A global map to aid the identification and screening of critical habitat for marine industries

C.S. Martin [a,*], M.J. Tolley [a], E. Farmer [a], C.J. Mcowen [a], J.L. Geffert [a,b], J.P.W. Scharlemann [c], H.L. Thomas [a], J.H. van Bochove [a,e], D. Stanwell-Smith [a], J.M. Hutton [a], B. Lascelles [d], J.D. Pilgrim [e], J.M.M. Ekstrom [e], D.P. Tittensor [a,f,g]

[a] United Nations Environment Programme, World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge CB3 0DL, UK
[b] Department of Geography, University of Cambridge, Downing Place, Cambridge CB3 3EN, UK
[c] School of Life Sciences, University of Sussex, Brighton BN1 9RH, UK
[d] BirdLife International, Wellbrook Court, Girton Road, Cambridge CB3 0NA, UK
[e] The Biodiversity Consultancy Ltd, 3E King's Parade, Cambridge CB2 1SJ, UK
[f] Computational Ecology and Environmental Science, Microsoft Research Cambridge, 21 Station Road, Cambridge CB1 2FB, UK
[g] Department of Biology, Life Sciences Centre, Dalhousie University, 1355 Oxford Street, Halifax, Canada NS B3H 4R2

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ABSTRACT

Marine industries face a number of risks that necessitate careful analysis prior to making decisions on the siting of operations and facilities. An important emerging regulatory framework on environmental sustainability for business operations is the International Finance Corporation's Performance Standard 6 (IFC PS6). Within PS6, identification of biodiversity significance is articulated through the concept of "Critical Habitat", a definition developed by the IFC and detailed through criteria aligned with those that support internationally accepted biodiversity designations. No publicly available tools have been developed in either the marine or terrestrial realm to assess the likelihood of sites or operations being located within PS6-defined Critical Habitat. This paper presents a starting point towards filling this gap in the form of a preliminary global map that classifies more than 13 million km^2 of marine and coastal areas of importance for biodiversity (protected areas, Key Biodiversity Areas [KBA], sea turtle nesting sites, cold- and warm-water corals, seamounts, seagrass beds, mangroves, saltmarshes, hydrothermal vents and cold seeps) based on their overlap with Critical Habitat criteria, as defined by IFC. In total, $5798 \times 10^3 \text{ km}^2$ (1.6%) of the analysis area (global ocean plus coastal land strip) were classed as *Likely Critical Habitat*, and $7526 \times 10^3 \text{ km}^2$ (2.1%) as *Potential Critical Habitat*; the remainder (96.3%) were *Unclassified*. The latter was primarily due to the paucity of biodiversity data in marine areas beyond national jurisdiction and/or in deep waters, and the comparatively fewer protected areas and KBAs in these regions. Globally, protected areas constituted 65.9% of the combined Likely and Potential Critical Habitat extent, and KBAs 29.3%, not accounting for the overlap between these two features. Relative Critical Habitat extent in Exclusive Economic Zones varied dramatically between countries. This work is likely to be of particular use for industries operating in the marine and coastal realms as an early screening aid prior to in situ Critical Habitat assessment; to financial institutions making investment decisions; and to those wishing to implement good practice policies relevant to biodiversity management. Supplementary material (available online) includes other global datasets considered, documentation and justification of biodiversity feature classification, detail of IFC PS6 criteria/scenarios, and coverage calculations.

1. Introduction

The goods and services provided by the global ocean play an integral role in supporting human wellbeing, yet they are coming under increasing pressure from anthropogenic exploitation [1]. Given a future of an increasing human population and synergistic impacts from climate change and other stressors, minimizing the impacts of marine industries is of critical importance if functional marine and coastal ecosystems are to be maintained and sustainable development achieved. Consequently, there is growing political and societal pressure on the users of the marine environment to conduct their operations in a more responsible and sustainable way, and minimise

their risks and impacts through careful evidence-based planning. From a business perspective, the increasing loss of biodiversity, and recognition that industry plays a role in this, is responsible for an increased focus on assessing and managing the biodiversity risks associated with their actions. Avoidance of biodiversity impacts before they occur is the most cost effective and politically straightforward approach to conservation for both industry and financial sectors.

Of critical importance to this process is the development of biodiversity maps, models, assessment methods and tools relevant to the spatial and temporal scales and the social, political and economic contexts within which these industries operate. Unfortunately the number of such effective tools is still very limited. Software to assess the biodiversity and ecological value of terrestrial, freshwater and marine sites, such as the Local Ecological Footprint Tool [2] and the Integrated Biodiversity Assessment Tool [3] exist, but, while pertinent, these are not directly designed for individual environmental policy frameworks. Systematic conservation planning software such as Marxan [4] and MarineMap [5], and ecosystem services mapping tools such as InVEST [6], can be used for spatial planning but similarly do not relate to policy standards. Databases and metrics such as the Ocean Biogeographic Information System (OBIS) [7], AquaMaps [8], the BirdLife marine e-atlas [9], and the Ocean Health Index [10], could potentially feed into such approaches, but are not in and of themselves sufficient.

Part of the reason for this lack of methodologies and tools is the challenge represented by the limited sampling of the oceans [11] and the difficulty of accessing and compiling existing data at regional to global scales. For example, although knowledge of global patterns of biodiversity is available for limited numbers of taxa (e.g. [12]), present understanding is taxonomically and spatially biased, and knowledge of patterns at the fine scales relevant to management implementation remains very limited [13].

