1-1-2011

Designing criteria suites to identify discrete and networked sites of high value across manifestations of biodiversity

Robin M. Warner
University of Wollongong, rwarner@uow.edu.au

E Gilman
Hawaii Pacific University

K D Hyrenbach
Hawaii Pacific University

D Dunn
Duke University, Durham US

A Read
Duke University, Durham, US

Recommended Citation

Warner, Robin M.; Gilman, E; Hyrenbach, K D; Dunn, D; and Read, A: Designing criteria suites to identify discrete and networked sites of high value across manifestations of biodiversity 2011, 3363-3363.
https://ro.uow.edu.au/lawpapers/498

Designing criteria suites to identify discrete and networked sites of high value across manifestations of biodiversity

Abstract

Suites of criteria specifying ecological, biological, social, economic, and governance properties enable the systematic identification of sites and networks of high biodiversity value, and can support balancing ecological and socioeconomic objectives of biodiversity conservation in terrestrial and marine spatial planning. We describe designs of suites of ecological, governance and socioeconomic criteria to comprehensively cover manifestations of biodiversity, from genotypes to biomes; compensate for taxonomic and spatial gaps in available datasets; balance biases resulting from conventionally-employed narrow criteria suites focusing on rare, endemic and threatened species; plan for climate change effects on biodiversity; and optimize the ecological and administrative networking of sites. Representativeness, replication, ecological connectivity, size, and refugia are identified as minimum ecological properties of site networks. Through inclusion of a criterion for phylogenetic distinctiveness, criteria suites identify sites important for maintaining evolutionary processes. Criteria for focal species are needed to overcome data

Keywords

Designing, criteria, suites, identify, discrete, networked, sites, high, value, across, manifestations, biodiversity

Disciplines

Law

Publication Details

Gilman, E., Dunn, D., Read, A., Hyrenbach, K. & Warner, R. (2011). Designing criteria suites to identify discrete and networked sites of high value across manifestations of biodiversity. Biodiversity and Conservation, 20 (14), 3363-3363.

Designing Criteria Suites to Identify Sites and Networks of High Value across Manifestations of Biodiversity

Eric Gilman[a,*], Daniel Dunn[b], Andrew Read[c], Robin Warner[d], K. David Hyrenbach[e]

[a] Associate Faculty, Hawaii Pacific University, College of Natural and Computational Sciences, 3661 Loulu Street, Honolulu, Hawaii 96822 USA; EricLGilman@gmail.com
[b] Research Associate, Duke University, Marine Geospatial Ecology Lab, 135 Duke Marine Lab Rd., Beaufort, North Carolina 28516 USA; daniel.dunn@duke.edu
[c] Associate Professor, Duke University, Duke Center for Marine Conservation, 135 Duke Marine Lab Rd., Beaufort, North Carolina 28516 USA; aread@duke.edu
[d] Senior Research Fellow, University of Wollongong, Australian National Centre for Ocean Resources and Security, 23 Bannister Gardens, Griffith, ACT, Canberra 2603 AUSTRALIA; rwarner@uow.edu.au
[e] Assistant Professor, Hawaii Pacific University, Marine Science Programs at Oceanic Institute, 41-202 Kalaniana'ole Highway, Waimanalo, Hawaii 96795 USA; khyrenba@gmail.com
* Corresponding author: Tel.: +1 808 888 9440

Abstract: Criteria suites, used to identify sites and networks of high biodiversity value, are a fundamental tool for balancing ecological and socioeconomic objectives of biodiversity conservation in terrestrial and marine spatial planning. We describe designs of suites of ecological, governance and socioeconomic criteria to comprehensively cover manifestations of biodiversity, from genotypes to biomes; compensate for taxonomic and spatial gaps in available datasets; balance biases resulting from conventionally-employed narrow criteria suites focusing on rare, endemic and threatened species; plan for climate change effects on biodiversity; and optimize the ecological and administrative networking of sites. Representativeness, replication, ecological connectivity, size, and refugia are identified as minimum ecological properties of site networks. Through inclusion of a criterion for phylogenetic distinctiveness, criteria suites can identify sites important for maintaining evolutionary processes. Criteria for focal species are needed to overcome data gaps and address limitations in understanding factors responsible for ecosystem integrity.

Keywords: biodiversity; criteria; data quality; site network; spatial planning

1. Introduction

Biological diversity has intrinsic value, is required to maintain the biosphere's structure and processes that support life, including ecosystem services that underpin human survival and dignity. This is now widely acknowledged despite limited understanding of the degree of redundancy at different levels of biodiversity, and incomplete comprehension of the relative importance of different components in regulating ecosystem structure and functioning, and in avoiding tipping points where irreversible regime shifts occur (McGrady-Steed et al., 1997; Ghilarov, 2000; Loreau, 2000; Karieva and Marvier, 2003; Balmford et al., 2002, 2005; Diaz et al., 2006; Dobson et al., 2006; European Environment Agency, 2006; European Communities, 2008; Leadley et al., 2010; Pereira et al., 2010).

Combined, the exponential growth in human population and biomass, humanity's broad spatial distribution, and the spatial distribution of population density and poverty patterns in relation to areas of high biodiversity, underlie cumulative and synergistic drivers of change and loss in biodiversity (Gehrt, 1996; Groombridge and Jenkins, 2000; Hassan et al., 2005; Millennium Ecosystem Assessment, 2005; European Environment Agency, 2006; IUCN, 2009). Direct anthropogenic drivers of change and loss in biodiversity have been placed into five broad categories: (i) habitat modification or loss, (ii) overexploitation, (iii) invasive alien species, (iv) climate change, and (v) pollution (Pauly et al., 2005; CBD, 2010). Globally, habitat degradation is the central direct driver of change and loss of terrestrial biodiversity (IUCN, 2009; Leadley et al., 2010). Overexploitation of target and bycatch species in marine capture fisheries currently is the most widespread and direct driver of change and loss of global marine biodiversity, and is predicted to become increasingly problematic over coming decades, while in coastal areas, eutrophication from nitrogen pollution and habitat degradation are also significant factors (Pauly et al., 2005; Leadley et al., 2010; Gilman, In Press). Climate change is predicted to become an increasingly significant factor for global terrestrial and marine biodiversity (CBD, 2010; Leadley et al., 2010).

Resulting changes and loss in biodiversity are occurring across all levels of manifestations of biodiversity, from genotypes to broad biogeographical regions, and range from reduced genetic diversity and altered evolutionary characteristics of populations, to an increased rate of species extinctions and concomitant reduced species diversity, to altered community to biome functioning, structure, resistance and resilience, distribution and extent (Smith et al., 1991; Chapin et al., 1998; Pauly *et al*., 1998; Stevens et al., 2000; Mills, 2001; Balmford et al., 2003; Hassan et al., 2005; Millennium Ecosystem Assessment, 2005; Gilman et al., 2008; Jackson, 2008; IUCN, 2009; CBD, 2010; Leadley et al., 2010; Pereira et al., 2010). Recognition, starting in the late 1980s, of a growing biodiversity crisis has generated support to augment our understanding of global biodiversity and mitigation of anthropogenic drivers of biodiversity change and loss (Ghilarov, 2000; Millennium Ecosystem Assessment, 2005; Pereira et al., 2010).

Biodiversity conservation typically requires making compromises in focus between geographical areas, components of biodiversity and threats (Crowder and Norse, 2008; Gilman et al., 2008; Lenton et al., 2008; Leadley et al., 2010). Suites of criteria specifying place-based ecological, biological, social, economic, and governance properties have been used to identify areas of relatively high biodiversity value, including identifying sites that possess characteristics needed for effective site networks (Table 1). Applications of these criteria suites entail place-based spatial planning and ecosystem-based management, including providing a basis for directing limited resources for conservation activities to prioritized areas. Table 1 presents examples of initiatives and programs employing criteria suites to identify sites of global- to local-scale biodiversity importance. Goals of employing suites of criteria have ranged from identifying areas of local importance to selected taxonomic groups to identifying networks of sites important for the maintenance of entire ecosystems at a global scale.

Here we present a comprehensive suite of ecological, governance and socioeconomic criteria to identify sites and networks of interconnected sites of relatively high biodiversity value, and provide examples of their application. This is the first compilation of a full suite of biodiversity criteria. This fundamental information enables conservation practitioners to refer to the complete set of criteria as a starting point to then select a subset to meet objectives of individual terrestrial and marine spatial planning initiatives, a precursor to implementing ecosystem-based management (Crowder and Norse, 2008). We identify considerations in applying each criterion and describe alternative designs for criteria suites, including assigning relative weights to criteria, to meet the objectives of individual initiatives. Objectives may be defined by the geospatial and temporal scales of interest; prioritized components of biodiversity, conservation targets, and threats; socioeconomic priorities, including maintaining or enhancing selected ecosystem services; and available resources for governance. We define an overarching goal for collective efforts to identify areas of global biodiversity value. We identify ecological criteria that are minimum, required components of suites for designing effective site networks. We propose a design for global-level criteria suites to comprehensively cover all facets of biodiversity, compensate for taxonomic and spatial gaps in available datasets, balance biases resulting from conventionally-employed criteria suites, and optimize the ecological and governance networking of sites. We critique the state of development of the integration of open-access datasets of primary, species-level, point occurrence biodiversity data and highlight next steps to augment applications in identifying areas of relative biodiversity importance. While criteria employed to identify areas of high global biodiversity value have generally focused on the species-level of biodiversity, focusing on rare, endemic and threatened species, we present arguments for expanding this scope to also include criteria for phylogenetically distinctive species and focal species, including common and widespread generalists, as a means to fill existing gaps to provide for comprehensive protection across manifestations of biodiversity, and to account for spatial, temporal and taxonomic gaps in coverage of available biodiversity data.

2. Comprehensive suite of ecological, governance and socioeconomic criteria

Tables 2 and 3 present a comprehensive suite of ecological criteria, and governance and socioeconomic criteria, respectively, to identify sites of high biodiversity value. Ecological criteria for phylogenetically distinctive species and focal species are identified as critical for comprehensive biodiversity conservation. A subset of the ecological criteria in Table 2 is identified as minimum, required properties for the long-term effectiveness of networks of sites of global biodiversity importance. Some of these network-relevant criteria are not attributes of an isolated site (e.g., ecological connectivity relates to multiple sites within a network, and not to a single site in isolation). Other criteria are potentially relevant to both isolated and networked sites. For example, sustainable financing and refugia are important characteristic to ensure the effectiveness of both isolated and networked sites.

Biodiversity conservation objectives are more likely to be achieved when ecological criteria are first assessed to identify sites before applying socio-economic and governance criteria. However, in practice, site-specific socioeconomic and political priorities often trump longer-term and global-scale ecological priorities (Gilman, 2002; Kareiva and Marvier, 2003; Roberts et al., 2003).

3. Primary data limitations to employing place-based biodiversity criteria

The existence of large taxonomic, spatial and temporal gaps in available information is a general limitation in applying place-based biodiversity criteria (Roberge and Angelstam, 2004; Balmford et al., 2005; Yesson et al., 2007; Collen and Rist, 2008; GBIF, 2009; Edwards et al., 2010; Gilman and Chaloupka, 2010). To begin with, only about 17% of the total possibly existing species have been discovered and described by systematists (Chapman, 2009). Working with such an incomplete understanding at just the species-level of biodiversity means our knowledge of the status and trends in biodiversity losses and changes are inherently limited. The Global Biodiversity Information Facility (GBIF), since its formation in 2001, has effectively developed the informatics infrastructure to enable open-access publication of datasets of primary, species-level, point occurrence data in standardized formats, and now hosts the world's largest portal to open source biodiversity data. For the known species, results from a first-order inventory of the GBIF data portal revealed substantial data quantity and quality issues:

- **Taxonomic gaps**: There were substantial data gaps for large numbers of higher level taxonomic groups (e.g., no records for any Virus species; records for only 10% of species in the kingdom Fungi, with a mean of 51 records per species; records for only 6% of species in the class Insecta, with a mean of 156 records per species) (Fig. 1), and no records for 83% of described species (GBIF, 2009). Data volume was biased towards well-studied groups, including birds, mammals and fish (e.g., $\geq$ 1 GBIF record with coordinates for 81% of species in the class Aves, with a mean of 7,118 GBIF records per species; 65% of species in the class Elasmobranchii [sharks and their relatives], with a mean of 277 records per species). Insufficient sample size can prevent robust species' distribution modelling (Stockwell and Peterson, 2002; Hernandez et al., 2006; Wisz et al., 2008; Gilman and Chaloupka, 2010);
- **Spatial gaps**: Most records are of observations made in the U.S. and Europe, with 59% of records located in the USA, UK and Sweden (as of 13 December 2010). Because, within most higher taxa, over large areas, the number of species in total and per unit of area increases from higher to lower latitudes (Rex et al., 1993; Gaston, 2000; Groombridge and Jenkins, 2000), the finding that the majority of GBIF records are from mostly temperate areas is consistent with and helps explain the observed lack of records for a large majority of described species. There was also uneven spatial distribution of

records. For example, 87%, 72% and 69% of marine Plantae, Animalia and Protozoa records, respectively, fall in the Atlantic Ocean; 60% of terrestrial Animalia records fall in North America; and 77% and 76% of terrestrial Plantae and Fungi records, respectively, fall in Europe. There is a need for a sufficient sample size in each area of an individual species' known native and introduced range to enable robust distribution modelling (Gilman and Chaloupka, 2010);

- **Time series length**: Despite a large proportion of GBIF data coming from natural history collections, known to contain long time series (Suarez, 2004), only 4% of records published to the GBIF portal were from observations made before 1950 (GBIF, 2009). Long time series enable the construction of baselines from times when ecosystems were relatively pristine in order to measure anthropogenic-caused change and loss in biodiversity (Jackson et al., 2001; Suarez, 2004; Gilman et al., 2008). Time series lengths need to span cyclical, short-term, serially correlated patterns in order to observe long-term temporal as well as spatial patterns, for example, to support robust modelling of temporal patterns in species' distributions, population trends of long-lived and low productive species, ecosystem landscape position, and to separate natural and anthropogenic signals (Kendall et al., 1998; Crouse, 1999; Musick, 1999; Gilman et al., 2008; Edwards et al., 2010; Gilman and Chaloupka, 2010). For example, long data series are needed to effectively differentiate between coastal ecosystem migration in response to long-term trends in relative sea-level from shorter-term and cyclical influences on coastal ecosystem position (Gilman et al., 2008). Because, at a given point in time, a portion of suitable habitat is predicted to be unoccupied by a population, short dataset time series of observational records have a higher potential to portray an incorrectly smaller distribution than if observed over longer periods. Furthermore, for populations of long-lived, low-productive species, there can be a lag of decades or longer for responses to drivers to become evident (e.g., Crouse, 1999); and
- **Seasonal gaps**: For some taxonomic groups, there was uneven distribution of records by season (e.g., 40% of bird observations were made in the first quarter of the year)

(GBIF, 2009). For some species, a lack of presence observations during a season might miss seasonal migrants and prevent robust species' distribution modelling (Roberge and Angelstam, 2004; Gilman and Chaloupka, 2010).

