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Ecological criteria to identify areas for biodiversity conservation

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ABSTRACT

A challenge in implementing biodiversity conservation is in reconciling criteria for identifying significant areas and representative networks for biodiversity protection. Many international environmental initiatives include biological, ecological, economic, social and governance criteria to aid selection of areas for biodiversity conservation. Here we reviewed criteria used by 15 international initiatives, and what minimum set of biodiversity variables would be needed to support them. From a range of ecological and biological criteria, we identified eight criteria commonly used to identify areas for biodiversity conservation across these initiatives. Four criteria identified areas that (1) contained unique and rare habitats; (2) included fragile and sensitive habitats; (3) were important for ecological integrity; and (4) were representative of all habitats. Another four criteria were based on species' attributes, including (5) the presence of species of conservation concern; (6) the occurrence of restricted-range species; (7) species richness; and (8) importance for life history stages. Information required to inform these criteria include: habitat cover, species occurrence, species richness, species' geographic range and population abundance. This synthesized set of ecological and biological criteria, and their biodiversity variables will simplify the process to identify additional areas of high biodiversity significance, that in turn support achieving the Convention on Biological Diversity (CBD) targets to fill gaps in the representativeness of the global coverage of protected areas.

1. Introduction

The loss of biodiversity is altering ecosystem functions and services that are essential for human well-being as well as threatening species with extinction (FAO, 2010; WWF, 2014). The primary management responses to this loss include managing human activities (Young et al., 2005) and species' populations (Stattersfield et al., 1998) and designating and implementing protected areas (Brooks et al., 2004). Protected areas are a key strategy to conserve biodiversity (Rodrigues et al., 2004), because they reduce rates of habitat loss (Butchart et al., 2012), prevent declines of threatened species (Ricketts et al., 2005), and maintain ecosystem services (Stolton et al., 2015). Several initiatives provide a framework to identify potential areas for biodiversity conservation (Brooks, 2010). The objectives of these initiatives have ranged from the protection of areas for selected taxonomic groups (Ricketts et al., 2005) to developing a network of areas designed to protect biodiversity in general (Clark et al., 2014). They have resulted in many areas having received formal protection, and/or being managed to conserve biodiversity (Langhammer et al., 2007). In addition to these initiatives, there has been a growing societal and political interest to improve the status of biodiversity by protecting areas of "importance for biodiversity that are ecologically representative through an effective, equitable and integrated management system" (CBD, 2010).

Aligned with those initiatives, the 11th Aichi Biodiversity Target of the Convention on Biological Diversity (CBD) aims to conserve at least 17% of terrestrial and 10% of marine environments globally by 2020 (CBD, 2010). Although the number and coverage of global protected areas have expanded in the past four decades (Juffe-Bignoli et al., 2014), the coverage of protected areas stands at 14.6% for terrestrial and only 2.8% for marine environments (Butchart et al., 2015). The target for terrestrial protected areas is achievable, requiring the addition of around 3.3 million km^2 to achieve the 17% target (Butchart et al., 2015). However, a further 2.2 million km^2 of marine areas within national jurisdictions and 21.5 million km^2 of areas beyond national jurisdictions need to be protected to achieve the 10% of the marine CBD target (Juffe-Bignoli et al., 2014). Moreover, the level of protection of biodiversity within protected areas can vary greatly (Costello & Ballantine, 2015). For example, only 0.7% of the oceans is within MPAs that aim to protect biodiversity at all levels, from genes to populations, food webs and ecosystems (Costello & Ballantine, 2015). It is estimated that

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only 27% of coral reef ecosystems (Burke et al., 2012), 6.9% of mangrove forests (Giri et al., 2011), and about 15% of threatened vertebrates have been protected within existing protected areas networks (Venter et al., 2014). Furthermore, the past establishment of protected areas often occurred in a biased or ad hoc fashion and did not deliver optimal biodiversity conservation (Stewart et al., 2007). Thus, identifying additional areas for biodiversity conservation is a prerequisite for achieving the CBD targets to fill gaps in the representativeness of the global coverage of protected areas (Spalding et al., 2013; Juffe-Bignoli et al., 2014; Venter et al., 2014; Butchart et al., 2015).