A second factor that makes development of methodologies challenging is that there is no obvious way either to select or combine different data layers to generate decision-support tools for industry. Combining data layers can be subjective and result in controversy for both tools and metrics (for example [10,14]). Using international standards [15,16] to define and constrain the selection and integration of data layers can help to address these issues, and results in an approach better tailored to the necessary industry decisions.

The key emerging standard for business is the International Finance Corporation's Performance Standard 6 (IFC PS6) on Biodiversity Conservation and Sustainable Management of Living Natural Resources [17], applicable to certain large-scale development projects financed by the IFC (a member of the World Bank Group) and to project finance $\geq$ $10 million of the 80 financial institutions adopting the Equator Principles [18]. IFC, the largest global development institution focused exclusively on the private sector in developing countries, released revised versions of their eight performance standards in January 2012, following three years of consultation with international experts to improve the requirements. The revised PS6 has rapidly gained recognition within the extractives industry as

a benchmark for biodiversity management and a baseline for assessing potential risks and impacts of activities and structuring mitigation responses [19]. In part or whole, it is beginning to be adopted voluntarily outside of compliance with financial lending requirements [20]. National governments and the conservation community are increasingly backing adoption and implementation of PS6 by industry, such as through the decisions adopted at the Convention on Biological Diversity's 11th Conference of the Parties in 2012 that encourage business to consider IFC's Performance Standards (Decision XI/7, paragraph 2) [21] and, in doing so, infer recognition of IFC PS6 as a credible biodiversity standard. PS6 is becoming established as the key international framework for private sector biodiversity management, currently championed by the extractives sector [20].

Within PS6, high biodiversity value is identified through the concept of 'Critical Habitat', which is based on five criteria and an additional two "scenarios" (named as such in this analysis and detailed in the associated Guidance Note 6 [22]) where these criteria might be applicable (Table 1; Supplementary material Table S1). Critical Habitat is designated when it is of significant importance to certain species, threatened or unique ecosystems, or key evolutionary processes. For development within Critical Habitat, adherents must demonstrate mitigation actions which achieve net gains of biodiversity values for which the Critical Habitat is designated [17].

Under the requirements of IFC's PS6, a Critical Habitat assessment within a defined Discrete Management Unit (DMU) needs to be undertaken to identify the presence of qualifying biodiversity values. The associated guidance document defines a three-step process for this assessment covering (i) stakeholder consultation and literature review, (ii) in-field data collection, and (iii) data analysis and interpretation. Whilst there is a strong focus on the site-specific field research element of such an assessment to ensure that the in situ presence of biodiversity values is accurately recorded, the relevance of desktop analyses, in particular with reference to assessing the relative biodiversity conservation importance and distinctiveness of a site at a regional or global scale, is also highlighted.

Currently no publicly available tools have been developed in either the marine or terrestrial realms to assess the likelihood of sites or operations being located within PS6-defined Critical Habitat, although broadly-applicable methods have been developed during local-scale environmental impact assessments and PS6 adherence requirements (e.g. [23,24]). The map presented herein uses global biodiversity data layers with the aim of supporting businesses in the identification of biodiversity features relevant to Critical Habitat criteria, and therefore of significance to the development of mitigation strategies. Whilst global-scale data alone are insufficient to map Critical Habitat comprehensively, mitigation planning (particularly avoidance of impacts) is often necessary early on in the project lifecycle (before or just after investment) prior to on the ground access to conduct detailed field surveys. A key reason behind the development of the approach described herein is that, pragmatically, companies benefit from biodiversity information about sites in advance of having on-ground access.

Table 1

Critical Habitat designation under the International Finance Corporation's Performance Standard 6 (IFC PS6) is based on five criteria and an additional two scenarios where these criteria might be applicable. See [17,22] and Supplementary material Table S1 for further detail. For full details on alignment of the selected biodiversity data layers with criteria/scenarios, see the Supplementary material Appendix S2. 'Critically Endangered'/'Endangered' species: as listed in [31].

IFC PS6 criteria and scenarios	Description
Criterion 1	Habitat of significant importance to Critically Endangered and/or Endangered species
Criterion 2	Habitat of significant importance to endemic and/or restricted-range species
Criterion 3	Habitat supporting globally significant concentrations of migratory species and/or congregatory species
Criterion 4	Highly threatened and/or unique ecosystems
Criterion 5	Areas associated with key evolutionary processes
Scenario A	Other recognized high biodiversity values that might also support a Critical Habitat designation
Scenario B	Internationally and/or nationally recognized areas of high biodiversity value that in general will likely qualify as Critical Habitat

This paper therefore provides a global map of Critical Habitat that can be used to help minimise environmental risks and impacts, and related costs to industry of their management, through an early warning of where potential issues may be encountered. The approach used involved assessing global marine and coastal biodiversity and ecological datasets against PS6 criteria for Critical Habitat, and using these assessments to build a global layer intended to inform environmental specialists and help guide site-level biodiversity assessments. Although the target audience is currently dominated by marine extractive industries such as oil and gas and mining, the approach is also broadly applicable to other marine industries. Furthermore, it will be of use to financial institutions wishing to assess projects and potential investments at an early stage.