There are also basic data quality issues, where, for example, 33.7 M (19%) of GBIF records lack coordinates (GBIF, 2009), precluding their use for most research applications. More narrowly focused studies have identified gaps in open access primary biodiversity data for specific taxonomic groups, such as certain plant taxa (e.g., legumes, Yesson et al., 2007), bats (Collen and Rist, 2008), and marine invasive alien species (Gilman and Chaloupka, 2010).

Disincentives for dataset publication, and thus to filling these identified gaps, are numerous. For example, data with potential market value, including information on medicinal plants, datasets collected from fishery observer programs, or genetic resources, are held as confidential under some domestic and international laws (e.g., Arico and Salpin, 2005; Gilman, In Press). Some governments have expressed concern over the risk of 'biopiracy', the monopolization of genetic resources and indigenous, traditional knowledge (Greene, 2004), as a reason for refraining from publishing their biodiversity datasets. Technical and financial resources needed to digitize natural history collections is another barrier. Other obstacles include concerns that other researchers will 'scoop' planned research; ownership and control of the data will be lost; locations of sensitive species would be revealed; and that dataset publication is overly arduous (Roberts and Chavan, 2008; Costello, 2009).

There is a need for policies by relevant bodies, including national and regional governments and private funding agencies, to require publication of biodiversity datasets and provide resources for effective enforcement (Andelman et al., 2004; Costello, 2009). The development of online data publication systems with metrics for data citation and impact factors based on data use may provide an incentive for voluntary publication of datasets by individual researchers (Andelman et al., 2004; Roberts and Chavan, 2008), but is unlikely to incentivize publication of large institution-owned datasets, or overcome legal confidentiality measures of some datasets.

Dataset-level metadata developed to enable users to discover its existence typically include information on the dataset's basic characteristics, ownership, and how to obtain further information. Metadata can be critical to: (i) enable data discovery, (ii) determine whether pooling individual datasets is appropriate, (iii) identify what information exists in the full, original dataset that might not be captured in standard, minimum fields of open-source data portals; and (iv) allow researchers to contact owners/custodians to request access and permission to the original dataset. More important than the publication of datasets in standardized formats with minimal information, there is a critical need for improved standards for the publication of rich metadata (e.g., sampling effort, data collection methods, spatial resolution) and development of metadata catalogues. For example, an estimate of error in positional accuracy is needed for research employing fine spatial scales, such as species distribution modelling (e.g., Guisan et al., 2007), but has not been routinely captured in metadata of almost a fifth of datasets published via GBIF, information critical for rigorous species distribution modelling and other applications that employ primary biodiversity data.

4. Optimal Designs for Criteria Suites

4.1. Collective overarching goal

The combined goal of initiatives to identify sites and protected area networks of global biodiversity importance could be to maintain the biosphere. To achieve this, criteria suites require designs that enable identifying areas of relative biodiversity importance to encompass the variability among living organisms, including the abundance and distributions of, and interactions within and between genotypes, species, communities, ecosystems, and biomes (Groombridge and Jenkins, 2000; Leadley et al., 2010). While the species level of diversity is the most common measure of biodiversity employed for research and management, it is critical to consider all components to the variability of life to maintain ecosystem functioning, structure, and services across Earth's biogeographical regions.

Long-term human wellbeing and dignity requires sustaining ecosystem services, which is contingent upon effective biodiversity conservation, including preventing ecosystems from reaching tipping points where irreversible regime shifts occur (Lenton et al., 2008; Leadley et al., 2010; Pereira et al., 2010). Sacrifices are required to reduce anthropogenic stressors to ecologically sustainable levels, and reduce the degradation of other ecosystem services, including regulating and supporting services. It will be necessary to reduce or reverse current rates of increase in ecosystem services that are incompatible with conservation objectives, especially provisioning services, including food, fiber and energy production, and incompatible cultural services, such as human access to sensitive areas (Nelson et al., 2009; Leadley et al., 2010). To effectively mitigate the fundamental drivers of multi-scale change and loss in biodiversity, humanity needs to mitigate underlying causes, including unsustainable lifestyles, human population and spatial distribution, and poverty levels and spatial distribution. Spatial planning, through the application of criteria suites to identify areas critical for biodiversity conservation, is a precursor to identifying requisite restrictions on incompatible human activities in these areas, where forfeiting certain activities and behaviours that contribute to our current quality of life will be necessary for the long-term maintenance of the biosphere's integrity and ecosystem services.

4.2. Selecting criteria and assigning weights for individual initiatives

Considerations in designing suites of criteria for individual initiatives include: the geospatial and temporal scales of interest, prioritized components of biodiversity and conservation targets, and available resources for governance, including threat abatement. For example, a criteria suite can be designed to prioritize areas that are relatively pristine, or degraded areas possessing high capacity for rehabilitation, or both (Ramsar Secretariat, 2008; IOSEA, 2010). Prioritizing ecosystem provisioning services will likely identify different areas than prioritizing ecological criteria or regulating and supporting services (Leadley et al., 2010).

The spatial scale identified for application of criteria is imperative, for example, as rare and unique features at a local scale may be typical at larger scales. Criteria weighting for a site network could be designed to aid in identifying the minimum network of sites for representation of all species in an area of focus by weighting sites that have high species richness for species not present in sites already in the network (Cabeza and Moilanen 2001; Roberts et al., 2003).

Weighting designs for criteria suites range from the least complex, where each criterion in a suite has a de facto equal weight, a site either meets or does not meet individual criteria, and a site achieves the designation via passing assessment against any one of the criterion in the suite (e.g., Darwall and Vie, 2005; IMO, 2006; Convention on Migratory Species, 2007; Ramsar Secretariat, 2008; Plantlife International, 2004, 2010). Other initiatives employ a design where sites need to meet one of a suite of criteria, again where each criterion has a de facto equal weight (e.g., IMO, 2006; UNESCO, 2008). Criteria suites have also been designed so that sites qualify for designation if they meet all criteria, each of de facto equal weight (e.g., UNESCO, 1995; UNESCO MAB Programme, 2004; Alliance for Zero Extinction, 2005; Rickets et al., 2005; ASEAN Centre for Biodiversity, 2010). A more complex design assigns scaled weighting to each criterion, where a site can meet a portion of the maximum possible criterion weight, minimum threshold weights are assigned to categorized subsets of criteria in the suite, where a site must meet a minimum threshold weight for each category, and a site must meet a minimum threshold weight for the entire criteria suite (IOSEA, 2010).

4.3. Criteria for phylogenetically distinctive species and focal species

Initiatives to identify areas of high biodiversity value have generally focused on the species-level of biodiversity, for rare, endemic and threatened species, employing small suites of criteria, with an overarching aim of mitigating species-level extinction rates (Table 1) (Myers 1988, 1990; Stattersfield et al., 1998; Myers et al., 2000; Mittermeier et al., 1999, 2004; Alliance for Zero Extinction, 2005; Darwall and Vie, 2005; Ricketts et al., 2005; Gaston and

Fuller, 2007; BirdLife International, 2010; Plantlife International, 2004, 2010). Application of these collective initiatives results in regional and taxonomic gaps, and inadequate protection of species with relatively unique genetic information.

There is no unequivocal way to compare biodiversity value resulting from the application of individual criterion. For instance, there may be little overlap of areas with high endemism, species richness and threatened species richness between and within taxa, even within a single taxonomic class (Groombridge and Jenkins, 2000; Orme et al., 2005; Kier et al., 2009). Each criterion addresses a different aspect or component of biodiversity; initiatives employing small number of criteria typically result in spatial and taxonomic biases. For example, the employment of a pair of criteria (high vascular plant endemic species richness, high habitat loss) to identify 'Biodiversity Hotspots' (Table 1) identified regions primarily occurring in tropical forests (Mittermeier et al., 2004). Over three quarters of areas identified based on the overlap of distributions of two or more restricted-range endemic bird species (Endemic Bird Areas, Table 1) are located in tropical and subtropical lowland forest and moist montane forest, on islands or in mountain ranges (Stattersfield et al., 1998). Locations where highly threatened species of selected taxa (mammals, birds, reptiles, amphibians and conifers) are confined to single sites also occur primarily in tropical forests and on islands (Ricketts et al., 2005). A focus on threatened species identifies sites of importance primarily to ecological specialist species with small population sizes and/or with restricted ranges, predominant characteristics of species with the greatest risk of regional extirpation or global extinction (Gaston and Fuller, 2007). Designing criteria suites to conserve the most species in the smallest possible areas, while cost-effective, as a stand-alone criterion, does not result in comprehensive biodiversity protection (Kareiva and Marvier, 2003). To cover all facets of biodiversity, initiatives require broad suites of ecological criteria, and require the inclusion of criteria to ensure the maintenance of evolutionary processes and to provide a surrogate for all coexisting species assemblages across taxa and ecological requirements, as well as an indication of changes in ecosystem functioning and structure.

To contribute to the maintenance of evolutionary processes, collective criteria suites require a criterion to identify areas of importance to phylogenetically distinct species. The loss of entire higher taxonomic groups and evolutionary lineages due to anthropogenic stressors threatens to alter the natural progression of evolution (McKinney, 1998; Kareiva and Marvier, 2003; Redding and Moores, 2006; Isaac et al., 2007). Prioritization of species based on phylogenetic uniqueness enables reducing the risk of losing species lacking or with few close taxonomic relatives with relatively distinct genetic diversity that are of relative importance for the potential continuation of evolutionary processes (Faith, 1992; Kareiva and Marvier, 2003; Diniz, 2004; Redding and Moores, 2006; Isaac et al., 2007).

There is evidence that clusters of taxonomically related species of well-studied groups (birds, mammals, plants) are at a higher threat of extinction than if extinction risk were phylogenetically random, creating the risk of loss of their evolutionary history (Purvis et al. 2000, Vamosi and Wilson 2008). This may be because the similar distributions, life history characteristics and behaviour of some groups of phylogenetically related species are affected by the same anthropogenic mortality sources (e.g., albatrosses and large petrels and bycatch in longline fisheries, Gilman et al. 2005). For these clusters of related species, defining priorities based on threatened status could provide for adequate protection and avoid the loss of their genetic diversity. However, threatened status would not afford protection to phylogenetically unique species that are not currently threatened.

Suites also require criteria to identify sites important to focal species. This addresses biases resulting from the traditional narrow focus on threatened, rare and endemic species, addresses gaps in biodiversity datasets, and provides a shortcut to often lacking ecosystem-level, physical and biotic data. Here we use the concept ‘focal’ species to encompass three somewhat distinct surrogate concepts of umbrella, indicator and keystone species. Umbrella species have the most demanding area and habitat requirements for their survival, encapsulating those of an array of sympatric, coexisting species, whereby protecting a sufficiently large area and critical habitat needed by the umbrella species, the requirements for survival of the coexisting species will also be captured (Lambeck, 1997; Caro and

O'Doherty, 1999; Snaith and Beazley, 2002; Bani et al., 2006). The concept has been applied using suites of umbrella species to identify minimum area and habitat requirements for all species in an area (Lambeck, 1997; Roberge and Angelstam, 2004). Indicator species have been used as a proxy to monitor changes in environmental conditions, to monitor changes in abundance and distributions of other species, for species richness and endemic species richness, and for ecosystem integrity (Stattersfield et al., 1998; Caro and O'Doherty, 1999; Myers et al., 2000; Snaith and Beazley, 2002; Gregory et al., 2003; Pauly and Watson, 2005; Bani et al., 2006). Species selected for use as indicators of environmental health have relatively high sensitivity to the full suite of stressors, which encompass the sensitivities to threats of coexisting species. Species selected for use as indicators of the presence and population trends of coexisting species will undergo changes in population sizes and distributions as a result of ecological factors that also control abundance and distributions of less-demanding species for which they are intended to serve as a surrogate (Lambeck, 1997; Roberge and Angelstam, 2004). Keystone species have relatively large roles in regulating an ecosystem's functioning and structure that is disproportionate to their abundance and/or biomass (i.e., they tend not to be the dominant components of a community or ecosystem), and tend to be of higher trophic levels (Caro and O'Doherty 1999; Kotliar, 2000; Snaith and Beazley, 2002; Estrada, 2007; Jordan, 2009). Unlike umbrella and indicator species, changes in the abundance of keystone species do not necessarily reflect that of sympatric species, as keystone species do not necessarily have survival requirements that encompass that of coexisting species.

Implementing the focal species concept entails identifying a suite of indicator, umbrella and keystone species that can be feasibly monitored to identify any trends in routinely observed parameters (e.g., abundance, spatial distribution, and various life history characteristics), that, when taken together, provide an accurate surrogate for all coexisting species assemblages across taxa and ecological requirements, as well as an indication of changes in ecosystem functioning and structure (Caro and O'Doherty 1999; Snaith and Beazley, 2002; Gregory et al., 2005; Collens and Rist, 2008; Jordan, 2009). Application of this broad concept involves monitoring a group of species as a cost-effective shortcut to monitoring all constituent species, and a more realistic method for obtaining a surrogate of ecosystem- and landscape-level integrity than conducting more complex, inconvenient, expensive, time consuming, and potentially infeasible monitoring of entire biotic and abiotic components of the ecosystem or landscape. Thus, in concept, identification of a suite of focal species, and identification of sites critical to their maintenance, will be the areas needed for ecosystem maintenance, this despite gaps in primary biodiversity data for other species, and gaps in information on the structure and functioning of the entire system. By mitigating threats to ensure the survival of focal species, in concept, this effectively protects sympatric species and maintains ecosystem functions, structure and services.

There can be high uncertainty in identifying a suite of species to serve as surrogates and validating effectiveness. For some ecosystems, there is insufficient understanding of interspecific interactions, the roles of constituent species of each community, links between trophic levels, and predominant regulating factors, including feedback mechanisms, as well as functional links between ecosystems to enable robust quantitative ranking of individual species based on their importance to sympatric species and in regulating and maintaining ecosystems (Snaith and Beazley, 2002; Mumby et al., 2004; Gilman et al., 2008; Jordan, 2009). As a result, species selected to serve as surrogates may not suitably characterize all co-occurring species and ecosystem integrity (Roberge and Angelstam, 2004). This is because co-occurring species have different controlling ecological factors, and respond differently to natural and anthropogenic stressors. A solution is to systematically select a suite of focal species with well understood responses to anthropogenic and natural changes, in order to provide effective characterization of all coexisting species across regions, higher taxon, and trophic levels, and surrogate for ecosystem structure and functioning (Roberge and Angelstam, 2004; Piatt et al., 2007). However, in complex ecosystems, the number of species that would need to be included in a suite of focal species might make its application infeasible (Lindenmayer et al., 2002).

