Identification of important marine areas using ecologically or biologically significant areas (EBSAs) criteria in the East to Southeast Asia region and comparison with existing registered areas for the purpose of conservation

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Abstract

The biodiversity of East to Southeast (E–SE) Asian waters is rapidly declining because of anthropogenic effects ranging from local environmental pressures to global warming. To improve marine biodiversity, the Aichi Biodiversity Targets were adopted in 2010. The recommendation of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), encourages application of the ecologically or biologically significant area (EBSA) process to identify areas for conservation. However, there are few examples of the use of EBSA criteria to evaluate entire oceans. In this article, seven criteria are numerically evaluated to identify important marine areas (EBSA candidates) in the E–SE Asia region. The discussion includes 1) the possibility of EBSA criteria quantification throughout the E–SE Asia oceans and the suitability of the indices selected; 2) optimal integration methods for criteria, and the relationships between the criteria and data robustness and completeness; and; 3) a comparison of the EBSA candidates identified and existing registered areas for the purpose of conservation, such as marine protected areas (MPAs). Most of the EBSA criteria could be quantitatively evaluated throughout the Asia-Pacific region. However, three criteria in particular showed a substantial lack of data. Our methodological comparison showed that complementarity analysis performed better than summation because it considered criteria that were evaluated only in limited areas. Most of the difference between present-day registered areas and our results for EBSAs resulted from a lack of data and differences in philosophy for the selection of indices.

Keywords

Ecologically or biologically significant area (EBSA), East Asia, Southeast Asia, West Pacific ocean, Complementarity, Gap analysis,

Highlights’

-Most EBSA criteria could be quantitatively evaluated in the Asia-Pacific region

-Complementarity analysis outperformed summation for integrating results

-Most gaps between existing areas registered for the purpose of conservation and selected important areas resulted from a lack of data

1. Introduction

The marine region from East Asia to Southeast Asia (E–SE Asia) is well known as a hot-spot for biodiversity [1,2]. It is also recognized as a region containing various habitats characterized by high species richness and an abundance of habitat-forming species such as seagrass, mangroves, and coral reefs [3–6]. Although the importance of the ecosystem services provided by marine biodiversity has been demonstrated by research projects at local to global scales, degradation of marine biodiversity is ongoing because of anthropogenic impacts such as population increase, overfishing, destructive land use, and the effects of climate change [7,8]. For example, a study of the current status of the ocean environments reported that the cumulative effects of human impacts are accelerating the decline of marine biodiversity in coastal areas, especially in the Asia-Pacific Ocean, which includes East and Southeast Asia [9]. Most of East Asia and the northern part of Southeast Asia is considered a high priority area for marine biodiversity conservation efforts considering the region's richness, high levels of species endemism, and human impacts [4].

Although there are several ways of the managing marine areas, the establishment of marine protected areas (MPAs) is one of the common processes of environmental conservation. The 10th meeting of the Conference of the Parties to the Convention on Biological Diversity 2010 (CBD COP10) adopted the Aichi Biodiversity Targets[10], including the goal of establishing 10% of the global ocean as MPAs in a broad sense. To select candidate areas of those managed it is ideal to choose from areas of particular importance for biodiversity and ecosystem services[10]. In 2008, the CBD COP9 adopted seven scientific criteria for identifying ecologically and biologically significant areas (EBSAs); the criteria were modified from the Fisheries and Oceans Canada EBSA guidelines to identifying EBSAs in need of protection in open-water and deep-sea habitats (UNEP/CBD/COP/DEC/IX/20). In 2010, COP 10 noted that application of the EBSA criteria is a scientific and technical exercise, that areas found to meet the criteria may require enhanced conservation and management measures, and that this can be achieved through a variety of means, including establishing MPAs and conducting impact assessments [11,12].