2. Materials and methods

2.1. Biodiversity data layers

An initial screening for available global data layers relevant to marine and coastal biodiversity identified over 50 datasets to be considered for potential inclusion into the Critical Habitat map (Supplementary material Appendix S1). Assessment of the data layers led to the selection of eleven biodiversity-related features (Table 2; 13 associated data layers) which met three key criteria: (i) direct relevance to one or more IFC PS6 Critical Habitat criteria/ scenarios, (ii) global extent, and (iii) the best available data of those identified for the purposes of this approach. Data layers were in vector (point, line and polygon) and raster formats. The datasets identified biodiversity relevant features through (i) (empirically) *observed* occurrence (e.g. sea turtle nesting sites, warm-water coral reefs, seagrass beds, mangroves, saltmarshes, hydrothermal vents, cold seeps), (ii) *modelled* occurrence (seamounts), (iii) both *observed* and *modelled* occurrence (cold-water corals), (iv) biodiversity governance designations such as internationally or nationally recognized protected areas and (v) sites of particular importance for biodiversity identified on the basis of

known occurrence of species of conservation interest (KBAs, including Important Bird and Biodiversity Areas [IBAs] and Alliance for Zero Extinction site [AZEs]). The overwhelming majority of KBAs currently identified in the marine realm are IBAs; further information on KBAs, IBAs and AZEs can be found in Supplementary material Appendix S2.

2.2. Data processing and analysis

An analysis mask covering all oceans was created and used to standardise all the biodiversity data layers to rasters (i.e. grids) of 1 km cell size in a cylindrical equal-area projection. Such a fine spatial resolution did not reflect the native resolutions of the data layers, which were generally much coarser, but allowed better preservation of contours and shapes at the local-scale, notably for polygon vectors. The 1 km spatial resolution represented the minimum-mapping-unit (MMU) of the analysis. It was applied to ensure that point features achieved a MMU and therefore had a spatial extent. This was necessary as, without such a definition, biodiversity features provided as points and known to have some spatial footprint would be represented as infinitesimal features. A MMU was also required to account for spatial inaccuracies within the data and to the frequent lack of hard ecological boundaries. The shoreline from the Global Self-consistent, Hierarchical, High-resolution Geography database (GSHHG version 2.2.2, January 2013; [25]) was used to create a "sea" mask, to which a 2 km coastal strip of land was added. The coastal strip was for the purpose of capturing biodiversity features such as sea turtle nesting sites, bird nesting sites (through the IBA subset of KBAs), mangroves and saltmarshes; the 2 km distance was selected as a conservative threshold for such sites. Based on this analysis mask, each biodiversity data layer was converted to a continuous raster layer of identical resolution and projection. During the conversion from vector to raster, a cell was coded as containing a biodiversity feature if any part of that feature overlapped the given cell, regardless of surface area coverage. This prevented information loss for very small polygons and points.

Table 2

Marine and coastal biodiversity features used to map Critical Habitat globally, and their overlap with the IFC PS6 criteria/scenarios used to define Critical Habitat (CH). See Supplementary material Appendix S2 for more complete details. 'Vulnerable'/'Critically Endangered' species: as listed in [31]; ~: Potential Critical Habitat; ✓: Likely Critical Habitat. Polygon versus point vector proportions are given for the global datasets, i.e. including the terrestrial component (e.g. KBAs, protected areas).

Biodiversity features		Data sources	Native format(s)	Trigger(s)	IFC PS6 criteria/ scenarios for Critical Habitat							Classification
					1	2	3	4	5	A	B	
Key biodiversity areas		[40]	Point (7.4%)/polygon (92.6%)	Triggered by Vulnerable species only							~	Potential CH
				Other than above	~	~	~				✓	Likely CH
Protected areas		[41]	Point (10.6%)/polygon (89.4%) (WDPA August 2013 release)	IUCN management categories Ia, Ib and II; Ramsar and World Heritage sites							✓	Likely CH
				IUCN management categories III-VI, not-reported, not-specified							~	Potential CH
Sea turtle nesting sites		[42]	Line	Critically Endangered species	✓		~	~				Likely CH
				Other than above			~	~				Potential CH
Cold-water corals	Stony	[43]	Point	Observed occurrence				✓		✓	~	Likely CH
		[44]	Raster	Modelled occurrence (probability > 90%)				~		~	~	Potential CH
	Soft	[43,45]	Point	Observed occurrence				~		~	~	Potential CH
		[45]	Raster	Modelled occurrence (probability > 90%)				~		~	~	Potential CH
Warm-water coral reefs		[46]	Polygon	Observed occurrence			✓	✓	✓	~		Likely CH
Seamounts		[37]	Point	Modelled occurrence				~		~	~	Potential CH
Seagrass beds		[47]	Point (18.0%)/polygon (82.0%)	Observed occurrence				✓				Likely CH
Mangroves		[48]	Polygon	Observed occurrence		~	✓			~	~	Likely CH
Saltmarshes		[49]	Point (0.2%)/polygon (99.8%)	Observed occurrence			✓				~	Likely CH
Hydrothermal vents		[50]	Point	Observed occurrence	✓			✓	✓	~		Likely CH
Cold seeps		[51]	Point	Observed occurrence		~		✓	✓	✓	~	Likely CH