In some cases, employing focal species criteria will prioritize sites of importance to common and/or widespread generalist species, which have tended to be overlooked through the traditional focus on rare/endangered/endemics. Taken collectively, abundant and widely distributed species are critical for the maintenance of ecosystem structure and functioning. Because a small number of species that are common and with broad distributions account for the majority of individuals and biomass, the value of these species in terms of maintaining abundance and regulating ecosystem dynamics is relatively high (Rice, 1995; Gaston and Fuller, 2007). Abundant and broadly distributed species, represented across trophic levels of terrestrial and marine ecosystems, have central roles in ecosystem regulation (Allen et al., 1997; Estes et al., 1998; Jackson et al., 2001; Leon and Bjorndal, 2001; Terborgh et al., 2001; Bjorndal and Jackson, 2003; Springer et al., 2003; FAO., 2008). In identifying sites important to common and/or widespread species, there is a need to separate the identification of areas of importance to generalist species that have increased in abundance and expanded distributions because they can thrive in altered habitats, contributing to biotic homogenization as generalists come to predominate in place of specialist niche species (Brown, 1984; McKinney and Lockwood, 1999; Olden and Rooney, 2006), vs. areas critical for common/widespread species with low resistance and resilience to human stressors. Although some abundant and/or broad ranging species fill multiple niches and are therefore relatively resistant and resilient to stressors (e.g., Brown, 1984), there are numerous examples of abundant and widely distributed species that are not relatively better suited to stressors.

As evidence, several species that have recently experienced dramatic declines were previously abundant species and/or had broad distributions, with strong evidence for anthropogenic causes of their declines. Pollinator populations have been declining due to multiple anthropogenic stressors, including habitat loss and fragmentation, land use changes, pollution, parasites, disease, alien species, and climate change (desynchronization of flowering plants and their pollinators, through changes in phenology and ranges) (Allen et al., 1997; Klein et al., 2007; FAO, 2008; Gallai et al., 2009). The demise of the American chestnut *Castanea dentata* due to human introductions of invasive alien species (Anagnostakis, 1987, 2001; Gaston and Fuller, 2007) and resulting extinction cascade (extinction of seven moth species that fed only on the chestnut) (Anagnostakis, 1987, 2001; Koh et al., 2004) is another example. Overexploitation in marine capture fisheries has caused declines of formerly abundant and broadly distributed species of sea turtles, seabirds and marine mammals, which have K-selected life-history strategies, as well as highly fecund species and/or with broad distributions (Stevens et al., 2000; Gilman et al., 2007; Leadley et al., 2010; Gilman, In Press). Climate change effects on common/widespread species range from changes in plant and animal phenology, altering species' distributions, converting habitat types, to possible loss of an entire ecosystem (Fynbos floral kingdom in South Africa) (Chapin et al., 1998; Midgley et al., 2002; Thomas et al., 2004; Gilman et al., 2008). As expected, as anthropogenic stressors are intensifying, as the human population approaches a peak and continues to broaden in spatial distribution (Millennium Ecosystem Assessment, 2005; European Environment Agency, 2006), a large and growing number of species, which are still abundant and have broad distributions, have been observed to be experiencing acute declines (Gaston and Fuller, 2007; PECBMS, 2007). Including criteria for focal species can ensure spatial planning considers conservation needs of these generalist common and widespread species.

4.4. Criteria for effective site networks

Site networks, in concept, are collections of individual protected sites operating cooperatively and synergistically, both ecologically and administratively, at various spatial scales, and with a range of protection levels, that are designed to meet objectives that a single protected site cannot achieve in isolation (Laffoley et al., 2008). Properly designed and governed protected area networks can optimize resistance, resilience, and reduced risk of the loss of biodiversity through representativeness and replication (NRC, 2000; Roberts et al., 2003; Wells, 2006; CBD, 2008), and ecological connectivity through strategic spacing and shape of sites within the network (Crowder et al., 2000; Stewart et al., 2003; Roberts et al., 2003;

Laffoley et al., 2008). Five ecological criteria described in Table 2 are identified as being minimum, required components of suites used to identify sites for inclusion in networks.

Representativeness is captured in a network of protected sites when a series of sites are included in the network and adequately represent the full range of ecosystems, community types, and geomorphic classes, including the biotic and habitat diversity of those landforms in the area of focus (Roberts et al., 2003; CBD, 2008). Ensuring that all components of an ecosystem are protected in the site network is a strategy for optimizing resistance and resilience, as the representation increases the chance that at least one community type, possessing disparate physical and biological features, will survive stressors and possibly provide a source for re-colonizing degraded sites (Gilman et al., 2008).

Replication within a network, where multiple examples of each ecosystem, community type, and geomorphic class are included, reduces the risk of losing individual components of biological diversity (Roberts et al., 2003; Salm et al., 2006; Wells, 2006; CBD, 2008).

Providing for ecological connectivity, where sites in the network are functionally linked, protects connectivity between ecosystems (Crowder et al., 2000; Stewart et al., 2003; Roberts et al., 2003). The systematic selection of individual sites to include in the network to address edge effects and spacing between sites is critical (Laffoley et al., 2008). The exchange of larvae and species between sites is an example of a functional link between sites of the same ecosystem type. Or, for example, the existence and health of coral reefs are dependent on the buffering capacity of these shoreward ecosystems, which support the oligotrophic conditions needed by coral reefs to limit overgrowth by algae. Coral reefs, in turn, buffer the soft sediment landward ecosystems from wave energy (Mumby et al., 2004; Victor et al., 2004).

The area of individual sites and combined area of sites within the network is of importance to ensure minimum territory requirements of certain species are protected Kareiva and Marvier, 2003), and to meet targeted species richness (Groombridge and Jenkins, 2000).

Including sites in a network that are relatively resistance and resilient to stressors, acting as refugia to current and predicted stresses, is critical to ensure the effectiveness of the network in achieving biodiversity conservation goals (Salm et al., 2006). The evaluation of sites nominated for inclusion in a network should specifically account for predicted effects on biodiversity value from climate change scenarios (Barber et al., 2004; Gilman et al., 2008). For instance, planners need to account for the likely movements of species distributions, and community, ecosystem and biome boundaries over time under different climate change scenarios, as well as consider an areas' resistance and resilience to projected climate change and contributions to adaptation strategies. Site-specific analysis of resistance and resilience to climate change when selecting areas to include in new protected area networks should include, for example, how discrete coastal habitats might be blocked from natural landward migration, and how severe are threats not related to climate change in affecting the site's health. Resistance refers to the amount of disturbance an ecosystem can absorb and remain within the same state without alteration to its functions and structure (Holling, 1973). Resilience refers to the capacity of an ecosystem to absorb and reorganize following the effects of a stress in order to revert to its previous state of functioning and structure (Carpenter et al., 2001).

To achieve an ecologically successful site network, first, identifying alternative network designs that enable meeting ecological objectives and then considering non-ecological criteria to select a realistic, manageable option, will optimize the likelihood of achieving ecological goals and objectives (Roberts et al., 2003). For example, the process to identify candidate sites for possible inclusion in the OSPAR Network of MPAs includes first applying the OSPAR Network ecological criteria to identify sites, and then referring to both the ecological and 'practical' criteria to prioritize identified sites (OSPAR Commission, 2007). However, as with the application of criteria suites to identify isolated sites, in practice, local socioeconomic and political considerations may drive processes for identifying sites for inclusion in protected area networks, and be the final arbiter in selecting criteria to identify biodiversity-important areas, with science on meeting ecological objectives informing the process (Gilman, 2002; Kareiva and Marvier, 2003; Roberts et al., 2003).

There are also socioeconomic and governance benefits of effective site networks. Site networks can reduce adverse socioeconomic impacts from restricting incompatible activities at individual sites, as restrictions needed to achieve conservation objectives can be spread out across the sites included in the network without compromising conservation and commercial benefits that result from protected areas (Laffoley et al., 2008; IOSEA, 2010). Additionally, site networks can augment local to international recognition of the importance of a site and of conservation efforts. Also, through economies of scale from coordinated governance activities, networking protected sites can optimize the use of limited resources for governance, including outreach, monitoring, establishing secure funding mechanisms, staff training, conservation interventions, enforcement, performance evaluation, and adaptive management (Sandwith et al., 2001). For instance, given uncertainties about future climate change and responses of coastal and marine ecosystems, there is a need to monitor and study changes systematically. Establishing ecosystem baselines and monitoring gradual changes through site networks, using standardized techniques, can enable the separation of site-based influences from global changes to provide a better understanding of ecosystem responses to global change, and alternatives adaptation options (Gilman et al., 2008).

5. Conclusions

Applying suites of criteria to identify areas of relative biodiversity importance enables optimizing limited resources to direct conservation interventions according to the objectives and context of individual efforts, and to balance ecological and socioeconomic objectives. To effectively achieve the maintenance of the biosphere, and concomitant human wellbeing and dignity, consideration across the hierarchical manifestations of biodiversity is required. However, efforts to identify areas of high global biodiversity value have generally focused on criteria for rare, endemic and threatened species (Table 1). This has resulted in a focus on tropical and island ecosystems of importance to ecological specialists with small population sizes and/or restricted ranges. Furthermore, spatial, temporal and taxonomic gaps in available, integrated, species-level, primary datasets (Fig. 1) have limited the application of place-based biodiversity ecological criteria; augmenting dataset publication is a priority, as is improved standards for the publication of rich metadata and the development of metadata catalogues. Designing broader, more comprehensive suites of criteria can address these limitations.

Criteria suites require designs that: (i) comprehensively identify sites required for biodiversity maintenance, from evolutionary processes to ecosystem structure and functioning across biogeographic regions; (ii) compensate for taxonomic and spatial gaps in available datasets; (iii) balance biases resulting from conventionally-employed, narrow criteria suites; (iv) plan for predicted effects on biodiversity from climate change projections; and (v) optimize the ecological and governance networking of sites. Representativeness, replication, ecological connectivity, size, and refugia are identified as minimum, required ecological properties for designing effective site networks. To enable the identification of sites needed for the maintenance of evolutionary processes, a criterion for phylogenetic distinctiveness is identified as a needed component of criteria suites. Criteria for focal species are also flagged as a needed component of criteria suites.

Acknowledgments

Preparation of a working paper, *Towards a System of Networked Protected Marine Turtle Habitat Sites in the Indian Ocean – South-East Asian Region* (IOSEA, 2010), co-authored by E. Gilman and Douglas Hykle of the IOSEA Marine Turtle MoU Secretariat, provided the initial impetus for this research. We are grateful for assistance in inventorying the GBIF data portal provided by Tim Robertson and Andrea Hahn of the Global Biodiversity Information Facility Secretariat, and Jörg Holetschek of the Botanic Garden and Botanical Museum Berlin-Dahlem.

REFERENCES

Allen, W., Peter, B., Bitner, R., Burquezs, A., Buchmann, S., Cane, J., Cox, P., Dalton, V., Feinsinger, P., Ingram, M., Inouye, D., Jones, E., Kennedy, K., Kevan, P., Koopowitz, H., Medellin, R., Medellin, M., Nabhan, G., 1997. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. Conservation Biology 12, 8-17.

Alliance for Zero Extinction. 2005. Pinpointing and Preventing Imminent Extinctions. American Bird Conservancy, Washington, D.C.

Anagnostakis, S., 1987. Chestnut blight: The classical problem of an introduced pathogen. Mycologia 79(1), 23-37.

Anagnostakis, S., 2001: The effect of multiple importations of pests and pathogens on a native tree. Biological Invasions 3, 245–54.

Andelman, S.J., Bowles, C., Willig, M., Waide, R., 2004. Understanding environmental complexity through a distributed knowledge network. BioScience 54(3), 240-246.

Andelman, S.J., Fagan, W.F., 2000. Umbrellas and flagships: efficient conservation surrogates or expensive mistakes? Proceedings of the National Academy of Sciences of the United States of America 97, 5954–5959.

Arico, S. Salpin, C., 2005. Bioprospecting of Genetic Resources in the Deep Seabed: Scientific Legal and Policy Aspects. United Nations University, Institute of Advanced Studies, Yokohama, Japan.

ASEAN Center for Biodiversity. 2010. 3rd ASEAN Heritage Parks Conference. ASEAN Heritage Parks. Moving Forward Towards Effectively Managed AHPs. ACB, Laguna, Philippines.

ASEAN Secretariat. 2003. ASEAN Declaration on Heritage Parks. Association of Southeast Asian Nations Secretariat, Jakarta, Indonesia.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., Turner, K.T., 2002. Economic reasons for conserving wild nature. Science 297, 950–953.

Balmford, A., Crane, P., Dobson, A., Green, R., Mace, G., 2005. The 2010 challenge: data availability, information needs and extraterrestrial insights. Philos. Trans. R. Soc. Lond. B Biol. Sci. 360, 221–228.

Balmford, A., Green, R., Jenkins, M., 2003. Measuring the changing state of nature. Trends in Ecology and Evolution 18, 326–330.

Bani, L., Massimino, D., Bottoni, L., Massa, R., 2006. A multiscale method for selecting indicator species and priority conservation areas: a case study for broadleaved forests in Lombardy, Italy. Conservation Biology 20(2), 512-526.

Barber, C.V., Miller, K., Boness, M. (Eds.), 2004. Securing Protected Areas in the Face of Global Change: Issues and Strategies. IUCN, Gland, Switzerland.

Bininda-Emonds, O., 2004. The evolution of supertrees. Trends in Ecology and Evolution 19, 315–322.

BirdLife International. 2010. Sites – Important Bird Areas (IBAs). Available online at http://www.birdlife.org/datazone/info/ibacriteria. BirdLife International, Cambridge, UK.

Bisby, F., Roskov, Y., Orrell, T., Nicolson, D., Paglinawan, L., Bailly, N., Kirk, P., Bourgoin, T., Baillargeon, G. (Eds.), 2009. Species 2000 & ITIS Catalogue of Life: 2009 Annual Checklist. Digital resource at www.catalogueoflife.org/annual-checklist/2009/. Species 2000: Reading, UK.

Boo, E., 1990. Ecotourism: The Potentials and Pitfalls. Washington, D.C.: World Wildlife Fund. 72 pp.