Various initiatives have developed biological, ecological, economic, social and governance criteria to identify areas of biodiversity importance. Biological and ecological criteria are the primary consideration in meeting biodiversity conservation objectives (Roberts et al., 2003; Gilman et al., 2011). A number of variables have been applied to quantify these criteria, although they vary across the initiatives. For example, several initiatives apply a criterion of biological diversity (e.g. Man and Biosphere Reserve, Particularly Sensitive Sea Areas, Natura 2000 sites, Ecologically and Biologically Significant Marine Areas). These initiatives broadly define biological diversity as an area that contains significant diversity of biodiversity elements (e.g. ecosystems, habitats, communities, species, and genetic diversity). Various indices that have been proposed to measure this criterion include richness of biodiversity elements, evenness level, and taxonomic distinctness. Naturally, each initiative's criteria reflect its area of special interest (e.g., species, habitats) (Roberts et al., 2003; Clark et al., 2014; IUCN, 2016). Here, we consider if it is possible for conservation management to address the needs of multiple initiatives through a common set of ecological and biological criteria. In addition, the availability of common variables to support the criteria would complement existing initiatives.

Standardized ecological and biological criteria would enable the systematic identification of areas of high biodiversity value (Gilman et al., 2011), support an ecosystem-based approach (Crowder & Norse, 2008), and categorize areas that potentially deliver the greatest contribution to preserving biodiversity (Pressey et al., 1993). Previous reviews on the criteria to identify areas important for biodiversity conservation have generated an extensive list of relevant ecological and biological criteria (Day et al., 2000; Roberts et al., 2003; Gilman et al., 2011). However, some criteria are not self-explanatory and only a few identified the biodiversity variables needed to assess their criteria (Hiscock, 2014).

If particular variables are used to identify areas for biodiversity conservation, then they are likely also important for monitoring biodiversity change within and outside protected areas. Data on these key variables is critically important, due to major gaps in our understanding of biodiversity change, particularly on the global scale (Pereira et al., 2012). The Biodiversity Indicator Partnership (BIP, www.bipindicators.net) provides global indicators of the CBD Aichi Biodiversity Targets (Bubb et al., 2014), and The Living Planet Index monitors trends in species populations (WWF, 2014). More recently, Pereira et al. (2013) proposed a framework of Essential Biodiversity Variables (EBVs) as a minimum set of indicators to measure biodiversity change. This was inspired by the application of Essential Climate Variables to support the Global Framework for Climate Services (GCOS, 2010). The EBVs comprise six classes of variables, ranging from genetic composition to ecosystem function, with each class consisting of multiple variables, and are conceptually located between primary observations and indicators (Pereira et al., 2013). However, these approaches require several primary variables (Geijzendorffer et al., 2015; Kissling et al., 2015; Schmeller et al., 2015; Brummitt et al., 2016). Amongst these, Costello (2013) proposed species occurrence as a Fundamental Biodiversity Variable (FBV) because it identifies species of conservation, ecological and economic importance, and provides the simplest metric of biodiversity (i.e. species richness). As the most widely used measure of biodiversity (Butchart et al., 2010; Tittensor et al., 2014), species occurrence is already supported by standardized sampling methods and open-access biodiversity databases (Costello et al., 2016a). It has also been proposed as one of three minimum EBV for invasive species monitoring, along with species alien status and impact (Latombe et al., 2016). EBVs have also been proposed to assess biodiversity change at the national level (Turak et al., 2016a) and in the freshwater environment (Turak et al., 2016b). However, the minimum EBVs for conservation management have not yet been identified. We suggest that the same variables used to identify areas for biodiversity conservation can also be used to monitor trends in biodiversity.

This paper reviews the conceptual framework of the international initiatives established to identify areas for biodiversity conservation. First, we reviewed ecological and biological criteria used across these initiatives, and determined key criteria that were included in most initiatives to allow objective assessment of biodiversity value. Then, we synthesized biodiversity variables required to inform these criteria. These ecological criteria provide guidance to direct assessment of areas significant for biodiversity conservation. The summarized biodiversity variables will help focus resources on what information and data should be prioritised for collection to inform conservation management across multiple biodiversity conservation initiatives. We recognized that other factors are involved in designating areas for legal protection which we do not consider here, such as the social, economic and governance context.