Identifying EBSAs is a useful tool for selecting areas deserving of protection while allowing sustainable activities to continue. Such areas provide important services to one or more species or populations in an ecosystem or to the ecosystem as a whole, compared with surrounding areas or areas of similar ecological characteristics. The 11 regional workshops on EBSAs, convened by the executive secretary of the CBD, have been held since 2011 and cover the following regions: western South Pacific, wider Caribbean and western Mid-Atlantic, Southern Indian Ocean, eastern tropical and temperate Pacific, North Pacific, southeastern Atlantic, Northwest Indian Ocean and adjacent Gulf areas, Northeast Indian Ocean Region, Mediterranean Region, northwest Atlantic, Arctic region and East Asia [13]. There have been examples of where the EBSA criteria have been applied to a local environment or a specific habitat to assess the situation at that time [14–18]. However, much of the discussion has concerned progress at specific sites selected on the basis of expert opinions; because of limitations in knowledge, data, and publications it has not covered the entire spatial extent of the subject regions.

The Ministry of the Environment, Japan, has collected data on the distribution of species throughout the Japanese archipelago and has applied the EBSA criteria to those data. This extensive effort and data collection enables the selection of important areas throughout this region with comparable methodology. In parallel with the government investigation, a research project for the integrated observation and assessment of biodiversity loss in a changing ocean was started following CBD COP10. This project is part of a research program called Integrative Observations and Assessments of Asian

Biodiversity, promoted from 2011 to 2015 by the Strategic Projects, S-9, of the Environment Research and Technology Development Fund of the Ministry of the Environment, Japan. This project collected data and then established a protocol for evaluating a wide geographic area by using EBSA criteria and applied it to kelp ecosystems in Hokkaido, Northern Japan as a case study [19]. The present study is an application of this protocol to the vast E–SE Asia Region. Important areas were identified according to the EBSA criteria by using as much data on species occurrence and habitat conditions as were available from databases and the literature.

To use the results of our analyses based on regional workshops for more efficient policy formulation it is important to compare present-day MPAs, fishery regulations and proposed EBSAs (CBD-EBSA) in our proposed important area by using EBSA criteria systematically (EBSA candidate). In this paper, the gaps between these different types of areas are discussed. Although there are more data than simple extraction of the data from the data base and it is substantially more or similar to the data provided to the regional EBSA workshop, the data coverage in the study area is limited compared with that in previous studies conducted in Japan [20,21]. To determine the adequacy of the analysis over this wider area, sensitivity to the change of the rank of the data was also assessed by considering sampling errors. Particular focus was placed on 1) the possibility of EBSA quantification throughout the E–SE Asia region, and the suitability of the indices selected; 2) the optimal way to integrate the criteria, considering the coverage of highly evaluated grids, the relationships between criteria, and robustness to incompleteness of the data; and 3) a comparison between the areas protected at present and those selected by this research as important areas.

2. Materials and Methods

2.1 Data Collection

This study focused on the E–SE Asia area from 90°E to 160°E and from 15°S to 50°N. Data were collected for species occurrence, species abundance, habitat use, and the state of the environment within this region. The data obtained were compiled into a 1-degree grid following the EBSA training manual [22]. For some criteria, data were separately compiled for different parts of the ocean (i.e. coastal, offshore pelagic, and offshore seafloor). For criterion 5 (productivity details are explained in the next section), in particular, offshore and coastal areas were independently evaluated because there are no overlapping grids. Although the offshore seafloor has unique characteristics among marine environments, seafloor data for only two EBSA criteria (1 and 4 ; Uniqueness and Vulnerability) were available for our indices. Discussions at this stage about these parts of the study area relied heavily on expert opinion at EBSA regional workshops. Therefore, in this study, EBSA candidates E-SE Asia were identified on the basis of data from the coastal region and offshore but not from the seafloor.

Data for species occurrence were obtained from the Ocean Biogeographic Information System (OBIS) [23], the Global Biodiversity Information Facility (GBIF) [24], and the Red List of the International Union for the Conservation of Nature and

Natural Resources (IUCN) [25]. Biogeographic data were obtained from the United Nations Environment Programme's (UNEP) World Conservation Monitoring Centre (UNEP-WCMC), Natural Geography in Nearshore Areas (NaGISA; the nearshore component of the Census of Marine Life) [26], and other published papers as shown in Supplementary Table 1. The data collected from the literature have been compiled in the Biological Information System for Marine Life (BISMaL) managed by the Global Oceanographic Data Center (GODAC) of the Japan Agency for Marine-Earth Science and Technology [27] and will be available to the public.