Bjorndal, K., Jackson, J., 2003. Roles of sea turtles in marine ecosystems: Reconstructing the past. Pp. 259-273 IN: Lutz, P.L., Musick, J.A. Wyneken, J. (Eds.). The Biology of Sea Turtles Volume II. CRC Press, Boca Raton, Florida (USA).

Brown, J., 1984. On the relationship between abundance and distribution of species. American Naturalist 124, 255–79.

Bruner, A., Gullison, R., Rice, R., Fonseca, G., 2001. Effectiveness of parks in protecting tropical biodiversity. *Science* 5(291), 125-128.

Cabeza, M., Moilanen, A., 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology and Evolution 16, 242–248.

CABI Biosciences. 2009. Index Fungorum. Available online http://www.indexfungorum.org/.

Cardinale, B., Srivastava, D., Duffy, E., Wright, J., Downing, A., Sankaran, M., Jouseau, C., 2006. Effects of biodiversity on the functioning of trophic groups and ecosystems. Nature 443, 989–992.

Caro, T.M., O'Doherty, G., 1999. On the use of surrogate species in conservation biology. Conservation Biology 13, 805-814.

Carpenter, S., Walker, B., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: Resilience of what to what? Ecosystems 4, 765-781.

CBD. 2010. Global Biodiversity Outlook 3. Secretariat of the Convention on Biological Diversity, Montreal, Canada. 94 pp.

CBD. 2008. IX/20 Marine and Coastal Biodiversity. Decision Adopted by the Conference of the parties to the Convention on Biological Diversity at its Ninth Meeting, Bonn, 19-30 May 2008. Annex I. Scientific Criteria for Identifying Ecologically or Biologically Significant Marine Areas in Need of Protection in Open-Ocean Waters and Deep-Sea Habitats. UNEP/CBD/COP/DEC/IX/20. Convention on Biological Diversity Secretariat, Montreal, Canada.

Chapin III, F., Sala, O., Burke, I., Grime, J., Hooper, D., Lauenroth, W., Lombard, A., Mooney, H., Mosier, Naeem, S., Pacala, S., Roy, J., Steffen, W., Tilman, D., 1998. Ecosystem consequences of changing biodiversity: Experimental evidence and a research agenda for the future. BioScience 48(1), 45-52.

Chapman, A.D. (Ed.), 2009. Numbers of Living Species in Australia and the World, 2nd Edition. Commonwealth of Australia, Canberra.

Christie, P., White, A., 2007. Best practices in governance and enforcement of marine protected areas: An overview. Pp. 183 – 220 IN Food and Agriculture Organization of the United Nations. Report and Documentation of the Expert Workshop on Marine Protected Areas and Fisheries Management: Review of Issues and Considerations. Rome, 12-14 June 2006. FAO Fisheries Report No. 825. FAO, Rome.

Collen, B., Rist, J., 2008. Streamlining European 2010 Biodiversity Indicators (SEBI 2010): Developing a Methodology for Using Bats as Indicator Species and Testing the Usability of GBIF Data for use in 2010 Biodiversity Indicators. EEA/BSS/07/008. European Environment Agency, Copenhagen.

Conservation International. 2000. Megadiversity Data Tables. Washington, D.C., USA. (http:// www.conservation.org/xp/CIWEB/home).

Convention on Migratory Species. 2007. Western/Central Asian Site Network for the Siberian Crane and other Waterbirds. Guidelines to Prepare Site Nomination Documentation. Convention on Migratory Species Secretariat, Bonn, Germany.

Costello, M., 2009. Motivating online publication of data. BioScience 59, 418-427.

Crowder, L., Norse, E., 2008. Essential ecological insights for marine ecosystem-based management and marine spatial planning. Marine Policy 32, 772-778.

Crowder, L., Lyman, S., Figueira, W., Priddy, J., 2000. Source-sink population dynamics and the problem of siting marine reserves. Bulletin of Marine Science 66(3), 22.

Crouse, D., 1999. The consequences of delayed maturity in a human-dominated world. pp. 195–202 In: Musick J. (Ed.). Life in the Slow Lane. Ecology and Conservation of Long-lived Marine Animals. Bethesda, Maryland: American Fisheries Society.

Darwall, W., Vie, J., 2005. Identifying important sites for conservation of freshwater biodiversity: Extending the species-based approach. Fisheries Management and Ecology 12, 287-293.

Diaz, S., Fargione, J., Chapin III, F., Tilman, D., 2006. Biodiversity loss threatens human well-being. PLoS Biology 4, e277.

Diniz, J., 2004. Phylogenetic diversity and conservation priorities under distinct models of phenotypic evolution. Conservation Biology 18, 698–704.

Dobson, A., Lodge, D., Alder, J., Cumming, G., Keymer, J., McGlade, J., Mooney, H., Rusak, J., Sala, O., Wolters, V., Wall, D., Winfree, R., Xenopoulos, M., 2006. Habitat loss, trophic collapse, and the decline of ecosystem services. Ecology 87, 1915-1924.

Edwards, M., Beaugrand, G., Hays, G., Koslow, A., Richardson, A., 2010. Multi-decadal oceanic ecological datasets and their application in marine policy and management. Trends in Ecology and Evolution (TREE) 1278, 1-9. doi:10.1016/j.tree.2010.07.007.

Eken, G., Bennun, L., Brooks, T.M., Darwall, W., Fishpool, L.D.C., Foster, M., Knox, D., Langhammer, P., Matiku, P., Radford, E., Salaman, P., Sechrest, W., Smith, M.L., Spector, S., Tordoff, A., 2004. Key Biodiversity Areas as site conservation targets. *BioScience* 54, 1110-1118.

Estes, J., Tinker, M., Williams, T., Doak, D., 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. Science 282, 473–476.

Estrada, E., 2007. Characterisation of topological keystone species: local, global and “meso-scale” centralities in food webs. Ecol. Complex. 4, 48–57.

European Communities. 1995. 1995 Protocol Concerning Mediterranean Specially Protected Areas and Biological Diversity in the Mediterranean. Official Journal of the European Communities L322-3 – L322-17.

European Communities. 2008. The Economics of Ecosystems and Biodiversity. An Interim Report. ISBN-13 978-92-79-08960-2. Welzel Hardt, Wesseling, Germany.

European Council. 1992. Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora. Consolidated version 1.1 (2007).

European Council. 2009. Directive 2009/147/EC of 30 November 2009 on the Conservation of Wild Birds.

European Environment Agency. 2006. Progress towards Halting the Loss of Biodiversity by 2010. EEA Report No. 5/2006. European Environment Agency, Copenhagen. ISBN 92-9167-846-5.

Faith, D., 1992. Conservation evaluation and phylogenetic diversity. Biological Conservation 61, 1–10.

FAO. 2008. A Contribution to the International Initiative for the Conservation and Sustainable Use of Pollinators. Rapid Assessment of Pollinators' Status. Food and Agriculture Organization of the United Nations, Rome. 52 pp.

FAO. 2009. International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. ISBN 978-92-5-006258-7. Food and Agriculture Organization of the United Nations, Rome. 73 pp.

Freiwald, A., Fosså, J.H., Grehan, A., Koslow, T., Roberts, J.M., 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK

Gallai, N., Salles, J., Settele, J., Vaissiere, B., 2009. Economic valuation of the vulnerability of world agriculture confronted to pollinator decline. Ecological Economics 68, 810-821.

Gaston, K., 2000. Global patterns in biodiversity. Nature 405, 220-227.

Gaston, K., Fuller, R., 2007. Biodiversity and extinction: losing the common and the widespread. Progress in Physical Geography 31(2), 213-225.

GBIF. 2009. Inventory of the Global Biodiversity Information Facility's Data Portal. Global Biodiversity Information Facility, Copenhagen. Gilman, E., Robertson, T., Holetschek, J. Code and 2009 summary statistics available at http://code.google.com/p/gbif-coverage/, accessed 4 December 2009.

Gehrt, S., 1996. The human population problem: educating and changing behaviour. Conservation Biology 10(3), 900-903.

Ghilarov, A., 2000. Ecosystem functioning and intrinsic value of biodiversity. Oikos 90, 408-412.

Gilman, E.L., In Press. Bycatch governance and best practice mitigation technology in global tuna fisheries. Marine Policy.

Gilman, E.L., 1997. Community-based and multiple purpose protected areas: A model to select and manage protected areas with lessons from the Pacific Islands. *Coastal Management* 25(1):59-91.

Gilman, E.L., 2002. Guidelines for coastal and marine site-planning and examples of planning and management intervention tools. Ocean and Coastal Management 45, 377-404.

Gilman, E., Brothers, N., Kobayashi, D., 2005. Principles and approaches to abate seabird bycatch in longline fisheries. Fish and Fisheries 6(1), 35-49.

Gilman, E., Chaloupka, M., 2010. Availability of Primary Data on Marine Invasive Alien Species for Robust Species Distribution Modelling. Blue Ocean Institute, Cold Spring Harbor, New York, U.S.A.

Gilman, E., Ellison, J., Duke, N., Field, C., 2008. Review: Threats to mangroves from climate change and adaptation options. Aquatic Botany 89, 237-250.

Gilman, E., Kobayashi, D, Swenarton, T, Brothers, N, Dalzell, P., Kinan, I., 2007. Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. Biological Conservation 139, 19-28.

Greene, S., 2004. Indigenous people incorporated? Culture as politics, culture as property in pharmaceutical bioprospecting. Current Anthropology 45(2), 211-237.

Gregory, R.D., Noble, D., Field, R., Marchant, J.H., Raven, M., Gibbons, D.W., 2003. Using birds as indicators of biodiversity. Ornis Hungarica 12-13, 11-24.

Groombridge, B., Jenkins, M., 2000. Global Biodiversity: Earth's Living Resources in the 21st Century. Cambridge, UK, United Nations Environment Programme, World Conservation Monitoring Centre.

Guisan, A., Graham, C., Elith, J., Huettmann, F., NCEAS Species Distribution Modelling Group., 2007. Sensitivity of predictive species distribution models to change in grain size. Diversity and Distributions 13, 332–340.

Hassan, R., Scholes, R., Ash, N. (Eds.), 2005. Ecosystems and Human Well-being: Current State and Trends: Findings of the Condition and Trends Working Group. The Millennium Ecosystem Assessment Series; v. 1. Island Press, London.

Hernandez, P.A., Graham, C.H., Master, L.L. & Albert, D.L., 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography, 29, 773–785.

Holling, C., 1973. Resilience and stability of ecological systems. Annu Rev Ecol Syst 4, 1–23.

IMO. 2006. Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas (PSSAs). Resolution A.982(24). International Maritime Organization, London.

IOSEA. 2010. Towards a System of Networked Protected Marine Turtle Habitat Sites in the Indian Ocean – South-East Asian Region. Working Draft - September 2010. Indian Ocean South-East Asian Marine Turtle Memorandum of Understanding Secretariat, Bangkok.

Isaac, N., Turvey, S., Collen, B., Waterman, C., Baillie, J., 2007. Mammals on the EDGE: Conservation Priorities Based on Threat and Phylogeny. PLoS ONE 2(3), e296. doi:10.1371/journal.pone.0000296.

IUCN. 2009. IUCN Red List of Threatened Species. Version 2009.2. International Union for the Conservation of Nature, Gland, Switzerland.

IUCN. 2002. Developing a Method for Prioritising Sites for Freshwater Biodiversity Conservation. Report on a Workshop Organized by the IUCN Freshwater Biodiversity Assessment Programme, June 27-29, 2002. IUCN, Gland, Switzerland.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R., 2001: Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629–38.

Jordan, F., 2009. Keystone species and food webs. Philosophical Transactions of the Royal Society B. 364, 1733-1741.

Kareiva, P., Marvier, M., 2003. Conserving biodiversity coldspots, American Scientist 91, 344-351.

Kendall, B., Prendergast, J., Bjoernstad, O., 1998. The macroecology of population dynamics: taxonomic and biogeographic patterns in population cycles. Ecology Letters 1(3), 160-164.

Kier, G., Kreft, H., Lee, T.M., Jetz, W., Ibisch, P.I., Nowicki, C., Mutke, J., Barthlott, W., 2009. A global assessment of endemism and species richness across island and mainland regions. PNAS 106, 9322-9327.

Klein, A.M., Vaissiere, B., Cane, J., Steffan-Dewenter, I., Cunningham, S., Kremen, C., Tscharnke, T., 2007. Importance of pollinators in changing landscapes for world crops. Review in Proceedings of The Royal Society 274, 303-313.

Koh, L., Dunn, R., Sodhi, N., Colwell, R., Proctor, H., Smith, V., 2004. Species coextinctions and the biodiversity crisis. Science 305, 1632–34.

Kotliar, N., 2000. Application of the new keystone-species concept to Prairie Dogs: How does it work? Conservation Biology 14(6), 1715-1721.

Laffoley, D., White, A., Kilarski, S., Gleason, M., Smith, S., Llewellyn, G., Day, J., Hillary, A., Wedell, V., Pee, D., 2008. Establishing Marine Protected Area Networks—Making It Happen. Washington, D.C.: IUCN-WCPA, National Oceanic and Atmospheric Administration and The Nature Conservancy.

Lambeck, R., 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11, 849-856.

Langhammer, P.., Bakarr, M., Bennun, L., Brooks, T., Clay, R., Darwall, W., De Silva, N., Edgar, G., Eken, G., Fishpool, L., da Fonseca, G., Foster, M., Knox, D., Matiku, P., Radford, E., Rodrigues, A., Salaman, P., Sechrest, W., Tordoff, A., 2007. Identification and Gap Analysis of Key Biodiversity Areas: Targets for Comprehensive Protected Area Systems. IUCN World Commission on Protected Areas: Best Practice Protected Areas Guidelines Series No. 15. IUCN, Gland, Switzerland.

Leadley, P., Pereira, H., Alkemade, R., Fernandez-Manjarres, J., Proenca, V., Scharlemann, J., Walpole, M. (Eds.), 2010. Biodiversity Scenarios: Projections of 21st Century Change in Biodiversity and Associated Ecosystem Services. A Technical Report for the Global Biodiversity Outlook 3. CBD Technical Series No. 50. Convention on Biological Diversity Secretariat, Montreal. ISBN 92-9225-219-4.

Lenton, T., Held, H., Kriegler, E., Hall, J., Lucht, W., Rahmstorf, S., Schellnhuber, H., 2008. Tipping elements in the Earth's climate system. Proceedings of the National Academy of Sciences 105, 1786-1793.

Leon, Y., Bjorndal, K., 2001. Selective feeding in the hawksbill turtle, an important predator in coral reef ecosystems. Marine Ecology Progress Series 245: 249-258.