2. Initiatives to identify conservation areas

We reviewed 15 initiatives that identified areas important for biodiversity conservation. These initiatives have different underlying objectives, spatial scales (either local, regional or global), and environmental focus (either terrestrial, wetlands or marine). Of these, ten were established by international conventions and five by non-governmental conservation organizations (NGOs) (Table 1). The former focused on identifying and developing networks of areas important for biodiversity conservation, e.g., Man and Biosphere Reserves (MAB) (UNESCO MAB, 1996), Wetlands of International Importance (Ramsar Secretariat, 2008), Natura 2000 sites (European Commission, 2002), and Ecologically and Biologically Significant Marine Areas (EBSA) (Convention on Biological Diversity (CBD), 2008). The initiatives launched by NGOs focused on identifying areas for particular species or taxonomic groups, namely, Important Bird and Biodiversity Areas (IBA) (BirdLife International, 2004), Important Plant Areas (IPA) (Plantlife International, 2004), and Alliance of Zero Extinction Sites (AZE) (Ricketts et al., 2005).

The first initiative was introduced by UNESCO in 1971 with its Man and Biosphere Reserve programme. It promoted a balanced relationship between conservation and sustainable development (UNESCO MAB, 1996). Several of the other initiatives were focused not only on conserving species but also maintaining biodiversity in general. Two initiatives that specifically aimed to safeguard threatened, rare, endemic and other species of conservation concern are the IBA and AZE. The former focused on the long-term viability of bird populations (BirdLife International, 2004; O'Dea et al., 2006) while AZEs identified areas critical for the survival of the world's most threatened species (Ricketts et al., 2005). Currently, there are over 12,000 areas in more than 200 countries that have been identified as IBAs (BirdLife International, 2013), and more than 588 areas that have been included as AZEs (Alliance for Zero Extinction, 2010). The objectives of the other 13 initiatives were focused on conserving habitat and aimed to maintain ecosystem elements, processes, and services (Table 1). For example, IPA identified areas of global significance for plants and threatened plant habitats (Plantlife International, 2004) and EBSA identified marine areas using biodiversity surrogates such as topographic and oceanographic habitat features (Kenchington et al., 2011; Clark et al., 2014; Yamakita et al., 2015). Currently, IPAs have been identified in over 66 countries (Plantlife International, 2014), and a total of 204 EBSAs have been described (Bax et al. 2016).

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Table 1
International initiatives for prioritization of areas important for biodiversity conservation (listed in chronological order).