2.3. Classification scheme

A classification scheme was established to reflect the alignment of biodiversity features with IFC PS6 Critical Habitat criteria and additional scenarios (Table 1 and Supplementary material Table S1), as well as degree of certainty in the data layers (Fig. 1), more specifically, the level of confidence in the actual occurrence on the ground of biodiversity features represented in the data layers. A clear alignment with one, or more, IFC PS6 Critical Habitat criteria and high certainty in the biodiversity data indicated that an area was very likely to qualify as Critical Habitat under IFC PS6. Such areas were therefore classified as *Likely Critical Habitat,* and coloured 'red' on the map. If features aligned to some extent with PS6 Critical Habitat criteria, but the degree of alignment was less clear or the confidence in the biodiversity data was lower, these areas were classified as *Potential Critical Habitat* and mapped using an 'orange' colour. Lower confidence in data occurred when using occurrence predictions from model outputs (i.e. cold-water corals). Remaining areas were left *Unclassified* and marked using a 'grey' colour to reflect two situations: first, data paucity and uncertainty (common in the marine realm), and, second, areas with reasonable biodiversity data but without features aligned with the PS6 Critical Habitat criteria.

Each of the eleven biodiversity data layers was independently assessed for data quality and alignment with IFC PS6 Critical Habitat criteria, and classified as Likely Critical Habitat and/or Potential Critical Habitat (Table 2). Four biodiversity features (KBAs, protected areas, sea turtle nesting sites and cold-water corals) contained both Likely and Potential Critical Habitat, due to the use of multiple
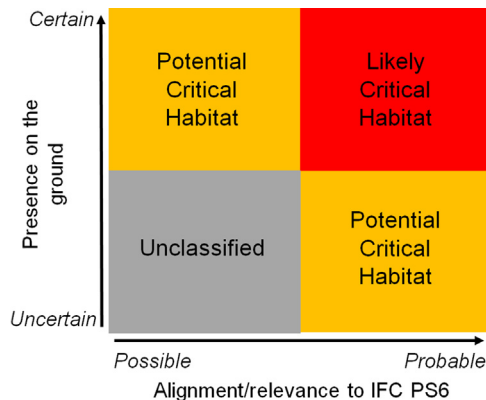

Fig. 1. Classification scheme developed to reflect biodiversity data layer alignment with IFC PS6 Critical Habitat criteria/scenarios and inherent degree of certainty.
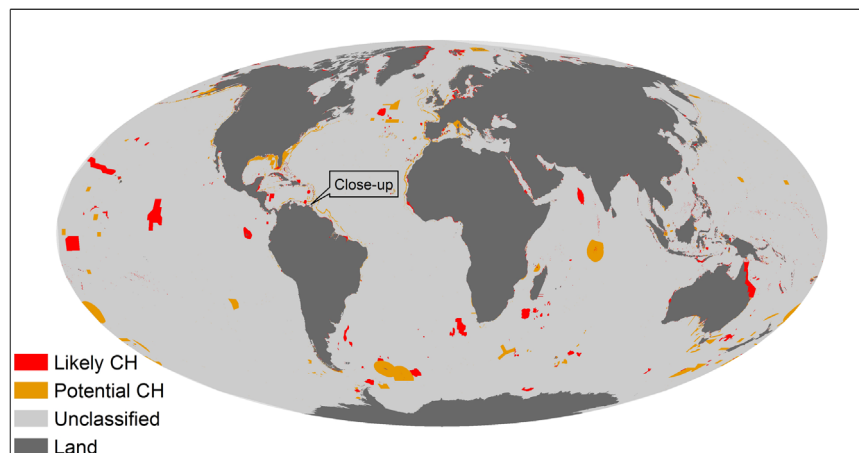
triggers within the individual datasets to identify the presence of sites or features, some of which were related to the IFC PS6 Critical Habitat criteria. For species distribution models (namely soft and stony cold-water corals), a very high threshold ($> 90\%$) of habitat suitability was chosen to determine occurrence areas. Areas exceeding this threshold were labelled Potential Critical Habitat (due to data uncertainty), rather than Likely Critical Habitat. Full documentation and justification of classification decisions can be found in Supplementary material Appendix S2.

It is important to recognise that, within the approach detailed here, Critical Habitat was only assessed at the global level and biodiversity features were considered on the basis of their global significance, not at the local, national, or regional scales. Assessments of the significance of certain habitats at a regional scale could heighten alignment with Critical Habitat criteria and move them from 'Potential' to 'Likely' Critical Habitat. In contrast, some features that trigger the Likely Critical Habitat designation in a global assessment may be found to be common or unthreatened at a local scale.

2.4. Global map of IFC PS6 Critical Habitat

A global map of Likely and Potential Critical Habitat was produced by combining all classified biodiversity data layers into one composite layer, in which the highest designation or 'warmest' colour (in order, red, orange, grey) was retained for each cell. Critical Habitat designation across main geographical divisions (coastal land strip, Exclusive Economic Zones [EEZs], marine Areas Beyond National Jurisdiction [ABNJ]) was investigated based on a boundary dataset for EEZs maintained by the Flanders Marine Institute [26]. A similar analysis was carried out against bathymetric contours using GEBCO data [27]. These two analyses aimed at describing changes in Critical Habitat extent in both the horizontal (political boundaries) and vertical (bathymetric contours) directions, to gain a better understanding of its three-dimensional distribution across the analysis area.