Lindenmayer, D., Manning, A., Smith, P., Possingham, H., Fischer, J., Oliver, I., McCarthy, M., 2002. The focal-species approach and landscape restoration: a critique. Conservation Biology 16, 338-345.

Loreau, M., 2000. Loss of biodiversity decreases biomass production in European grasslands. GCTE News 15, 3-4.

McGrady-Steed, J., Harriss, P., Morin, P., 1997. Biodiversity regulates ecosystem predictability. Nature 390, 162-165.

McKinney, M., 1998. Branching models predict loss of many bird and mammal orders within centuries. Animal Conservation 1, 159–164.

McKinney, M., Lockwood, J., 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in Ecology and Evolution 14(11), 450-453.

Midgley, G., Hannah, L., Millar, D., Ruthorford, M., Powrie, L., 2002. Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Global Ecology & Biogeography 11, 445-451.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

Mills, C., 2001. Jellyfish blooms: are populations increasing globally in response to changing ocean conditions? Hydrobiologia 451, 55–68.

Mittermeier, R., 1988. Primate diversity and the tropical forest. Case studies from Brazil and Madagascar and the importance of megadiversity countries. Pp. 145-154 IN Wilson, E.O. (Ed.). Biodiversity. National Academic Press, Washington, D.C.

Mittermeier, R.A., Gil. R., Mittermeier, C., 1997. Megadiversity: Earth's Biologically Wealthiest Nations. Conservation International, Cemex.

Mittermeier, R.A., Myers, N., Gll, R.P., Mittermeier, C.G., 1999. Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. Mexico City: CEMEX, Conservation International. ISBN 9686397582.

Mittermeier, R., Gil, P., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C., Lamoreux, J., da Fonseca, G., 2004. Hotspots Revisited. Mexico City: CEMEX, Conservation International.

Mumby, P., Edwards, A., Arlas-Gonzalez, J., Lindeman, K., Blackwell, P., Gall, A., Gorczynska, M., Harbone, A., Pescod, C., Renken, H., Wabnitz, C., Llewellyn, G., 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427, 533-536.

Musick, J., 1999. Ecology and conservation of long-lived marine animals. Pp. 1–10 IN: Musick, J. (Ed.). Life in the slow lane: ecology and conservation of longlived marine animals. Symposium 23. Bethesda, Maryland: American Fisheries Society.

Myers, N., 1988. Threatened biotas: 'hotspots' in tropical forests. Environmentalist 8, 1-20.

Myers, N., 1990. The biodiversity challenge: expanded hotspot analysis. Environmentalist 10, 243-256.

Myers, N., Mittermeier, R., Mittermeier, C., da Fonseca, G., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853-858.

Naeem, S., Thompson, L., Lawler, S., Lawton, J., Woodfin, R., 1994. Declining biodiversity can alter the performance of ecosystems. Nature 368, 734–737.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K., Daily, G., Goldstein, J., Kareiva, P., Lonsdorf, E., Naidoo, R., Ricketts, T., Shaw, M., 2009.

Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7, 4-11.

NRC. 2000. Marine Protected Areas: tools for sustaining ocean ecosystems. National Research Council. Washington, D.C., USA, National Academy Press.

Orme, C., Davies, R., Burgess, M., Eigenbrod, F., Pickup, N., Olson, V., Webster, A., Ding, T., Rasmussen, P., Ridgely, R., Stattersfield, A., Bennett, P., Blackburn, T., Gaston, K., Owens, I., 2005. Global hotspots of species richness are not congruent with endemism or threat. Nature 43, 1016-1019.

OSPAR Commission. 2007. Guidelines for the Identification and Selection of Marine Protected Areas in the OSPAR Maritime Area. Reference number: 2003-17, as amended by BDC 2007 Summary Record (BDC 07/12/1) §3.43b. OSPAR Secretariat, London.

Pauly, D., Alder, J., Bakun, A., Heileman, S., Kock, K., Mace, P., Perrin, W., Stergiou, K., Sumaila, U., Vierros, M., Freire, K., Sadovy, Y., 2005. Chapter 18. Marine Fisheries Systems. PP. 477 – 511 IN Ecosystems and Human Well-Being: Current State and Trends. Findings of the Condition and Trends Working Group. Millennium Ecosystem Assessment. Series Vol. 1. Washington, D.C., Island Press.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F. Jr., 1998. Fishing down marine food webs. Science 279, 860–863.

Pauly, D., Watson, R., 2005. Background andinterpretation of the ‘Marine Trophic Index’ as a measure of biodiversity. Phil. Trans. R. Soc. B 360, 415–423.

PECBMS. 2007. State of Europe’s Common Birds, 2007. Pan-European Common Bird Monitoring Scheme, Prague.

Pereira, H., Leadley, P., Proença, V., Alkemade, R., Scharlemann, J., Fernandez-Manjarrés, J., Araújo, M., Balvanera, P., Biggs, R., Cheung, W., Cooper, D., Gilman, E, Guenette, S., Hurtt, G., Huntington, H., Mace, G., Oberdorff, T., Revenga, C., Scholes, R, Sumaila, U., Walpole, W., 2010. Scenarios for global biodiversity in the 21st century. Science DOI: 10.1126/science.1196624.

Phillips, A., 2000. *Financing Protected Areas. Guidelines for Protected Area Managers*. Gland, Switzerland: IUCN World Commission on Protected Areas.

Piatt, J., Sydeman, W., Wiese, F., 2007. Introduction: a modern role for seabirds as indicators. Marine Ecology Progress Series 352, 199-204.

Plantlife International. 2004. Identifying and Protecting the World's Most Important Plant Areas: A Guide to Implementing Target 5 of the Global Strategy for Plant Conservation. Plantlife International, Salisbury, UK.

Plantlife International. 2010. Important Plant Areas Around the World: Target 5 of the CBD Global Strategy for Plant Conservation. Plantlife International. Salisbury, UK.

Pomeroy, R., Mascia, M., Pollnac, B., 2007. Marine protected areas: The social dimension. Pp. 149-182 IN Food and Agriculture Organization of the United Nations. Report and Documentation of the Expert Workshop on Marine Protected Areas and Fisheries Management: Review of Issues and Considerations. Rome, 12-14 June 2006. FAO Fisheries Report No. 825. FAO, Rome.

Prendergast, J., Eversham, B., 1997. Species richness covariance in higher taxa: empirical tests of the biodiversity indicator concept. Ecography 20, 210-216.

Prendergast, J., Quinn, R., Lawton, J., Eversham, B., Gibbons, D., 1993. Rare species, the coincidence of biodiversity hotspots and conservation strategies. Nature 365, 335-337.

Purvis, A., Agapow, P., Gittleman, J., Mace, G., 2000. Nonrandom extinction and the loss of evolutionary history. Science 288, 328–330.

Ramsar Secretariat. 2008. Strategic Framework and guidelines for the future development of the List of Wetlands of International Importance of the Convention on Wetlands (Ramsar, Iran, 1971). Secretariat of the Convention on Wetlands of International Importance, Gland, Switzerland.

Redding, D., Mooers, A., 2006. Incorporating evolutionary measures into conservation prioritization. Conservation Biology 20, 1670-1678.

Rex, M., Stuart, C., Hessler, R., Allen, J., Sanders, H., Wilson, G., 1993. Global-scale latitudinal patterns of species diversity in the deep-sea benthos. Nature 365, 636-639.

Rice, J., 1995. Food web theory, marine food webs, and what climate change may do to northern marine fish populations. Climate change and northern fish populations. Canadian Special Publication of the of Fisheries and Aquatic Sciences 121 (ed. R.J. Beamish), pp. 561–568. National Research Council of Canada, Ottawa.

Ricketts, T., Dinerstein, E., Boucher, T., Brooks, T., Butchart, S., Hoffmann, M., Lamoreux, J., Morrison, J., Parr, M., Pilgrim, J., 2005. Pinpointing and preventing imminent extinctions. *Proceedings of the National Academy of Sciences* 102(51),18497-18501.

Roberge J, Angelstam P., 2004. Usefulness of the umbrella species concept as a conservation tool. Conservation Biology 18, 76-85.

Roberts, C.M., Branch, G., Bustamante, R,H., Castilla, J.C., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., McArdle, D., Ruckelshaus, M., Warner, R.R., 2003. Application of ecological criteria in selecting marine reserves and developing reserve networks. Ecol. Appl. 13, S215-S228.

Roberts, D., Chavan, V., 2008. Standard identifier could mobilize data and free time. Nature 453, 449-450.

Royal Botanic Gardens. 2008. International Plant Names Index. Royal Botanic Gardens, Kew, UK. Available online at http://www.ipni.org/.

Safriel, U.N., Ben-Eliahu, M.N., 1991. The influence of habitat structure and environmental stability on the species diversity of polychaetes in vermetid reefs. In: Bell, S.S., McCoy, E.D., Mushinsky, H.R. (Eds.), Habitat Structure: the Physical Arrangement of Objects in Space. Chapman and Hall, New York, pp. 349–369.

Salm, R., Done, T., McLeod, E., 2006. Marine protected area planning in a changing climate. In: Phinney, J.T., Hoegh-Guldberg, O., Kleypas, J., Skirving,W., Strong, A. (Eds.), Coral Reefs and Climate Change: Science and Management. American Geophysical Union, Washington, D.C., pp. 207-221.

Sandwith, T., Shine, C., Hamilton, L., Sheppard, D., 2001. Transboundary Protected Areas for Peace and Co-operation. Gland, Switzerland and Cambridge, UK. IUCN

Smith, P. Francis, R., McVeagh, M., 1991. Loss of genetic diversity due to fishing pressure. Fisheries Research 10, 309-316.

Snaith, T., Beazley, K., 2002. Moose (Alces alces Americana [Gray Linnaeus Clinton] Peterson) as a focal species for reserve design in Nova Scotia, Canada. Natural Areas Journal 22, 235-250.

Southwick E.E, Southwick L., Jr., 1992. Estimating the economic value of honey bees (Hymenoptera Apidae) as agricultural pollinators in the United States. J. Econ. Entomol. 85, 621–633.

Springer, A.M., Estes, J.A., van Vliet, G.B., Williams, T.M., Doak, D.F., Danner, E.M., Forney, K.A., Pfister, B., 2003: Sequential megafaunal collapse in the North Pacific Ocean: an ongoing legacy of industrial whaling? Proceedings of the National Academy of Sciences, USA 100, 12223–28.

Stattersfield, A., Crosby, M., Long, A., Wege, D., 1998. Endemic Bird Areas of the World. Priorities for Biodiversity Conservation. BirdLife Conservation Series No. 7. BirdLife International, Cambridge, UK.

Stevens, J.D., Bonfil, R., Dulvy, N.K., Walker, P.A., 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES Journal of Marine Science 57(3), 476-494.

Stewart, R.R., Noyce, T., Possingham, H., 2003. Opportunity cost of ad hoc marine reserve design decisions: an example from South Australia. Marine Ecology Progress Series 253, 13.

Stockwell, D., Peterson, A., 2002. Effects of sample size on accuracy of species distribution models. Ecological Modelling 148, 1-13.

Suarez, A., 2004. The value of museum collections for research and society. BioScience 54, 66-74.

Terborgh, J., Lopez, L., Nuñez, V.P., Rao, M., Shahabuddin, G., Orihuela, G., Riveros, M., Ascanio, R., Adler, G.H., Lambert, T.D., Balbas, L., 2001: Ecological meltdown in predator-free forest fragments. Science 294, 1923–26.

Thomas, J., Telfer, M., Roy, D., Preston, C., Greenwood, J., Asher, J., Fox, R., Clarke, R., Lawton, J., 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. Science 303, 1879-1881.

Tilman, D., Downing, J., 1994. Biodiversity and stability in grasslands. Nature 371, 363-365.

UNESCO. 1972. Convention Concerning the Protection of the World Cultural and Natural Heritage. United Nations Educational, Scientific and Cultural Organisation, Paris.

UNESCO. 1995. Statutory Framework for the World Network of Biosphere Reserves. United Nations Educational, Scientific and Cultural Organisation, Paris.

UNESCO. 2008. Operational Guidelines for the Implementation of the World Heritage Convention. Intergovernmenatl Committee for the Protection of the World Cultural and Natural Heritage. United Nations Educational, Scientific and Cultural Organisation, Paris.

UNESCO MAB Programme. 2004. Biosphere Reserve Nomination Form [February 2004]. Man and the Biosphere (MAB) Programme, United Nations Educational, Scientific and Cultural Organisation, Paris.

Vamosi, J., Wilson, J., 2008. Nonrandom extinction leads to elevated loss of angiosperm evolutionary history. Ecological Letters 11, 1047-53.

Victor, S., Neth, L., Golbuu, Y., Wolanski, E., Richmond, R., 2004. Sedimentation in mangroves and coral reefs in a wet tropical island, Pohnpei, Micronesia. Estuarine, Coastal and Shelf Science 66(3-4), 109-416.

Wells, S., 2006. Establishing National and Regional Systems of MPAs – a Review of Progress With Lessons Learned. UNEP World Conservation Monitoring Centre, UNEP Regional Seas Programme, ICRAN, IUCN/WCPA – Marine.

Wisz, M., Hijmans, R., Li, J., Peterson, A., Graham, C., Guisan, A., 2008. Effects of sample size on the performance of species distribution models. Diversity and Distributions 14, 763-773.

Yesson, C., Brewer, P., Sutton, T, Caithness, N., Pahwa, J., Burgess, M., Gray, W., White, R., Jones, A., Bisby, F., Culham, A., 2007. How global is the Global Biodiversity Information Facility? PLoS ONE 2, e1124.

Figure captions

Fig. 1. Percent of 1.8 M species' names described by three authoritative lists (Bisby et al., 2007; Royal Botanic Gardens, 2008; CABI Biosciences, 2009) with $\geq$ 1 record with coordinates in the Global Biodiversity Information Facility data portal by (a) kingdom, and (b) selected phyla and classes in the Animalia kingdom. Data labels are the number of species with $\geq$ 1 record with coordinates. Data from GBIF (2009).

Table 1. Examples of initiatives and programs employing criteria suites to identify sites and/or manage site networks of local- to global- scale biodiversity importance.