Initiative	Supporting organization, establishment year	Biodiversity scope	Objective
Man and Biosphere Reserves	United Nations Educational, Scientific, and Cultural Organization (UNESCO), 1971	Terrestrial, freshwater, and marine environments	To identify internationally recognized areas with significant biodiversity value that demonstrate and promote a balanced relationship between conservation and sustainable development.
Ramsar sites of Wetlands of International Importance	Ramsar Convention of Wetlands, 1971	Wetlands and aquatic environments	To develop and maintain an international network of wetlands that are important for the conservation of biological diversity and for sustaining human life.
World Heritage Natural Sites	UNESCO, 1972	Terrestrial, freshwater, and marine environments	To identify areas with cultural and natural heritage significance, which have an outstanding universal value.
Important Bird and Biodiversity Areas	Birdlife International, 1981	Bird species and populations	To identify and develop a network to protect key sites for the conservation of global avifauna.
Particularly Sensitive Sea Areas	International Maritime Organization, 1990	Marine environments	To identify areas with which have significant ecological and socio-economic value or scientific attributes that are vulnerable to damage by international shipping activities.
Natura 2000	European Commission, 1992	Terrestrial, freshwater, and marine environments.	To protect the most valuable and most threatened species and habitat in Europe.
Important Plant Areas	Plantlife International, 1995	Plant and fungal species, and habitat.	To identify and protect areas of globally significance for plants and threatened plant habitats.
Emerald Network	Council of Europe, 1998	Terrestrial, freshwater, and marine environments.	To identify a regional network of ecologically important areas in Europe and North Africa.
Alliance for Zero Extinction Sites	Alliance for Zero Extinction, 2000	Species	To identify and preserve key sites of endangered or critically endangered species, in order to prevent species extinction.
Important Site for Freshwater Biodiversity	International Union for Conservation of Nature (IUCN), 2002	Freshwater environments	To identify important sites for biodiversity conservation in inland waters.
ASEAN Heritage Parks	Association of Southeast Asian Nations (ASEAN), 2003	Terrestrial, freshwater, and marine environments.	To identify protected areas in the ASEAN Region that are characterized by its outstanding wilderness, ecological and cultural values.
OSPAR Network of Marine Protected Areas	The Oslo and Paris Commissions of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Commission), 2003	Marine environments	To ensure the sustainable use, protection and conservation of marine biodiversity and its ecosystems in the western coast of Europe.
Ecological and Biologically Significant Marine Areas	Convention on Biological Diversity, 2008	Marine environments	To identify areas of high ecological and biological significance in open-ocean waters and in deep sea habitats, both within EEZ or beyond national jurisdiction, that need protection and to establish a representative network of marine protected areas.
Vulnerable Marine Ecosystems	Food and Agriculture Organization, 2009	Marine environments	To identify and protect marine areas in the high seas that are vulnerable to deep-sea fishery activities.
Key Biodiversity Areas	IUCN, 2016	Species, terrestrial, freshwater, and marine environments	To identify areas that contribute significantly to the global persistence of biodiversity.

3. Ecological and biological criteria

We reviewed the criteria established by the initiatives and conducted a two-tier evaluation: (a) assessment of the definitions, objective(s), and measured variables (Tables 1 and S1), and (b) analysis of the frequency of inclusion of ecological and biological criteria in the initiatives (Table 2).

3.1. Selection criteria

3.1.1. Unique and rare habitats

Habitats that occur only in specific areas are highly significant for biodiversity conservation. Such habitats would be irreplaceable, and their loss would increase risk of local and global species extinctions. Identifying the uniqueness or rarity of habitats should consider the spatial scale of the application, either global, regional or local. Some habitats may be considered as unique or rare at the local level, but abundant elsewhere in the world. A globally unique or rare habitat is significant even if it is relatively abundant within a specific region. Consideration should also be taken for a habitat that experiences a decline in area (cover) and/or quality, even if that habitat may occur elsewhere. This criterion can be evaluated through data on the distribution, occurrence, or relative abundance of species or habitats. The presence of a potentially unique habitat, in turn indicates the presence of a unique species assemblage. Marine examples include hydrothermal vents and seamounts in the Pacific Ocean (Clark et al. 2014); kelp forest and endemic seagrasses in Japan (Yamakita et al., 2015). New Zealand developed a typology of naturally uncommon terrestrial habitats (called ecosystems in this management regime), based on the presence of specialized and diverse assemblages of flora and fauna with endemic and rare species (Holdaway et al., 2012).

3.1.2. Fragile and sensitive habitats

This criterion defines habitats that are relatively susceptible to natural or human-induced threats. Protecting such areas may help reduce disturbance from human activities and increase resilience to natural events. This criterion can be assessed through maps of vulnerable or sensitive habitat derived from field surveys, remote sensing technique or habitat modelling. Examples include habitat maps of warm-water coral (UNEP-WCMC et al., 2010), cold-water coral (Yesson et al., 2012), seagrass (UNEP-WCMC & Short, 2005), and mangroves (Giri et al., 2011).

3.1.3. Representativeness

Representativeness is defined as the degree to which areas within a network include examples of all habitats, ecosystems, and species so as

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Table 2
Eight ecological criteria that have been used for the identification of areas important for biodiversity conservation, ranked by frequency of occurrence in international conservation initiatives.

