perspectives of the Satoyama Initiative, and that each of the perspectives are reflected in actions spanning most of the qualitative elements of Aichi Biodiversity Target 11. It further highlights the interconnectivity between the LMMCs' commitments to enhance the qualitative elements of Target 11 and the perspectives of the Satoyama Initiative. This interconnectivity corroborates that these commitments, although not always addressed in explicit language, bear actions that promote the SEPLS vision and, therefore, could be achieved by the implementation of the SEPLS strategies. Implementation of SEPLS-related commitments would result in substantial improvements to the qualitative elements of Aichi Biodiversity Target 11 and support progress towards the 2050 Vision for Biodiversity—a world in harmony with nature.

5. Discussion

To make the achievement of Aichi Biodiversity Target 11 a reality, concerted efforts will be required to facilitate the implementation of national commitments. The second phase of the CBD Secretariat's strategy on protected areas is geared towards addressing this requirement. It includes, among other facets, the identification and mobilisation of relevant regional partners, bilateral and multilateral funding agencies and experts to enable regional implementation support networks for Target 11. These networks will facilitate implementation on the ground and provide technical

support through regular communications with national implementers and relevant stakeholders, and provide capacity development, as well as monitoring and reporting on the progress towards the achievement of Target 11 (SCBD 2018c; Gannon et al. 2017; SCBD 2016b).

It is clear from their commitments that the LMMCs aim to improve the status of protected areas in their countries building upon the call made in the LMMCs' *Carta*. To accomplish this, many national commitments of the LMMCs have specified sustainable production within or adjacent to protected areas. The identified SEPLS-related commitments intrinsically incorporate the overarching vision for a society in harmony with nature, the approach and the main ecological and socio-economic perspectives of the Satoyama Initiative. The intricate network of synergies among Target 11 commitments and the ecological and socio-economic perspectives of the Satoyama Initiative suggest that the LMMCs could make use of the SEPLS strategy as a mechanism to facilitate the implementation of these commitments. This synergistic implementation would contribute to improving the overall status of Aichi Biodiversity Target 11, and especially target protected area integration and equitable management, the elements that require increased efforts to meet the target by 2020.

SEPLS, if managed effectively, can contribute to the integration of protected areas into the wider landscape, seascape, and various sectors. This could occur through the facilitation of landscape planning processes and multi-stakeholder participation, favouring more equitable management initiatives with the participation of local communities, improving management effectiveness by mainstreaming biodiversity across sectors and within communities, facilitating connectivity by reducing the resistance to wildlife movement in the landscape, and conserving areas important for ecosystem services that support sustainable production (Bélair et al. 2010; Plieninger et al. 2014).

These efforts can significantly contribute to improving the livelihoods and well-being of local communities while ensuring the long-term conservation of biodiversity within protected areas. Improving these key qualitative elements of Target 11 can strengthen relationships between conservation practitioners and other stakeholders, in particular with local communities and indigenous peoples, responsible for the management of land and marine resources across the broader landscape and seascape. These efforts could likewise help not only to increase the effectiveness of protected areas, allowing for the management of ecological processes that occur over large spatial scales, such as hydrological processes, pollination, and larval dispersal in marine systems, but also to tackle threats that occur outside protected areas such as fire, pollution and hunting, and address drivers of change that occur at large scales, such as economic, demographic and political factors. For example, Chao et al. (2018) report in this issue significant transformations towards sustainable use of natural resources and restoration of degraded ecosystems around Yangmingshan National Park in Taiwan, following the rebuilding of a SEPLS by the local community. The collective actions of the Gongrong and Ankang communities in applying eco-friendly farming, engaging government officers to strengthen law enforcement, and implementing sewage purification greatly contributed to reducing pollution in the landscape resulting in significant improvement of stream water quality. Chao et al. (2018) also shows that SEPLS mobilize people, in this case, a group of visionary, highly motivated elders in the communities, to help local residents realize the long-term and devastating impacts of land degradation and loss of biodiversity and ecosystem services on their livelihoods and ignite their willingness to make a difference. The SEPLS approach, in this case, has improved the management effectiveness of the Yangmingshan National Park and increased its effective size by integrating large privately owned areas in the surrounding landscape (Chao et al. 2018). The International Partnership of the Satoyama Initiative has a wide network of partners within the LMMCs and has implemented the SEPLS approach in many of these countries. By embracing the network of IPSI partners, LMMCs would have access to funding sources including the Satoyama Development Mechanism (SDM) and the Community Development and Knowledge Management for the Satoyama Initiative (COMDEKS), capacity building initiatives developed by IPSI and a wealth of knowledge, guidelines and case studies to accelerate implementation of actions to reach synergistic goals. IPSI may hold the key and the potential to fill in the gaps and improve progress for the qualitative elements of Target 11 through the goal of establishing, restoring and maintaining SEPLS within and around protected areas.

6. Conclusion

SEPLS are a valuable model for sustainable productive practices which can support the development of mutually beneficial relationships between societies and protected areas. A subset of LMMCs' national commitments to Aichi Biodiversity Target 11 is aligned with the perspectives of the Satoyama Initiative. These commitments are predominantly related to the elements integration and equitable management of Target 11, elements that form the backbone for a harmonious relationship between societies and protected areas and whose progress requires more action to meet the target by 2020. The network resulting from the synergistic links of Target 11 national commitments

with the perspectives of the Satoyama Initiative is highly interconnected, suggesting that implementation of these commitments has the potential to promote multiple benefits. This implies that efforts to mainstream SEPLS to the LMMCs will have the potential to facilitate effective implementation of national commitments for Target 11 and to encourage accounting for the concepts of SEPLS in the national planning process. Taking into consideration the relevance of LMMCs to biodiversity conservation and the challenges to promote sustainable socio-economic development, progress toward implementation of the national commitments through the SEPLS approach will have a global positive impact on biodiversity, contribute to safeguard protected areas in hotspots for conservation and promote societies in harmony with nature through socio-ecological production and sustainable development.

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1 The elements of Target 11 refer to the individual clauses in the language of the target, and include both quantitative elements (at least 17% terrestrial and at least 10% marine coverage) and qualitative elements: ecological representation, coverage of areas important for biodiversity and ecosystem services, connectivity, integration into the wider landscapes and seascapes, and effective, and equitable management (governance and equity).

2 The group of the Like-Minded Megadiverse Countries (LMMCs) consist of: Bolivia, Brazil, China, Colombia, Costa Rica, Democratic Republic of Congo, Ecuador, Ethiopia, Guatemala, India, Indonesia, Iran (Islamic Republic of), Kenya, Madagascar, Malaysia, Mexico, Peru, Philippines, South Africa and Venezuela (Bolivarian Republic of).

3 See footnote 1 for more information.

4 This modified set of perspectives merged "resource use within carrying capacity of the environment" and "cyclic use of natural resources" from the original conceptual framework of the Satoyama Initiative. These are described under a new perspective called sustainability due to the uncertainty in classification of identified commitments. Additionally, gender equality was included as a new perspective in this study in order to add information on how gender is being addressed in the context of SEPLS and Target 11.