Name	Purpose	Spatial Scale	Facet(s) of Biodiversity	Criteria Suite
Global-scale Biodiversity Importance				
Alliance for Zero Extinction Sites[1]	Identify and safeguard key sites where species are in imminent danger of extinction.	Global	Species	• Endangerment (site contains one or more Endangered or Critically Endangered species, as listed on the IUCN Red List of Threatened Species; • Irreplaceability (i) Is the sole area where an Endangered or Critically Endangered species occurs, or (ii) contains more than 95% of the global population of the species, or (iii) contains the overwhelmingly significant known population for one life-history segment (e.g., breeding or wintering) of the species; • Discreteness (the site has a definable boundary).
Biodiversity Hotspots[2]	Identify regions with both exceptional levels of plant endemism and serious levels of habitat	Global	Endemic plant species; terrestrial and freshwater	• Region contains $\geq$ 1,500 endemic vascular plant species (0.5% or more of the world's total); • Region has lost $\geq$ 70% of its original native habitat.

	loss.		habitats	
Ecologically or Biologically Significant Marine Areas in Need of Protection in Open-Ocean Waters and Deep-Sea Habitats[3]	Identify ecologically or biologically significant marine areas beyond the limits of national jurisdiction in need of protection, and design representative networks of marine protected areas.	Global – international waters/ seabed	Marine ecosystems	<u>Scientific Criteria</u> • Uniqueness or rarity; • Special importance for lifehistory stages of species; • Importance for threatened, endangered or declining species and/or habitats; • Vulnerability, fragility, sensitivity, or slow recovery; • Biological productivity; • Biological diversity; • Naturalness. <u>MPA Network Criteria</u> • Ecologically and biologically significant areas; • Representativity; • Connectivity; • Replicated ecological features; • Adequate and viable sites.
Endemic Bird Areas[4]	218 regions of the world that represent natural	Global	Bird species	<u>Criterion to Identify an EBA</u> Area encompasses overlapping breeding ranges of restricted-

	areas of bird endemism where the distributions of two or more restricted-range bird species overlap.			range (< 50,000 km^2) bird species, such that the complete ranges of two or more restricted-range species are entirely included within the area's boundary. <u>Criteria to Define Relative Priority of Identified EBAs</u> • Biological importance (number of restricted-range species, taxonomic uniqueness of those species and the size of the EBA); • Current threat level (percentage of restricted-range species in the area which are threatened, and the categories of threat of these species).
Important Bird Areas[5]	Identify and protect sites critical, individually and as networks, for the conservation of birds.	Global, Regional, and Sub-Regional	Terrestrial, freshwater and marine bird species and populations	• Species of global conservation concern; • Assemblages of restricted-range species; • Assemblages of biome-restricted species; • Congregations.
Important Plant Areas[6]	Identify natural or semi-natural site exhibiting exceptional botanical	Global, regional, national	Plant and fungal populations	• Presence of threatened species; • Botanical richness; • Threatened habitat or vegetation type.

	richness and/or supporting an outstanding assemblage of rare, threatened and/or endemic plant species and/or vegetation of high botanic value.		and species, and habitats	
Important Sites for Freshwater Biodiversity[7]	Prioritize inland water sites for conservation.	Global, regional, local	Freshwater ecosystems	• Significant number[15] of globally threatened species or other species of conservation concern; • Non-trivial numbers of one or more restricted-range species; [15] • Significant component of the group of native species that are confined to an appropriate biogeographical unit(s); [15] • Critical for any life history stage of a species; • More than a threshold[15] number of individuals of a congregatory species; • Representation of inland water habitats; • Representation of keystone species.
Key Biodiversity Areas[8]	Identify globally significant sites for	Global	Populations, species,	• Vulnerability – globally threatened species;

	biodiversity conservation.		assemblages of species	- Irreplaceability:
				  - Restricted-range species;
				  - Species with large but clumped distributions;
				  - Globally significant congregations;
				  - Globally significant source populations;
				  - Biome-restricted assemblages.[13]

Megadiversity Nations[9]	Identify sovereign nations with the highest biodiversity.	Global (Australia, Brazil, China, Colombia, Democratic Republic of Congo, Ecuador, India, Indonesia, Madagascar, Malaysia,	Terrestrial species biodiversity and endemism at species and higher taxonomic levels by political country-level boundaries	- Species richness; - Endemic species richness; - Endemic family and genus richness.

		Mexico, Papua New Guinea, Peru, Philippines, South Africa, United States of America, Venezuela)		
Particularly Sensitive Sea Areas[10]	An area that needs special protection through action by the International Maritime Organization because of its significance for recognized ecological,	Global	Marine ecosystems	Ecological criteria: • Uniqueness or rarity; • Critical habitat; • Dependency; • Representativeness; • Diversity; • Productivity;

	socio-economic, or scientific attributes, where such attributes may be vulnerable to damage by international shipping activities. At the time of designation, one or more protective measures must have been approved or adopted by the International Maritime Organization to prevent, reduce, or eliminate the threat or identified vulnerability.			• Spawning or breeding grounds; • Naturalness; • Integrity; • Fragility; • Biogeographic importance. Social, cultural and economic criteria: • Social or economic dependency; • Human dependency; • Cultural heritage Scientific and educational criteria: • Research; • Baseline for monitoring studies; • Education • The recognized attribute(s) of the area should be vulnerable to international shipping activities.
Ramsar List of	Develop and maintain an	Global	Wetland,	• Contains a representative, rare, or unique example of a natural

Wetlands of International Importance[11]	international network of wetlands which are important for the conservation of global biological diversity and for sustaining human life through the maintenance of their ecosystem components, processes and benefits/services.		aquatic, and adjacent ecosystems	or near-natural wetland type found within the appropriate biogeographic region; • Supports vulnerable, endangered, or critically endangered species or threatened ecological communities; • Supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region; • Supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions; • Regularly supports 20,000 or more waterbirds; • Regularly supports 1% of the individuals in a population of one species or subspecies of waterbird; • Supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity; • Is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend;

				• Regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species.
Vulnerable Marine Ecosystems[12]	Identify vulnerable marine ecosystems as a precursor to determining if deep sea fishing activities are likely to cause significant adverse impacts.	Global	Marine ecosystems	• Uniqueness or rarity; • Functional significance; • Fragility; • Life-history traits of component species that make recovery difficult; • Structural complexity.
World Heritage List[13]	Collective system for the international protection of the world cultural and natural heritage of outstanding universal value, including sites that are outstanding demonstrations of human coexistence with the land as well as	Global	Terrestrial, freshwater and marine habitats and ecosystems	Natural Heritage Criteria[1] • Be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change; • Be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance; • Contain superlative natural phenomena or areas of exceptional

	human interactions, cultural coexistence, spirituality and creative expression.			natural beauty and aesthetic importance; • Be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features; • Be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals; • Contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.
World Network of Biosphere Reserves[14]	A global network of internationally recognized areas of ecosystems that demonstrate and promote a balanced relationship between	Global	Terrestrial, freshwater and marine ecosystems	• Encompass a mosaic of ecological systems representative of major biogeographic regions, including a gradation of human interventions; • Be of significance for biological diversity conservation; • Provide an opportunity to explore and demonstrate approaches to sustainable development on a regional scale; • Have an appropriate size to serve the three functions of

	humans and the biosphere.			biosphere reserves; • Include appropriate zonation of (i) core area(s), (ii) buffer zone(s); and (iii) an outer transition area; • Provide organisational arrangements for the involvement and participation of a suitable range of inter alia public authorities, local communities and private interests in the design and carrying out the functions of a biosphere reserve; and • Make provisions for (i) mechanisms to manage human use and activities in the buffer zone(s); (ii) a management policy or plan for the area as a biosphere reserve; (iii) a designated authority or mechanism to implement this policy or plan; and (iv) programmes for research, monitoring, education or training.
Regional- to Local-Scale Biodiversity Importance				

Association of Southeast Asian Nations (ASEAN) Heritage Parks[15]	Protected areas of high conservation importance, preserving in total a complete spectrum of representative ecosystems of the ASEAN region	Regional (Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam)	Terrestrial and freshwater ecosystems	• Ecological completeness; • Representativeness; • Naturalness; • High conservation importance; • Legally gazetted area.
Natura 2000[16]	Assure the long-term survival of Europe's most valuable and threatened habitats and	Regional (EU); national	Terrestrial, freshwater and marine ecosystems	Birds (Special Protection Areas) • Most suitable territories in number and size for the especially endangered bird species listed in Annex I of the Birds Directive; • Most suitable territories in number and size for regularly

	species, through a network of protected areas comprised of Special Protection Areas for birds under the EU Birds Directive, and Special Areas of Conservation under the EU Habitats Directive.			occurring migratory species not listed in Annex I of the Birds Directive. Special Areas of Conservation • Habitat representativity; • Habitat relative surface area; • Habitat conservation status and restorability; • Habitat global assessment; • Species relative population size; • Species conservation status; • Species degree of isolation; • Species global assessment.
OSPAR Network of Marine Protected Areas[17]	• Protect, conserve and restore species, habitats and ecological processes which are adversely affected as a result of human activities;	Regional	Marine ecosystems	Ecological Criteria • Threatened or declining species and habitats/biotopes; • Important species and habitats/biotopes; • Ecological significance; • High natural biological diversity; • Representativity; • Sensitivity;

	• Prevent degradation of and damage to species, habitats and ecological processes, following the precautionary principle; • Protect and conserve areas that best represent the range of species, habitats and ecological processes in the OSPAR maritime area.			• Naturalness Practical Criteria • Size; • Potential for restoration; • Degree of acceptance; • Potential for success of management measures; • Potential damage to the area by human activities; • Scientific value
Specially Protected Areas of Mediterranean Importance[18]	Sites, "of importance for conserving the components of biological diversity in the Mediterranean; contain ecosystems specific to	Regional	Coastal and marine ecosystems/ habitats.	• Uniqueness; • Natural representativeness; • Diversity; • Naturalness; • Presence of habitats critical to endangered, threatened or endemic species;

	the Mediterranean area or the habitats of endangered species; are of special interest at the scientific, aesthetic, cultural or educational levels" (Article 8(2), European Communities, 1995).			- Cultural representativeness.
System of Networked Protected Marine Turtle Habitat Sites in the Indian Ocean – South-East Asian Region[19]	Achieve long-term protection of nesting beaches, foraging grounds and other areas that are of high regional value for the conservation of marine turtles; to derive unique benefits through the systematic addition of sites that collectively	Regional	Coastal and marine ecosystems/ sea turtle habitats	Network-wide Ecological Criteria - Representativeness and replication; - Ecological Connectivity; - Area Ecological and Biological Criteria - Rare turtle stock or species; - Species and/or genetic stock richness; - Number of turtle clutches or hatchlings; - Turtle abundance; - Refugia;

	encompass essential ecological properties; and to optimize the use of limited financial and human resources through the coordinated operation of networked sites.			• Degraded but with capacity for rehabilitation Governance Criteria • Legal framework; • Conservation actions; • Collaborative management, surveillance and enforcement; • Research and monitoring significance; • Sustainable human and financial resources Socio-economic and Political Criteria • Cultural and traditional importance; • Compatible activities; • Educational value; • National importance; • Existing recognition and protection
Western/Central Asian Site Network for the Siberian Crane and other	To ensure the long-term conservation of the Siberian Crane and other migratory	Regional	Ecosystems/ Siberian crane habitats	• Siberian Crane(s) were recorded at the site at least five times during the last 10 years; • The site has held one or more Siberian Cranes during the last 50 years, but there are less than five records during the 10 last

Waterbirds[20]	waterbirds along the Western and Central Asian Flyways through recognition and appropriate management of a network of internationally important sites.			years; • The site is historical habitat of the Siberian Crane, but there are less than five records during the last 50 years; • There are no records of Siberian Crane at a site, but it is considered to contain appropriate habitat for the species and it is suitable for release and reintroduction projects.

[1] Alliance for Zero Extinction (2005); Rickets et al. (2005).

[2] Myers (1988, 1990); Myers et al. (2000); Mittermeier et al. (1999, 2004).

[3] CBD (2008).

[4] Stattersfield et al. (1998).

[5] BirdLife International (2010). Criterion thresholds are set globally or regionally. BirdLife has also established additional regional and sub-regional criteria suites, and has defined four categories of marine IBAs (BirdLife International, 2010).

[6] Plantlife International (2004, 2010). A set of regional criteria has been developed, along with methodologies and thresholds to identify sites as Important Plant Areas within Europe, and are being developed in other regions (Plantlife International, 2004).

[7] IUCN (2002); Darwall and Vie (2005). Thresholds for ‘significant’, ‘non-trivial’, and ‘threshold’ numbers, defining ‘restricted range’, and defining biogeographical units are taxon-specific (Darwall and Vie, 2005).

[8] Eken et al. (2004), Langhammer et al. (2007). Thresholds are specified for the vulnerability criterion and each of the five sub-criteria of the criterion ‘irreplaceability’ (Langhammer et al., 2007). Intended to serve as an umbrella for the Alliance for Zero Extinction sites (Alliance for Zero

Extinction, 2005; Rickets et al., 2005), Ecologically or Biologically Significant Marine Areas in Need of Protection in Open-Ocean Waters and Deep-Sea Habitats (CBD, 2008), Important Bird Areas (BirdLife International, 2010), Important Plant Areas (Plantlife International, 2004, 2010), and Important Sites for Freshwater Biodiversity (ASEAN Secretariat, 2003; ASEAN Center for Biodiversity, 2010).

[9] Mittermeier (1988); Mittermeier et al. (1997); Conservation International (2000).

[10] IMO (2006).

[11] Ramsar Secretariat (2008).

[12] FAO (2009).

[13] UNESCO (1972, 2008). There are also four Cultural Heritage criteria, not listed here.

[14] UNESCO (1995); UNESCO MAB Programme (2004).

[15] ASEAN Secretariat (2003); ASEAN Center for Biodiversity (2010).

[16] European Council (1992, 2009).

[17] OSPAR Commission (2007).

[18] European Communities (1995).

[19] IOSEA (2010).

[20] Convention on Migratory Species (2007).

Table 2. Ecological criteria for identifying sites and networks of sites of high biodiversity value and prioritizing the use of limited resources for conservation. Criteria describing minimum, required ecological properties of site networks are described first.