Criterion	Application	Justification
Species of conservation concern (2–4, 6–13, 15)	An area that is inhabited by species that are categorized as threatened or protected (e.g. Listed in the IUCN Red List of Threatened species, CITES Appendix, EU Bird and Habitat Directive Annex or other regional/national legislations)	Need to protect species which are in decline. Protecting this area contributes to reducing the risk of species extirpations and extinction.
Important area for life history stage (2–6, 8–10, 12–15)	An area that is important for evolution and/or life history, such as areas of species' aggregation, refugia, spawning, breeding, nursery or migratory routes.	Some species, particularly highly migratory species (e.g. birds, mammals, fish or sea turtles), show aggregation behavior at some stage of their life cycle. Thus, disturbance or degradation to such sites may impact the global population. As an important site during critical life stages of a species, the protection of this site contributes to the survival of the species.
Representativeness (1–3, 5–8, 11–13)	An area that enables a network to encompass a full range of biodiversity.	Protecting representative areas contributes to preserving populations of all species and habitats in a geographic region.
Unique and rare habitat (2, 3, 5, 7, 11, 13–15)	A habitat that occurs only at a specific site or a small number of sites.	The concept of being "the only one of its kind" is highly significant for conservation, as its loss could deplete the number of known species.
Restricted-range species (2–4, 6, 7, 9, 10, 13, 15)	An area inhabited by a species that has a restricted geographic distribution. If naturally restricted this is an 'endemic' species.	Species that are geographically restricted are more vulnerable to extinction. Any disturbance to their habitat, either natural or anthropogenic, may decrease species' abundance and increases the risk of extinction.
Biological diversity (1, 2, 4–8, 11, 13)	An area that is inhabited by a large number of species, and/or will increase the number of species in the network of areas.	Species richness is the most popular metric of diversity; an effective strategy to conserve biodiversity is protecting a network of sites that collectively encompasses a large number of species.
Ecological integrity (2, 3, 5, 6, 8, 11, 13, 15)	An area that exhibits a contiguous natural habitat with negligible anthropogenic disturbance.	This area supports species assemblages and ecological processes in their natural condition. Preserving this area will provide benefits by reducing human induced threat, and increase ecosystem resilience.
Fragile and sensitive habitat (2, 3, 5, 12, 13)	A habitat that is highly susceptible to natural or human-induced threats.	Protecting a site with a habitat vulnerable to disturbance would increase site resilience and reduce the potential impact of natural or human-induced threats.

Numbers in parentheses refers to the supported initiatives: (1) UNESCO MAB, 1971; (2) Ramsar Secretariat, 1971; (3) UNESCO, 1972; (4) Birdlife International, 1981; (5) International Maritime Organization, 1990; (6) European Commission, 1992, (7) Plantlife International, 1995; (8) Council of Europe, 1998; (9). Alliance for Zero Extinction, 2000; (10) IUCN, 2002; (11). ASEAN Secretariat, 2003; (12) OSPAR Commission, 2003; (13) Convention on Biological Diversity, 2008; (14) Food and Agriculture Organization, 2009; (15) IUCN, 2016.

to encompass a full range of biodiversity (Day et al., 2000; Roberts et al., 2003; Hiscock, 2014). Remote sensing methods (e.g. satellite, airborne and shipborne-based approaches) can be used to delineate the extent, distribution and structure of habitats (Andréfouët et al., 2008). Using biological and physical spatial datasets of habitat distribution, the Great Barrier Reef Marine Protected Areas (GBR MPAs) incorporated 70 specific bioregions in their zonation system (GBR MPA, 2014). The California MLPA design recognized 13 habitats based on two ecological patterns: community assemblage and depth. In Europe, the BioMar project developed a classification of benthic seabed habitats (Picton & Costello, 1998; Costello & Emblow, 2005) which has been expanded (JNCC, 2015) and incorporated within the European Nature Information System (EUNIS) habitat classification, which already includes terrestrial habitats.

At a global scale, biogeographic regions reflect connectivity between areas on evolutionary timescales. Biogeographic realms distinguish areas based on species endemicity, and global biogeographic classifications exist for terrestrial (Holt et al., 2013), freshwater (Abell et al., 2008), and marine (Costello et al., 2016b) environments. Thus there should be networks of protected areas that represent the range of habitats and species within each realm.