3. Results

3.1. The global and regional maps

A global Critical Habitat map (Fig. 2) was generated from the eleven biodiversity features listed in Table 2, which were identified as meeting one or more of the Critical Habitat criteria/ scenarios detailed in IFC PS6 (and associated Guidance Note 6). A total of 5798×10^3 km^2 of the analysis area (1.6%) was classified as

Fig. 2. Global map of marine and coastal areas classified as Potential (orange) and Likely (red) Critical Habitat (CH) under IFC PS6 criteria, based on available and relevant global datasets. Unclassified zones are shown in the lighter shade of grey.

Likely Critical Habitat and 7526×10^3 km^2 (2.1%) as Potential Critical Habitat (feature-specific surface areas are given in Supplementary material Table S2). The remainder was Unclassified ($349,576 \times 10^3$ km^2; 96.3%).

The most dominant triggering features for Likely/Potential Critical Habitat were protected areas (comprising 65.9% of the combined Likely and Potential Critical Habitat extent) and KBAs (comprising 29.3%) (Supplementary material Table S3). Protected areas contributed to 16.6% of the Likely Critical Habitat extent, and to 49.3% of the Potential Critical Habitat extent; corresponding figures for KBAs were 28.6% and 0.7%, respectively. The other main determinants of the composite Critical Habitat map were cold-water corals (contributing to 7.4% of the Critical Habitat extent, primarily the model outputs for soft corals ranked as Potential Critical Habitat), followed by warm-water coral reefs (3.6%, all Likely Critical Habitat), seagrass beds (3.0%, all Likely Critical Habitat) and mangroves (2.1%, all Likely Critical Habitat), the latter two figures being consistent with their relatively small global footprints. Biodiversity data layers that were spatially represented as point and line vectors such as sea turtle nesting sites, sea-mounts, hydrothermal vents, and cold seeps had only minor spatial influences (contributing to less than 2% of the combined Likely and Potential Critical Habitat extent in total) on the global composite map, but were important in Critical Habitat determination within individual regions. Overlap occurred between the datasets used when locations were covered by more than one represented biodiversity feature (e.g. many KBAs are also protected areas) and due to the working spatial resolution of 1 km. The figures given do not take into account these overlaps between the various features.

The significance of the different biodiversity features to the identification of Critical Habitat is illustrated at finer scales through a more detailed view of individual regions. For example, in the Caribbean (Fig. 3), multiple features triggering Likely/Potential Critical Habitat are present. In this selected example, eight of the eleven Critical Habitat biodiversity features are represented (KBAs, protected areas, sea turtle nesting sites, cold-water corals, warm-water coral reefs, seagrass beds, hydrothermal vents and cold seeps).

3.2. Results within political boundaries and depth regions

The distributions of Likely and Potential Critical Habitat were geographically uneven, with 44% of the 'coastal land strip' identified in the Critical Habitat map, and 7% of the EEZs, while most marine ABNJ were Unclassified (Fig. 4). Most EEZs were found to contain Likely/Potential Critical Habitat, with the relative extent varying vastly between EEZs (Supplementary material Table S4 gives a full listing). For example, 11% of the Australian EEZ was classed as Potential/Likely Critical Habitat, this figure reaching 26% for the USA, 32% for France, and 74% for South Georgia. Such country-specific high-level information is likely to be of use to businesses considering new country access or planning new developments and needing to be aware of possible sensitivities linked to biodiversity.

The distributions of Likely and Potential Critical Habitat against bathymetric contours were uneven, with shallower waters (0–6000 m) containing comparatively more Potential/Likely Critical Habitats than deeper areas (Fig. 5). Feature-specific depth distributions are given in Supplementary material Fig. S12. Deeper contours cover smaller surface areas than shallower ones, and thus Critical Habitat extent relative to this will tend to be greater in the deep sea.