Criterion	**Definition**	**Rationale**	**Considerations / Constraints / Criticisms**	**Example(s)**
Representative[1]	One or more sites are included in a network to include each example of the full range of biological diversity, from genotypes to biomes, and representing the full diversity of ecological processes, physiographic feature, geomorphic classes (the range of landforms where a single ecosystem type is found) within an ecosystem type, habitat or community types, or ecosystems	Protecting sites with representative properties can augment resistance and resilience. The diversity of geomorphic settings in which an ecosystem is found, combined with representation of the diversity of ecosystem types within the network, might be effective surrogates for biodiversity at lower manifestations.	A precursor to implementing this criterion is to classify habitats and biogeographic settings at the spatial scale of interest.	The criteria suite for identifying areas for inclusion in the Specially Protected Areas of Mediterranean Importance includes ‘natural representativeness’, defined as an area that has, “highly representative ecological processes, or community or habitat types or other natural characteristics,” (European Communities, 1995).

	present in a biogeographical region of interest (European Communities, 1995; Roberts et al., 2003; CBD, 2008).			
Replication[1]	A network includes multiple sites of the same ecosystem, community type, and geomorphic classes, and multiple examples of ecological processes and structure that naturally occur in each biogeographic area (Roberts et al., 2003; Salm et al., 2006; Wells, 2006; CBD, 2008). Also referred to as redundancy.	Replication can help avoid the loss of a single biodiversity feature by spreading the risk and increase the chance for the survival of all components of biodiversity (Roberts et al., 2003; Salm et al., 2006; Wells, 2006).	Biodiversity features that are inherently highly variable or are only very generally defined may require substantial replication (CBD, 2008).	'Replicated ecological features' is one of a suite of criteria for required properties of a site network for ecologically or biologically significant marine areas in need of protection in open-ocean waters and deep-sea habitats (CBD, 2008).
Ecological	A series of sites that are	A network of protected areas	Ecological connectivity	'Connectivity' is one of a suite of

Connectivity[1]	functionally connected are included in the network.	can be designed, taking into account the distribution and shape of individual sites included in the network, to adequately protect ecological connectivity between ecosystems, where individual sites in the network benefit from one another (Crowder et al., 2000; Stewart et al., 2003; Roberts et al., 2003). The shape (to consider edge effects, where margins of protected areas may be heavily exploited) and spacing of the individual sites in the network achieve the ecological connectivity of the network as a whole (Laffoley et al., 2008). For individual	among sites is difficult to establish for some species, such as sea turtles, where there is a dearth of information from migration and genetic studies (IOSEA, 2010).	criteria for required properties of a site network for ecologically or biologically significant marine areas in need of protection in open-ocean waters and deep-sea habitats (CBD, 2008).

		species and habitats, spacing requirements for the exchange of adults, juveniles, larvae, eggs, or spores require consideration of the distance to protected sites where suitable habitat exists (Laffoley et al., 2008).		
Size[1]	The area of a site, or combined area of a network of sites.	Some species require a minimum territory size which in some cases might require large continuous tracts of relatively undisturbed habitat (Kareiva and Marvier, 2003). Land area is positively correlated with species richness (the Arrhenius relationship), where an order of magnitude increase in area will double	At small spatial scales, increases in area do not typically result in increased habitat diversity or species richness.	The OSPAR Network of MPAs includes the criterion 'size' in its suite, defined to consider both ecological integrity and manageability (OSPAR Commission, 2007).

		the number of species (Groombridge and Jenkins, 2000).		
Refugia[1]	Relatively resistant and resilient to stressors, such as climate change, introductions of invasive alien species, disease, storms, etc.	Sites that act as refugia are relatively resistant and resilient to stresses (Salm et al., 2006). Protecting refugia areas that resist and/or recover quickly from disturbance can serve as a source of recruits to re-colonize areas that are lost or degraded (Gilman et al., 2008). Included in this criterion is consideration of effects of climate change scenarios on the future biodiversity value of candidate isolated and networked sites.	Some models for predicting response of ecosystems to stressors have low robustness, and there can be high uncertainty in projections of stressors (Gilman et al., 2008; Leadley et al., 2010)	The criteria suite to nominate a protected area to become part of the ASEAN Heritage Parks network includes the criterion ‘ecological completeness’, defined as a site that is “an intact ecological process and the capability to regenerate with minimal human intervention,” (ASEAN Centre for Biodiversity, 2010).

Focal/surrogate species	A systematically selected suite of species with well understood responses to anthropogenic and natural changes, that provide a comprehensive characterization of all coexisting species across regions, higher taxon, and trophic levels, and surrogate for ecosystem structure and functioning (Roberge and Angelstam, 2004; Piatt et al., 2007). A suite of indicator, umbrella and keystone species that exhibit trends in routinely monitored parameters (e.g., abundance, spatial distribution, and various	Monitoring a small group of species is a cost-effective shortcut to monitoring all constituent species and conducting more complex, expensive, time consuming, and potentially infeasible monitoring of entire biotic and abiotic components of an ecosystem or landscape. By mitigating threats to ensure the survival of focal species, in concept, this effectively maintains ecosystem functions, structure and concomitant services.	In complex ecosystems, the number of species that would need to be included in a suite of focal species might make its application infeasible (Lindenmayer et al., 2002). There can be high uncertainty in identifying a suite of species to serve as surrogates and validating effectiveness. This is because, for some ecosystems, there is insufficient understanding of interspecific interactions, the roles of constituent species of each community, links between trophic levels, and factors predominant in	The criteria suite employed to identify Important Sites for Freshwater Biodiversity includes a criterion for representation of abundant, widespread keystone species (IUCN, 2002; Darwall and Vie, 2005).

	life history characteristics), that, when taken together, provide an accurate surrogate for all coexisting species assemblages across taxa and ecological requirements, as well as an indication of changes in ecosystem functioning and structure (Caro and O'Doherty 1999; Snaith and Beazley, 2002; Gregory et al., 2005; Collens and Rist, 2008; Jordan, 2009).		regulating some ecosystems, as well as functional links between ecosystems, to enable robust quantitative ranking of individual species based on their importance to sympatric species and in regulating and maintaining ecosystems (Snaith and Beazley, 2002; Mumby et al., 2004; Gilman et al., 2008; Jordan, 2009).	

Phylogenetic distinctiveness	The number or richness of species that have relatively high phylogenetic uniqueness (the species' taxonomic originality) (Faith, 1992; Diniz, 2004; Redding and Moores, 2006; Isaac et al., 2007).	A greater loss of future potential for evolution occurs when a species is lost that lacks close taxonomic relatives/has unique genetic information (Kareiva and Marvier, 2003; Redding and Moores, 2006).	The evolutionary history (branching pattern of a phylogenetic tree and length of its branches) is not available for all taxonomic groups (Bininda-Emonds, 2004). Comparing taxonomic distinctness from unrelated taxonomic groups requires consideration (Isaac et al., 2007).	A criterion included in the suite for identifying priority sites for freshwater biodiversity conservation includes consideration of taxonomic distinctiveness of an entire site (i.e., the average value of all species in the site) and of individual species present at the site (Darwall and Vie, 2005).
Total species richness	Number of species per unit of area.	Protecting the largest number of species in the smallest possible area is a cost-effective method to optimize biodiversity conservation. Species richness is positively correlated with ecosystem functioning and services (Naeem et al., 1994; Tilman	Areas rich in species in one taxonomic group are not necessarily species-rich in other groups (Prendergast et al., 1993; Prendergast and Eversham, 1997; Groombridge and Jenkins, 2000). Diversity indices	The criteria suite to identify Important Plant Areas includes a criterion for 'botanical richness', defined as a site containing a high number of plant or fungal species within a range of defined habitat or vegetation type (Plantlife International, 2004).

		and Downing, 1994; Cardinale et al., 2006). A site network design can adapt the total species richness criterion to protect habitat for all species found in the region of focus by weighting sites that have high species richness for species not present in sites already included in the network (Cabeza and Moilanen 2001; Roberts et al., 2003).	may be indifferent to species introductions. Species-poor systems might be less resistant and resilient, where extirpation of an entire species can trigger drastic alteration to ecosystem functioning (Roberts et al., 2003). Focusing on sites with relatively high species richness may not protect vulnerable systems.	
Biological diversity	A site containing a relatively high number or density of life, from genotypes to biomes.	Broad criterion encompassing all components of biodiversity, where efforts to protect sites with high overall relative biodiversity value in order to mitigate the change and loss in biodiversity are	In practice, employment of such a broadly defined criterion results in the identification of an unmanageably large number of relevant sites. Splitting the criterion to cover more	"Diversity" is included in the criteria suite for the identification of Particularly Sensitive Sea Areas, defined as, "An area that may have an exceptional variety of species or genetic diversity or includes

		conducted in order to ensure the persistence of the biosphere, including evolutionary processes, and human wellbeing.	distinct components of diversity facilitates more practical prioritization of sites.	highly varied ecosystems, habitats, and communities," (IMO, 2006).
Endemic species	The number or richness of endemic species.	Protecting relatively small sites that harbour a large number of endemic species may result in protecting sites that are of highest biodiversity value across taxa.	Hotspots for different taxa have been found to not spatially overlap (Prendergast et al., 1993; Prendergast and Eversham, 1997; Groombridge and Jenkins, 2000; Kareiva and Marvier, 2003). Hotspots tend to not overlap with areas of high rare species richness or global species richness (Kareiva and Marvier, 2003; Orme et al., 2005).	In the most recent assessment against two criteria to identify 'Biodiversity Hotspots' (Table 1, high vascular plant endemic species richness, high habitat loss), Mittermeier et al. (2004) identified 34 biodiversity hotspots comprising 2.3% of the Earth's surface, most occurring in tropical forests, which contain half of global endemic plant species and 42% of terrestrial vertebrates. Stattersfield et al. (1998) identified 218 Endemic

				Bird Areas, areas encompassing breeding ranges of bird species with ranges that are restricted to < 50,000 km^2, such that the complete ranges of two or more restricted-range species are entirely included within the site.
Threatened species and/or populations	The number or richness of threatened species and/or populations.	Protection of sites containing threatened biodiversity contributes to reducing the risk of extirpations and extinctions, halting declines, and achieving recovery.	Given the existence of substantial taxonomic and spatial gaps in available information for the large majority of species and distinct population segments, it is unlikely that conservation of habitat critical for known threatened species- and population-levels of biodiversity will effectively protect threatened	A site where there is regular occurrence of a globally threatened species according to the IUCN Red List, can be identified as a Key Biodiversity Area, with the presence of a single individual of a Critically Endangered or Endangered species, or 30 individuals or 10 pairs of a Vulnerable species (Langhammer et al., 2007).

			species and populations that we do not know about.	
Threatened ecosystem, habitat or ecological community[2]	An ecosystem, habitat or community type that, on a given spatial scale, has suffered large losses in area and/or health.	If an ecosystem, habitat or community is becoming rare, the biodiversity value of remaining areas containing this ecosystem, habitat or community type rises.	Identifying threatened ecosystems, habitats and ecological communities requires the existence of an agreed classification system for these biogeographic settings at these large scales (see considerations under the criterion 'Representative').	Ramsar Criterion 2 for identifying wetlands of international importance is a wetland that, "supports vulnerable, endangered, or critically endangered species or threatened ecological communities," (Ramsar Secretariat, 2008).
Biological productivity	A site contains species, populations or communities with relatively high natural biological productivity.	Areas with high productivity are valued for fuelling ecosystems and for increasing the growth rates of organisms and their capacity for reproduction (CBD, 2008). A positive correlation has been found between	Relatively disturbed, ruderal sites generally possess relatively low biodiversity value but can have high biological productivity.	'Productivity' is included in the criteria suite for the Particularly Sensitive Sea Areas, defined as, "An area that has a particularly high rate of natural biological production. Such productivity is the net result of biological and physical

		species richness and productivity (Naeem et al., 1994; Tilman et al., 1996; Groombridge and Jenkins, 2000; Loreau, 2000; Cardinale et al., 2006); sites observed to have relatively high productivity for the ecosystem types represented might be an indicator of high species-level biodiversity.		processes which result in an increase of biomass in areas such as oceanic fronts, upwelling areas and some gyres," (IMO, 2006).
Abundance	The number of individuals of a taxa of interest supported by a site, or the proportion of a population of a species supported by a site.	Sites that support large numbers of individuals of a taxa of interest possess intrinsic value.	Long-term monitoring data are required, including to observe significant trends (see considerations for criterion 'Research and monitoring value', Table 3).	A site that, "is known or thought to hold, on a regular basis, 1% or more of a bio-geographic population of a congregatory waterbird species, OR 1% or more of the global population of a congregatory seabird or terrestrial [bird] species, OR at least 20,000 waterbirds, OR at

				least 10,000 pairs of seabirds, OR the site is thought to be a 'bottleneck' where at least 20,000 storks, raptors and/or cranes pass regularly during spring or autumn migration," can be identified as an Important Bird Area (BirdLife International, 2010).
Rarity[2]	A site with biodiversity resources (genotype to biome) that occur only in a small number of locations, at the spatial scale being considered, such that loss of the biodiversity supported by this site would be irreplaceable.	The resource is nearly irreplaceable, and its loss would very likely result in its extirpation or extinction.	At relatively small scales, areas that contain rare species often do not coincide for different taxonomic groups (Groombridge and Jenkins, 2000). Areas were rare species are found tend to not include locations of biodiversity hotspots (Kareiva and Marvier, 2003).	FAO (2009) includes rarity/uniqueness as a criterion for identifying vulnerable marine ecosystems, including areas containing endemic species; areas supporting rare, threatened or endangered species occurring only in discrete areas; nursery areas; and discrete feeding, breeding and spawning areas.