3.1.4. Ecological integrity

Ecological integrity is defined as the degree to which an area exhibits a contiguous natural habitat with a relative absence or minimum level of anthropogenic disturbance. It can be analysed by comparing the state of a given area to other representative areas and from historical information. An area with a higher degree of ecological integrity is considered as an area of higher biodiversity significance, as that area supports species assemblages and ecological processes in their natural condition. A cumulative effect of human activities on the marine environment can be used as a proxy of ecological integrity, and such data are available at a global (Halpern et al., 2008) or regional scale (Burke et al., 2012).

3.1.5. The presence of species of conservation concern

A number of initiatives and regulations focus on the rarity, decline, areas of occupancy and total known populations of a given species to assess the degree of threat to that species. Species conservation assessments are included within the Red-List of Threatened Species of IUCN (www.iucnredlist.org), the appendices of CITES (www.cites.org), the annexes of EU Habitats and Birds Directives (www.ec.europa.eu.org), and lists of regional and national threatened species. Protecting areas that contain threatened species reduces the risk of species extirpation and extinction, and supports species recovery (Ardron et al., 2009).

3.1.6. Restricted-range species

Most species have naturally limited geographic distributions, and often these are further limited by loss of habitat or hunting. Endemicity is applied as a criterion where species are naturally restricted to a defined geographic location, while restricted range species may have suffered range loss due to human activities. Such species' are more vulnerable to extinction than more cosmopolitan species. Areas isolated for hundreds of thousands of years, such as islands or remote island groups, are likely to have a high proportion of endemic species. It is estimated that approximately 51% marine species in New Zealand (Gordon et al., 2010), 45% in Antarctica (Costello et al., 2010), and 20% in the Galapagos Islands are categorized as endemic species (Edgar et al., 2008).

Species with restricted ranges can be assessed either by setting an absolute threshold for all taxa and an arbitrary cut-off point or using a percentile approach which measures a range restriction relative to the overall distribution of range sizes (Langhammer et al., 2007). For terrestrial birds, Stattersfield et al. (1998) applied a breeding range of 50,000 km^2 or less as an arbitrary cut-off point to classify species as restricted range. This threshold found 25% of birds had restricted ranges. Hawkins et al. (2000) defined restricted-range species of coral reef fishes as those with ranges of 800,000 km^2 or less and identified 24% of coral reef fishes as having restricted ranges.

3.1.7. Biological diversity

Biological diversity is frequently used as a criterion and prioritises the degree to which an area has a relatively higher number of biotopes, habitats, species or genetic diversity. An effective strategy to conserve biodiversity is protecting a network of areas that collectively encompasses a large number of communities. Diverse communities may provide resilience to perturbation and improve management efficiency by containing a variety of habitats or species (Hiscock, 2014).

Indices used to indicate diversity include richness, composition, relative abundance and taxonomic distinctness (e.g., Schipper et al., 2016). The most popular index is species richness (Costello et al., 2004). Species occurrence records can be derived from field survey, specimens in museum collections, citizen science observations and other sources. Access to over half a billion records of species occurrence data is provided by the Global Biodiversity Information Facility (GBIF) and Ocean Biogeographic Information System (OBIS) (Costello et al., 2015). These data also provide the basis for species distribution modelling (e.g., Saeedi & Costello, 2012; Basher et al., 2014; Basher & Costello, 2014, 2016).

3.1.8. Areas important for life history stages

Areas where individuals of a species congregate, particularly migratory and threatened species, are often prioritised for protection. These include areas where spawning, breeding, nesting, resting, wintering, or moulting occurs; or that may be nurseries or parts of migratory routes. Some geographical areas or topographical features are more suitable for particular life stages than others (Ardron et al., 2009). Maps of such areas are available for taxa such as birds (Important Bird Areas, BirdLife International, 2016), fishes (spawning aggregations sites (SCRFA, 2013)), sea turtles (nesting ground and migratory route (Kot et al., 2015)), and marine mammals (Hoyt, 2012). Animal tracking through bio-logging and satellites provides understanding of species' movements and is used to identify areas important for the life history stages of species (Graham et al., 2012; Hays et al., 2016).