4. Discussion

The alignment of biodiversity features with the Critical Habitat criteria in IFC PS6 provides a useful categorisation tool for companies to avoid, minimise, restore and offset environmental impacts across
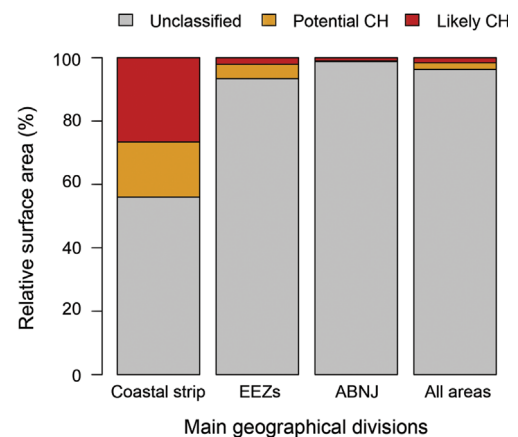
Fig. 4. Relative surface areas of Potential (orange) and Likely (red) Critical Habitat (CH) and Unclassified zones (grey) under IFC PS6 criteria, for main geographical divisions. 'Coastal (land) strip': a band of land of 2 km width running along the coastline (see text for details); EEZ: Exclusive Economic Zone; ABNJ: marine Areas Beyond National Jurisdiction.
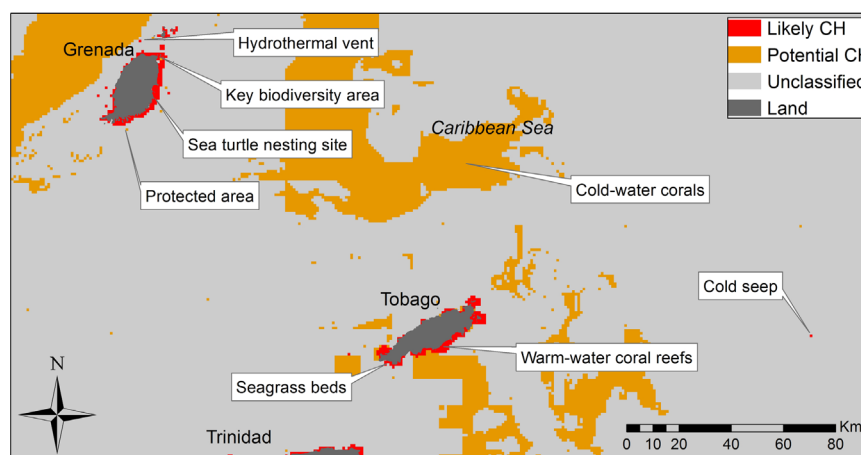
Fig. 3. Close-up of Fig. 2 showing the south-eastern Caribbean region and highlighting relevant biodiversity features present in this area. Eight biodiversity features relevant to marine Critical Habitat are present (i.e. all except seamounts, mangroves and saltmarshes). CH: Critical Habitat.
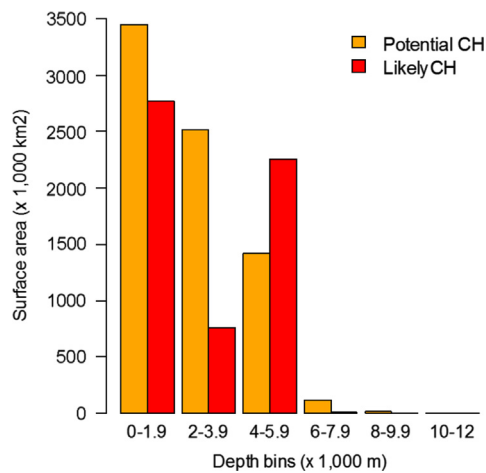
Fig. 5. Surface areas of Potential (orange) and Likely (red) Critical Habitats (CH) for each 2000 m bathymetric contour.

current and future operating sites. This study used large-scale biodiversity datasets and aligned them against the criteria defined in IFC PS6 to provide a global map of marine and coastal Critical Habitat, covering more than 13 million km². Compared to the extent of the global oceans, the extent of Likely and Potential Critical Habitat was not extensive, being 1.6 and 2.1% respectively. This will be an underestimate of the total, due to both the paucity of biodiversity data, and to the limited identification of biodiversity features and delineation of sites representing biodiversity value in areas beyond national jurisdiction [11]. In contrast, Critical Habitat covered higher proportions of the EEZs (7%) and the coastal land strip (44%), where field sampling is less operationally challenging and more cost-effective and has therefore resulted in greater availability of data. At the global scale, protected areas and KBAs in total constituted 65.9% and 29.3% of Critical Habitat extent (with some overlap between the two), consistent with the significance of these features to Critical Habitat identification, as well as the extent to which they have been mapped and the large areas covered by these designations. A number of EEZs (e.g. Monaco, Mayotte, British Indian Ocean Territory, Slovenia) showed almost 100% Critical Habitat classification coverage, due to two (sometimes interlinked) factors: the presence of large protected areas and/or the relatively small size of the EEZ (e.g. as often occurs with short coastlines).

Three broad challenges were faced when using global data to identify Critical Habitat: (i) data availability; (ii) data limitations; and (iii) accurate alignment of the data to IFC PS6 Critical Habitat criteria.

4.1. Data availability

Currently, and in comparison to the terrestrial realm, availability of marine biodiversity data remains limited. As mentioned above, from a spatial perspective there is an issue with the lack of data in marine ABNJ and in the deep sea, due to the paucity of sampling effort in these regions. This needs to be remedied in order to improve the usefulness of this map for companies acting in marine ABNJ, though it remains an extremely challenging task due to the expense and difficulty of sampling these areas. As extractives companies are increasingly developing the technology needed to exploit at greater depths, it is clearly important to acquire and provide biodiversity data from deeper areas of the ocean. Expansion of industries such as deep-sea mining into these regions is anticipated in the near future [28]. In the medium-term, global data layers of Vulnerable Marine Ecosystems (VMEs) [29] and Ecologically or Biologically Significant Areas (EBSAs) [30] may

become available, which would help to reduce this limitation at a broad scale.

Beyond the geographic bias, there is also a realm bias that is associated with the distribution of biodiversity data in the oceans versus the land. For example, from more than 70,000 plants and animals currently listed on the IUCN Red List of Threatened Species [31], only 8171 (11%) are marine, a figure representing 0.37% of the estimated 2,210,000 marine species on the planet [32]. Current spatial and biodiversity data on marine species is biased to well-studied, economically important and charismatic taxa (e.g. marine mammals, seabirds, warm-water corals, mangroves, seagrass beds, marine reptiles, selected fish families, and sea cucumbers) and, as a consequence, there is a bias in the groups assessed for the Red List (although ongoing initiatives by IUCN and its partners are working to address this issue). However, many of these species are indicators of the broader marine environment (e.g. [33]) or keystone species (e.g. [34]), play an important functional role (e.g. [35]) or are 'ecosystem engineers' that provide biogenic habitat (e.g. [36]). Using information on these species may thus provide proxies for key areas and habitats for associated species, and therefore be of significant utility for decision-support. Furthermore, as databases such as OBIS [7] and AquaMaps [8] continue to grow and synthesise observational biodiversity information, they will help to ease these constraints.