			A resource that is rare at a fine scale might be typical of less importance at regional and global scales (CBD, 2008). A dearth of data might result in a false identification of a resource as being rare (CBD, 2008).	Also, see 'Endemic' criterion.
Uniqueness[2]	A site with biodiversity resources (genotype to biome) that occur only at this site, i.e., it is the only one of its kind, at the spatial scale being considered.	The resource is irreplaceable, and its loss would result in its extirpation or extinction.	See criterion 'Rarity'.	See criteria 'Rarity' and 'Endemic species richness'.
Sensitive/Fragile	A site containing a high proportion of habitats that exhibit low resistance or resilience, or species groups that are particularly	Protecting sensitive habitats and hotspots of sensitive species increases the ability to manage human activities and possibly natural	Given limited resources, it may be more effective to invest in conserving relatively resistant and resilient sites than sites that	'Vulnerability, fragility, sensitivity, or slow recovery' is included in the criteria suite for the identification of ecologically or biologically significant marine

	vulnerable to increased mortality above natural levels due to their life history traits.	disturbances (CBD, 2008).	are vulnerable to current or imminent stressors.	areas in need of protection in open-ocean waters and deep-sea habitats (CBD, 2008).
Structural complexity	A site with a complex physical structure, created by significant concentrations of biotic and abiotic features (FAO, 2009).	Ecosystems with relatively complex structure generally rely on the intactness of the physical structure to maintain ecosystem functioning, and tend to support high diversity of structure-forming invertebrates (Safriel and Ben-Eliahu, 1991; Freiwald et al., 2004).	Implementation requires the development of agreed metrics for comparing the relative degree of structural complexity.	The criteria suite for identifying Particularly Sensitive Sea Areas includes the criterion 'Dependency', defined as, "An area where ecological processes are highly dependent on biotically structured systems (e.g. coral reefs, kelp forests, mangrove forests, seagrass beds). Such ecosystems often have high diversity, which is dependent on the structuring organisms…" (IMO, 2006).
Degraded Site	Area that has experienced a relatively high degree of degradation.	Targeting conservation investment to areas that have already experienced	The degree that a site has been disturbed does not provide an indication of	The criteria suite to identify Biodiversity Hotspots includes a criterion for high habitat loss,

		substantial habitat loss, especially when these areas also harbour high numbers of endemic species, might protect the remaining now rare habitat from future misuse and loss (Myers et al., 2000), and might also provide opportunities for ecological restoration to achieve conservation gains (see the following criterion).	future threat (Kareiva and Marvier, 2003).	where a region had to have lost ≥70% of the area of original vegetation (Myers, 1988, 1990; Myers et al., 2000; Mittermeier et al., 2004).
Degraded with reversible alteration	Area that is relatively disturbed, e.g., that has experienced substantial habitat modification, but retains the capacity for rehabilitation.	A degraded site that possesses the potential to be rehabilitated to resume ecosystem functioning, structure and provision of services similar to a least-disturbed site is of high conservation value.	It may not be possible to restore a distributed ecosystem to perform functions at a level of a relatively undisturbed ecosystem, and some sites might require active management.	The IOSEA Marine Turtle Site Network includes “degraded with capacity for rehabilitation” as one of a suite of ecological criteria, defined as substantially disturbed sites with the (i) capacity for rehabilitation, where there is a high degree of

		Recovery of threatened biodiversity may require reestablishment in areas of historic range.		confidence that the site's turtle habitat could be restored to approximate pre-disturbance condition; and (ii) existence of ongoing management interventions to rehabilitate the degraded habitat (IOSEA, 2010).
Naturalness	Least disturbed, relatively pristine sites.	Protecting sites that contain relatively pristine habitat reduces the risk of future anthropogenic disturbance, maintains these areas as reference sites for assessment and monitoring activities, and safeguards ecosystem resistance and resilience.	Protecting sites that contain relatively pristine habitat, but are not threatened with degradation, does not achieve a conservation gain, using resources that otherwise could be used to protect sites actually requiring protection from current or future threats of degradation.	The criteria suite to nominate a protected area to become part of the ASEAN Heritage Parks network includes the criterion 'naturalness', defined as a site that is "for the most part, in a natural condition such as a second growth forest or a rescued coral reef formation, with the natural processes still going on," (ASEAN Centre for Biodiversity, 2010).

Taxa-specific habitat/areas vital for vulnerable life stages	Habitat critical for one or more life history stage of a taxa, such as migratory species or popular charismatic megafauna, where a site may contain habitat required for the continued existence of a species, population, or genetic stock.	The selected taxonomic group might be a suitable focal species. By protecting habitat critical for these species or groups, sympatric species would also be protected, and ecosystem structure and functioning would be maintained. 'Source areas', such as nurseries, spawning areas, nesting beaches, and areas that will receive recruits are critical in the life stages of certain species and have been identified as important for inclusion in site networks (Crowder et al., 2000; Laffoley et al., 2008; IOSEA, 2010).	Areas that are critical habitat for megafauna species might not coincide with areas of high biodiversity value for the maintenance of ecosystems.	Convention on Migratory Species (2007) includes a suite of criteria for the identification of sites of importance to the Siberian crane (*Grus leucogeranus*) with additional importance to other waterbirds, which was adapted from a subset of the criteria employed by the Ramsar Convention to identify wetlands of international importance (Ramsar Secretariat, 2004).

[1] Criterion is a property of a site network, and not necessarily an attribute of an individual site within a network.

[2] The spatial scale identified for application of criteria is imperative, as rare and unique features at a local scale may be typical at a larger scale.

Table 3. Governance and socioeconomic criteria for identifying sites and site networks of relatively high biodiversity value and prioritizing the use of limited resources for conservation.

Criterion	**Definition**	**Rationale**	**Considerations / Constraints / Criticisms**	**Example(s)**
Stakeholder direct involvement	Representatives of all interest groups are directly involved in all aspects of identifying and governing a site or network.	Stakeholders will be more likely to comply with restrictions on their traditional resource use activities if they understand and support the rules. This can be accomplished through direct community involvement in spatial planning and governance (Gilman, 1997, 2002; Pomeroy et al., 2007).	It can be challenging to identify all relevant interest groups and obtain their direct involvement in identifying and managing sites and networks (Gilman, 1997).	The criteria suite for areas to qualify for designation as Biosphere Reserves includes a criterion for providing, "organisational arrangements for the involvement and participation of a suitable range of inter alia public authorities, local communities and private interests in the design and carrying out the functions of a biosphere reserve," (UNESCO, 1995; UNESCO MAB Programme, 2004).
Demonstrated	There is broad political	Support by political leaders	Indices for 'sufficient' political	The criterion 'degree of

political will and leadership to protect ecological, socioeconomic and cultural resources	support among government agencies and leaders of key interest groups to protect individual sites and networks.	and stakeholder groups is necessary to ensure effective allocation of resources for the governance of a protected area (Laffoley et al., 2008), or network of protected sites.	will are needed. Knowledge of historical biodiversity conservation and management activities and efficacy in balancing economic and environmental objectives may be the best indicator of political will for biodiversity conservation.	acceptance', defined as "high potential level of support from stakeholders and political acceptability", is included in the suite for identifying sites for inclusion in the OSPAR Network of MPAs (OSPAR Commission, 2007).
Sustainable financing	Long-term sustainable financing mechanisms are in place for site/network governance.	Effective implementation of governance activities requires funding. Secure financing requires a diverse portfolio of complementary revenue sources (Laffoley et al., 2008).	Different funding mechanisms will be appropriate depending on the type of organization seeking financial assistance, the types of permanent and short-term activities, and whether support is sought for an isolated site, a site within a network, or for network operations.	Alternative national-level funding mechanisms include taxes, levies, surcharges, and tax incentives; tax deduction schemes; grants from private foundations; national environmental funds; debt swaps; national and provincial lotteries; public-good service payments; and workplace donation schemes (Phillips,

				2000). Site-level funding mechanisms include user fees, cause-related marketing, adoption programs, corporate donations, individual donations, planned giving, and site memberships (Phillips, 2000).
Legal and management frameworks in place	Existing governance structures, including traditional knowledge and management systems if relevant, and the conventional governance framework, provide sufficient mechanisms for the protection of a site.	While legal and management frameworks vary for protected areas depending on the local context, from traditional management to government-led management (Christie and White, 2007), the existence of legal and management frameworks that call for adequate protection of a site can determine the effectiveness of future	Documentation of customary governance may not exist. The longevity of the legal protection needs to be consistent with the anticipated duration of threats.	All properties inscribed on the World Heritage List require long-term legislative, regulatory, institutional and/or traditional protection and management (UNESCO, 2008).

		conservation interventions. Customary or traditional approaches might not require legislation.		
Resources for management, surveillance and enforcement	Resources, including for participatory work with local stakeholders to strengthen local stewardship, personnel, equipment and finances, exist to prevent violations of existing laws and rules protecting biodiversity within the site. The size and shape of the individual sites in a network affect enforceability: the smaller the size, the easier to govern, including enforce;	For most protected areas, if resources for enforcement are lacking, efforts to prevent overuse and misuse of resources will not be achieved. Obstacles to effective enforcement include inadequate surveillance due to inaccessibility of portions of a site, inadequate funding for enough enforcement staff and equipment to police the entire site, and a lack of legal mechanisms assigning surveillance and enforcement responsibilities (Laffoley et al.,	While larger protected areas can have higher biodiversity value (Table 1, criterion Size), for instance by supporting a larger number of species, capturing home-range sizes and larval dispersal distances (Laffoley et al., 2008), as size increases, the more difficult and resource intensive it becomes to govern.	Bruner et al. (2001) found direct correlations between enforcement actions and park effectiveness.

	protected sites with designed with straight line edge boundaries can be delineated by lines of latitude and longitude, and are more easily identified by stakeholders.	2008). In areas where customary management systems remain in place, community-based approaches to management and enforcement, including co-management (management through the collaboration of the local community, agencies from all levels of government, NGOs, and potentially additional external organizations) may be appropriate (Gilman, 2002).		
Political will for effective collaborative management of transboundary sites	For proposed transboundary sites, political will exists for requisite cooperation across boundaries between jurisdictions.	Demonstration of political will for the coordinated governance of transboundary sites can ensure effective conservation of resources. In addition to general ecological	Indices for 'sufficient' political will are lacking.	6% of the properties on the World Heritage List are transboundary sites (UNESCO, 2008).

		and governance benefits achieved with site networks, potential benefits of transboundary protected areas include: (i) enhanced conservation and governance of shared resources and biodiversity; (ii) international cooperation for governance, including education, monitoring, management, and enforcement; (iii) cost-effectiveness through coordinated governance activities and expanded financing mechanisms (Sandwith et al., 2001).		
Resources for communication	Sufficient resources are available for communication, education	Communication efforts can augment stakeholder support for protected area rules.	Communication efforts by conservation and resource management organizations	Examples of outreach activities include education kits for tour operators; training

	and outreach.	Education and outreach programs are an investment to bring about changes in behaviour and attitudes by having a better informed community of the value of the coastal and marine environments (Gilman, 2002).	have tended to avoid addressing politically-sensitive root causes of change and loss in global biodiversity – human population growth and distribution, including of impoverished human communities (Gehrt, 1996).	school teachers; developing school curriculums or activity modules for students; constructing boardwalks and interpretive signs; disseminating management information via pamphlets, radio, and television; and developing educational videos (Gilman, 2002; Laffoley et al., 2008).
Compatible existing uses	Current activities are compatible with biodiversity conservation goals.	The likelihood of achieving conservation targets is higher if existing activities are not causing change and loss in prioritized biodiversity components.	Future activities and degree of threat may deviate from current activities and level of threat.	The IOSEA Marine Turtle Site Network includes a criterion for "Socioeconomic Activities, Human Impacts and Risk" that considers whether activities are incompatible with the conservation of marine turtles and their habitat, the goal of the site network (IOSEA,

				2010).
Buffer / Compatible adjacent uses	The site has a degree of insulation from external destructive influences.	Activities occurring in areas adjacent to sites identified as having high biodiversity value can affect the site's biodiversity resources.	Future adjacent activities and degree of threat may deviate from current adjacent activities and level of threat.	The criteria suite for areas to qualify for designation as Biosphere Reserves includes a criterion for zonation that includes buffer zones, "where only activities compatible with the conservation objectives can take place," (UNESCO, 1995; UNESCO MAB Programme, 2004).
Socioeconomic value	The site makes an existing or potential contribution to socioeconomic value by virtue of its protection for recreation, tourism, agricultural production, grazing, water supply, or fisheries production.	Providing opportunities for compatible socioeconomic activities in a multiple use protected area, but effectively excluding activities that are incompatible with ecological conservation objectives, can be critical to achieving community support for the site	A site that is valued due to its support of socioeconomic activities and resources might include activities that are incompatible with conservation objectives. Areas of import to species exploited commercially might not coincide with areas of high	"Social or economic dependency" is included in the criteria suite of the Particularly Sensitive Sea Areas, defined as, "An area where the environmental quality and the use of living marine resources are of particular social or economic importance

	Areas that support commercially exploited species.	(Gilman, 1997). Areas critical for commercially valuable biodiversity might also be critical for ecosystem maintenance. For example, economic incentives to conserve pollinator abundance and diversity support the continued existence of global terrestrial plant life. Declines in animal pollinator populations threaten crop production (Southwick and Southwick, 1992; Klein et al., 2007; Gallai et al., 2009), and threaten global terrestrial plant biodiversity: the majority (an estimated 85%) of wild terrestrial plants relies on	biodiversity value for the maintenance of ecosystems.	including fishing, recreation, tourism and the livelihoods of people who depend on access to the area," (IMO, 2006).

		pollinating species, such that reduced pollinator populations will reduce terrestrial plant biodiversity worldwide (FAO, 2008).		
Educational value	The site provides opportunities for educational and outreach activities.	Education and outreach programs are an investment to bring about changes in behaviour and attitudes by having a better informed community of the value of sites identified as having high biodiversity value. This increase in public knowledge of the importance of a site of high biodiversity value provides the local community with information to make informed decisions about the use of their resources, and	Some educational activities can be incompatible with biodiversity conservation goals (e.g., nature tourism, Boo, 1990).	The criteria suite for the Particularly Sensitive Sea Areas includes the criterion “education”, defined as “An area that offers an exceptional opportunity to demonstrate particular natural phenomena,” (IMO, 2006).

		results in grassroots support for measures to conserve and sustainably manage the site (Gilman, 2002).		
Cultural value	The site contains prehistoric or historic resources of cultural and traditional significance.	The World Heritage Convention links the conservation of sites of natural and cultural value. A site that possesses both ecological and cultural importance may be more likely to be afforded effective protection.	Activities permitted due to the presence of cultural resources may be incompatible with biodiversity conservation objectives.	The criteria suite the Particularly Sensitive Sea Areas includes the criterion “Cultural Heritage”, defined as “An area that is of particular importance because of the presence of significant historical and archaeological sites”, and the criterion “Human Dependency”, defined as an, “An area that is of particular importance for the support of traditional subsistence or food production activities or for the protection of the cultural

				resources of the local human populations” (IMO, 2006).
Research and monitoring value	The site has existing or potential value for research and/or monitoring.	Information obtained through monitoring enables assessments of the performance of management actions and informs adaptive management, and can be a mechanism for involving stakeholders, including local communities (Gilman, 2002).	A sufficiently long time series, of observational data, as well as long-term understanding of management interventions, is critical to separate long-term temporal and spatial trends from cyclical, shorter-term, serially correlated patterns in physical, chemical and biological parameters, and to separate natural and anthropogenic signals (Gilman et al., 2008; Edwards et al., 2010; Gilman and Chaloupka, 2010). This is relevant for understanding trends in species’ distributions and abundance, in particular for	The IOSEA Marine Turtle Site Network includes “research and monitoring significance” as one of a suite of governance criteria (IOSEA, 2010). For sea turtles, an example of long-lived, low-productive species, IOSEA (2010) recognized that anthropogenic mortality of juveniles and subadults may be undetected when monitoring only focuses on adult nesting females (Crouse, 1999) and with insufficiently long data series, and therefore placed a priority on sites with monitoring data series > 20

			populations of long-lived, low-productive species; interactions of species at multiple trophic levels; and patterns in ecosystem structure, processes and landscape position (Kendall et al., 1998; Crouse, 1999; Musick, 1999; Gilman et al., 2008; Edwards et al., 2010).	years and monitoring sea turtle population patterns outside of nesting habitat.