3.2. Frequency of inclusion and weighting scenario

The most frequently cited criteria for prioritisation of areas for biodiversity protection were the presence of species of conservation concern and important areas for life history stages. These two criteria were applied by 12 out of the 15 initiatives we examined (Table 3). The presence of species of conservation concern has been used on its own to identify significant areas of conservation priority in the Galapagos (Edgar et al., 2008), Philippines (Ambal et al., 2012) and Europe (European Commission, 2014). The least-cited criterion was fragile and sensitive habitat (Table 3). This criterion was used by initiatives that focused on areas in the oceans that were vulnerable to damage from anthropogenic activities such as shipping (e.g. Particularly Sensitive Sea Areas) (Ünlü, 2004), and fisheries (e.g. Vulnerable Marine Ecosystems) (Food and Agriculture Organization (FAO), 2009).

Each initiative applied a different approach to guide the selection of areas of high conservation value. A number of initiatives assign an equal weight to their criteria (e.g. UNESCO MAB, 1996; UNESCO, 2013) and others set a threshold (e.g. Ricketts et al., 2005; IUCN, 2016). Some initiatives considered an area important for biodiversity conservation if it met a single criterion (e.g. International Maritime Organization, 2005; Convention on Biological Diversity (CBD), 2008), while others applied multiple criteria (e.g. ASEAN-Secretariat, 2003; Plantlife International, 2004). Data may not be available to support all criteria. Thus, as a minimum set of criteria, we suggest that meeting any one of the eight criteria is sufficient for an area to be considered as an area of high biodiversity conservation value.

4. Biodiversity variables

We reviewed the variables used to quantify each criterion in the initiatives (Tables 1and S1), and then synthesized these variables into five biodiversity variables (Table 4). The biodiversity variables that we proposed here are a minimum set of measurements to quantify each criterion and are applicable across the initiatives.

The extent of habitat (habitat cover) is proposed to evaluate the criteria of unique and rare habitat, fragile and sensitive habitat, ecological integrity and representativeness. The distribution of unique and

Table 3
Alignment of the eight criteria for the identification of areas important for biodiversity conservation with each initiatives (+ indicates included, − indicates excluded).

	Criteria							
	Habitat				Species			
Initiative	Unique, rare habitat	Fragile, sensitive habitat	Ecological integrity	Representativeness	Conservation concern	Restricted range	Biological diversity	Important area for life history stages
Man and Biosphere Reserves	−	−	−	+	−	−	+	−
Ramsar sites of Wetlands of International Importance	+	+	+	+	+	+	+	+
World Heritage Natural Sites	+	−	+	+	+	+	−	+
Important Bird and Biodiversity Areas	−	−	−	−	+	+	+	+
Particularly Sensitive Sea Areas	+	+	+	+	−	−	+	+
Natura 2000	−	−	+	+	+	+	+	+
Important Plant Areas	+	−	−	+	+	+	+	−
Emerald Network	+	−	−	+	+	−	+	+
Alliance for Zero Extinction Sites	−	−	−	−	+	+	−	+
Important Site for Freshwater Biodiversity	−	−	−	−	+	+	−	+
ASEAN Heritage Parks	+	−	+	+	+	−	−	−
OSPAR Network of Marine Protected Areas	−	+	+	+	+	−	+	+
Ecological and Biologically Significant Marine Areas	+	+	+	+	+	+	+	+
Vulnerable Marine Ecosystems	+	+	−	−	−	−	−	+
Key Biodiversity Areas	+	−	+	−	+	+	−	+

Table 4
Biodiversity variables that can inform the criteria to identify areas important for biodiversity conservation (+ indicates applicable, − not applicable).