4.2. Data limitations

Global data layers provide a starting point for identifying Critical Habitat features but on the ground surveys are crucial to a thorough assessment to determine the presence or absence of Critical Habitat unambiguously. Since known presence of biodiversity features on the ground is important for identification of Critical Habitat, data limitations need to be clearly understood. Data that had an elevated level of uncertainty associated with identifying actual occurrences on the ground were classified as 'Potential' rather than 'Likely' Critical Habitat (Fig. 1). The main distinction used to separate data layers along this axis was whether they were (i) modelled, or (ii) empirically observed occurrences; the former were classed as lower certainty, and the latter as higher. Whilst the best available data was used in this analysis, the currency, i.e. age, of the datasets was not used as criteria in the data selection process. However, data currency is likely to affect the probability of an area continuing to support Critical Habitat features. It is hence essential to consider the currency of any individual dataset in interpretation of the map.

One key data limitation is that all datasets used in this study are likely to have errors of commission and/or omission. Some of the polygon (i.e. boundary) data used for several biodiversity features (e.g. seagrass beds, mangroves) may show the limits of distribution in a given area, rather than the actual fine-scale locations at which a species actually occurs. Hence within individual polygons, there may be areas from which a feature will be absent (commission errors). Similarly, the 1 km grid size used in the global map is not the native resolution of the data layers. There are thus likely to be commission errors due to the overestimation of biodiversity-relevant features at this spatial scale.

In contrast, point data (e.g. 11% of protected areas, 7% of non-IBA KBAs, and other data identified in Table 2) often depicted the centroid of an area for which polygon delineation was unavailable (omission errors). This is also true for those habitats that are difficult to sample and hence remain widely undersampled, such as deep-water vents and seeps. Similarly, KBA boundaries are currently available only for limited numbers of taxonomic groups (resulting in omission errors); only the IBA subset (for birds) is fully consistent globally.

Habitat suitability models (cold-water corals, seamounts) are useful in that they predict probability of occurrence including for those areas where dedicated field surveys have not yet taken place, by relating known presence points to predictive environmental or biotic variables. However, they are likely to contain errors of both commission and omission. Exhaustive ground-truthing of such datasets is generally not realistic, meaning that the certainty of the occurrence of the modelled species or habitat in any area cannot be absolute. Using a high habitat suitability threshold (> 90%) for the cold-water coral species distribution models used in this analysis minimised commission errors for those layers. Other modelled outputs, such as seamount locations, are also susceptible to methodological limitations [37].

4.3. Data alignment with IFC PS6 Critical Habitat criteria

The Critical Habitat criteria are well defined in IFC's PS6 [17] and associated Guidance Note 6 [22], but alignment of data layers with those criteria is not always straightforward. For each of the eleven biodiversity features used in this study, clear scientific justifications for alignment with IFC PS6 criteria (and the additional two scenarios) for Critical Habitat are given in Supplementary material Appendix S2.

For the species-relevant criteria (Criteria 1–3; Table 1 and Supplementary material Table S1), numerical thresholds and clear sub-criteria are used within PS6 and GN6, which have been based on international conservation approaches and definitions, and hence support the process of data alignment; for example, Tier 1 of Criterion 1 identifies areas required to sustain $\geq 10\%$ of the global population of an IUCN Red-listed Critically Endangered or Endangered species [...]. Sufficient knowledge of species in terms of occurrence and abundance is, however, almost never available to identify perfectly areas which meet the numerical thresholds. For example, whilst 6755 (83%) of the 8171 marine species assessed under the IUCN Red List criteria have associated range maps [31], these maps do not present abundance data (i.e. number of individuals per unit of surface area or volume) or ontogeny information, which makes them difficult to align with the quantitative thresholds listed under Criteria 1–3. Also, the IUCN Red List range maps portray the limits of species distribution but do not imply that a species occurs, or is evenly distributed, throughout the range. Therefore, although the IUCN Red List of Threatened Species is one of the best available global sources of information on species distribution and threat status, it requires further manipulation or interpretation to align with Critical Habitat criteria and thresholds: for example via methods outlined by [23].

Species-level information in the current methodology was in part incorporated through the use of sites identified as important for species conservation such as KBAs, some of the quantitative thresholds and criteria of which were used by IFC to define individual tiers of Critical Habitat criteria. These designations, however, tend to be much better represented terrestrially than in the marine realm. IUCN's evolving approach to KBAs, intended to create a globally agreed standard identifying "areas that contribute significantly to the global persistence of biodiversity" [38] should also help to identify sites meeting the Critical Habitat definition and aligned with the thresholds and descriptions used for each criterion. As the methodology for this approach is still in development, a revised spatial dataset developed using the new approach is not yet available, although many areas that will be represented are already included in the current KBA dataset and in data included in this analysis. As the inclusion of species data is limited in this approach, the map presented provides a much better representation of areas meeting Criteria 4 and 5 of Critical Habitat identification as opposed to Criteria 1–3.