	Variable						
		Species attributes					
Criteria	Habitat cover	Endemic	Threatened	Native	Species richness	Geographic range	Species abundance
Unique and rare habitat	+	+	+	+	−	−	−
Fragile and sensitive habitat	+	+	+	+	−	−	−
Ecological integrity	+	+	+	+	+	−	+
Representativeness	+	+	+	+	+	−	+
Species of conservation concern	−	+	+	+	−	−	−
Restricted-range species	−	+	+	+	−	+	−
Biological diversity	−	+	+	+	+	−	+
Important area for life history stages	−	+	+	+	+	−	+

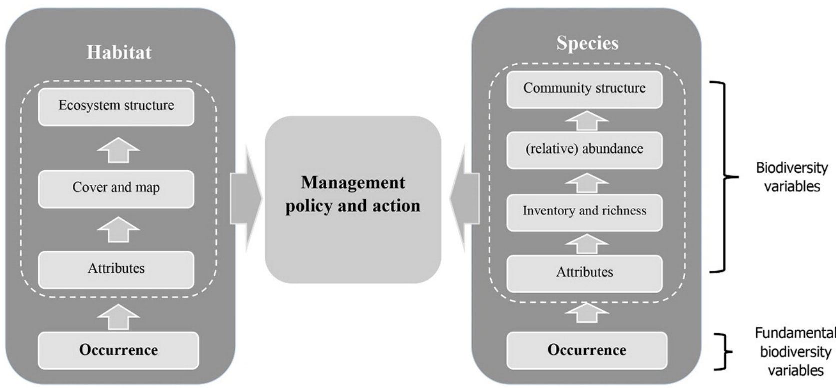

Fig. 1. Relationship of biodiversity variables for conservation. Habitat and Species comprise two complementary sets of ecology-based biodiversity variables. The most fundamental variable in each is their occurrence, i.e., whether habitats and species are present. These are given added value by knowing additional attributes and abundance (or spatial cover) of the habitats and species . For example: a biogenic habitat that is endangered (e.g. maerl, seagrass, coral reef) or that supports a threatened species; or species that are endangered or ecologically or economically important. These variables directly inform appropriate management policy and action. Monitoring would involve repeated observations of these biodiversity variables over time.

rare habitat combined with the presence of threatened species has been used to identify important biodiversity areas for Natura 2000 (European Commission, 2002), and in New Zealand (Holdaway et al., 2012). The criterion of representativeness may be evaluated through the combination of habitat cover with richness and abundance of species. Habitat cover may be mapped using remote sensing data, in situ measurement and expert opinion (Costello, 2009). These methods provide complementary information at different spatial scales. Satellite and aerial images can be used to map forested land cover (Giri et al., 2011) and shallow coastal habitat distributions (Andréfouët et al., 2008; Kakuta et al., 2010). However, in situ observations are usually needed to identify species-habitat relationships that enable evaluation of the quality of habitats (Costello, 2009). Expert opinion on available data and knowledge on specific areas may also be used to map habitats (Krueger et al., 2012).

Four of the biodiversity variables require information on species' occurrence, namely: species attributes; species richness; geographic range; and population abundance (Fig. 1). A species inventory can include endemic, threatened, introduced, and native species. Species occurrence provides an estimate of species richness. Additional information on species abundance, including the relative abundance of the species, characterizes the community and its habitat (Fig. 1).

The biodiversity variables that we have identified as important to support criteria for selecting areas for conservation are already included within the EBV classes (Pereira et al., 2013). For example, the EBV class of ecosystem structure is comprised of three variables, i.e. habitat structure, ecosystem extent, and ecosystem composition (Pereira et al., 2013), and can be assessed through habitat cover. Other EBV classes such as species populations and community composition can be measured through species occurrence, geographic range, and species abundance.

These variables should also be considered for use in biodiversity monitoring and when designing networks of protected areas. For example, a protected area network would wish to include sites representing the full range of species and habitat within a country or region.

5. Conclusions

Our review shows that although the 15 different initiatives used a variety of terminologies and criteria to select areas of conservation importance, these can be captured by four habitat-based and four species-based criteria. In turn, these criteria can be measured by five biodiversity variables, including those that assess the status of habitat and those that evaluate the composition of species. These biodiversity variables underpin all the criteria used to identify areas of biodiversity conservation. They are already in use, and thus practical to support prioritisation of protected areas for biodiversity conservation. These biodiversity variables will also support monitoring efforts to determine trends in biodiversity, planning a network of protected areas, and allow for a global comparison of protected areas effectiveness.

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