Critical Habitat Criteria 4 and 5, identifying highly threatened and/or unique ecosystems and areas associated with key evolutionary processes (Table 1 and Supplementary material Table S1), are less distinct in definition and therefore more open to scientific interpretation in terms of the ecology and conservation status of the biodiversity features. They thus require more detailed scientific justification in aligning biodiversity features with the criteria. However, as they do not have associated thresholds (in contrast to Criteria 1–3), they are easier to map, although available marine information generally has a coastal bias. Global maps of warm-water coral reefs, mangroves, saltmarshes, seagrass beds, hydrothermal vents, cold seeps, and modelled distributions of seamounts and cold-water corals provided the ability to spatially locate many unique and/or threatened ecosystems (Criterion 4) and sites associated with key evolutionary processes (Criterion 5).

Current knowledge regarding marine species, the distribution of marine habitats and the locations of key evolutionary processes, is far from complete. For example, a range of locations known to be of importance to marine species, such as sites of breeding aggregations, have yet to be accurately and consistently identified and compiled at a global scale, and represent a gap in knowledge and therefore contribute to the extent of Unclassified areas of marine Critical Habitat in this current approach. Continuing to compile these datasets at large scales would be a valuable exercise to support identification and mitigation of potential impacts from industry. One example of a work in progress for ecosystem classification that would contribute to the spatial identification of areas meeting Criterion 4 of Critical Habitat (and is referenced by IFC in GN6) is the IUCN Red List of Ecosystems [39].

In addition to the five criteria laid out in IFC PS6 for Critical Habitat, there are two additional scenarios (named in this analysis as Scenarios A and B), identified in Guidance Note 6 [22], where Critical Habitat is likely to occur. Scenario A allows for the inclusion of significant biodiversity values that may not have been captured in the descriptions and thresholds of the criteria; for example, areas containing concentrations of species new and/or little known to science. Whilst a number of data layers used in the composite Critical Habitat map reflected features given in Guidance Note 6 as examples meeting Scenario A, they also triggered one or more of the five main criteria. None of the datasets considered fell solely under this scenario.

Under Scenario B, Guidance Note 6 identifies certain protected area categories and designations as likely qualifying as Critical Habitat and others as potentially meeting the Critical Habitat criteria dependent on the biodiversity values present at those individual sites (see Supplementary material Table S1). Other protected area categories not specifically referenced in Guidance Note 6 as qualifying as Critical Habitat (in effect any protected area not designated as IUCN management category Ia, Ib or II, UNESCO World Heritage sites, or Ramsar Wetlands of International Importance) were also included in this analysis in the Potential Critical Habitat layer due to the possibility of these sites also hosting appropriately high biodiversity values.

4.4. Future developments and refinements

With increasing attention given to IFC's definition of Critical Habitat, alignment of available spatial data with the criteria is clearly a useful exercise to support Critical Habitat assessments. Expansion of this approach beyond the marine realm to create a global map which also identifies terrestrial Critical Habitat is desirable. Despite the greater availability of public mapping and ecosystem assessment tools for terrestrial systems, none as yet specifically targets Critical Habitat identification, although methods have been developed through individual project assessments in the terrestrial realm. Data are likely to be more readily available for

terrestrial systems, so global mapping of possible terrestrial Critical Habitat is indeed feasible. Nonetheless, ensuring consideration of all relevant data is likely to be a more complicated task since a much greater array of global biodiversity datasets exists than in the marine realm. This also clearly highlights the need to support marine sampling efforts to generate further biodiversity information and spatial data to create a more comprehensive marine Critical Habitat map, addressing omissions due to data paucity.

An important approach to maximise the utility of the map developed here would be its link to existing screening tools specifically offered to industry and currently used to support the identification of Critical Habitat features. For example, the Integrated Biodiversity Assessment Tool (IBAT) [3] brings together key site-based designations for biodiversity (many used within this analysis) and species information in a portal specifically designed for private sector use. In recognition of the value of IBAT to Critical Habitat screening, the tool is currently being developed to provide report outputs specific to information provision for Critical Habitat assessments. It would therefore be valuable to build on the utility of IBAT to present the spatial map developed here for Critical Habitat, which includes additional data layers not available in the IBAT portal. The advantage of presenting the map through an online tool (rather than as a static data layer) is that it could accommodate regular updates to datasets (such as the World Database on Protected Areas [41]) through revising individual data layers and re-creating the composite Critical Habitat map. A web-based approach would allow this process to be kept up-to-date by querying the latest versions of datasets within the areas of interest and returning live results.

5. Conclusions

IFC's definition of Critical Habitat provides a mechanism for industries to identify biodiversity values under defined criteria, and reflects many approaches currently used by the conservation sector. The map presented here shows that existing global biodiversity datasets can be interpreted within the context of IFC PS6 Critical Habitat criteria, and areas of Likely or Potential Critical Habitat can be identified at a scale relevant to industry, enabling early warning when planning the siting of facilities or operations. The map was developed with the intent of adhering as closely as possible to the IFC PS6 definitions and associated guidance for Critical Habitat criteria. Although there remain substantial data limitations and uncertainties, this process has helped to identify such gaps. Facilitating the easy access of industry to biodiversity information directly linked to relevant environmental regulation has the potential to positively affect biodiversity management in the marine environment.

Acknowledgements

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2014.11.007.

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