2.2 Evaluation of EBSA criteria

2.2.1 Selection of indices for evaluation of each criterion

This study used the CBD seven scientific criteria for EBSA identification that are described in the annex I decision IX/20 [22]. According to the definition for each criterion, quantifiable indices were proposed on the basis of expert opinion and practicable indices were adopted. The indices and methods of evaluation are explained below along with definitions for each criterion. Maps of the values of each index were created with a resolution of 1° latitude by 1° longitude for this study.

Criterion 1: Uniqueness or rarity

Definition: The area contains either (i) unique (the only one of its kind), rare (occurs only in few locations) or endemic species, populations or communities, and/or (ii) *unique, rare or distinct, habitats or ecosystems, and/or (iii) unique or unusual geomorphological or oceanographic features.*

It is difficult to consider uniqueness and rarity in many taxa because of a lack of occurrence data and endemic species lists. In this study, therefore, two indices were used for this criterion: 1) distribution of species recorded only within the study area, and 2) distribution of species known for their distinct uniqueness or rarity.

1) Species recorded only within the study area

Occurrence data for species recorded only within the study area were obtained from OBIS, GBIF, and the literature. Cnidaria, Arthropoda, Mollusca, and Perciformes were chosen as target taxa because there are comparatively large numbers of records available and advanced classification status (e.g. to genus or species level) was expected for these taxa. The species number for each grid was then calculated (Fig. S-1a). This analysis can include non-indigenous species, because the accuracy of species classification depends on the provider of data to OBIS and GBIF and there is limited data-quality control. It should also be noted that this index is probably considerably affected by the degree of sampling effort.

2) Distribution of unique or rare species

Unique or rare species were selected as follows. The crab-eating frog *Fejervarya cancrivora* was selected because in Southeast Asia it is the only amphibian living in brackish water and recorded from the mangrove forests [28]. For mollusks, shell prices can be a guide to species rareness, because rare shells are exchanged at high prices in the marketplace. Shell prices at an online store [29] were examined and 15 of 53 species that cost more than 10,000 yen were used as rare species for this study. The coelacanth was selected because it is very rare in the world ocean and there have been only two coelacanth species reported from specific regions of the world. One of the two species, *Latimeria menadoensis*, has been reported only from Indonesian seas [30–32]. The occurrence data for these species were obtained from OBIS, GBIF, and the literature, and species numbers were calculated on a 1° grid (Fig. S-1b).

Criterion 2: Special importance for life-history stages of species

Definition: Areas that are essential for a population to survive and thrive.

This criterion is intended to identify specific areas that support critical life-history stages of individual species or populations. Breeding or nesting sites and sites for juvenile growth fit this criterion. As important areas for species' life history, CBD's EBSA identification processes used nesting sites of sea turtles and foraging sites of sea birds [13]. Indices for this criterion in this study were 1) the number of sea turtle species at nesting sites, and 2) the number of eel species on spawning areas. Several other potential indices were not used because of a lack of data or research. For example, marine important bird and biodiversity areas (IBAs) fit this criterion well. Selection of marine IBAs, however, is still in progress in the Asia region. Breeding sites of marine mammals and areas with high concentrations of zooplankton (important feeding areas) were not evaluated in this study because of a lack of data. For copepods in particular, mapping is still in progress (Sudo et al., in prep.). Productive coastal habitats (sea-grass beds, seaweed beds, coral reefs, and mangrove forests) are also important areas for habitation and reproduction of many marine organisms [33]. However, it is still necessary to conduct more research and review of the life history of major species and to acquire their distribution data.

1) Number of sea turtle species at nesting sites

Distribution data for the location of nesting sites of six sea turtle species that are known to breed in the study area—*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata*, *Lepidochelys olivacea*, and *Natator depressus*—were obtained from the Global Distribution of Marine Turtle Nesting Sites database [34], and the number of nesting species was calculated for a 1° grid (Fig. S-1c).

2) Number of eel species in spawning areas

The natural reproductive ecology of two eels, *Anguilla japonica* and *Anguilla marmorata*, was first revealed by Tsukamoto *et al.* [35]. Spawning-site data for these two species were extracted from the work by Tsukamoto *et al.* and the species number for each grid was evaluated (Fig. S-1d).

Criterion 3: Importance for threatened, endangered, or declining species or habitats

Definition: Areas containing habitat for the survival and recovery of endangered, threatened or declining species or areas with significant assemblages of such species.

This criterion targets threatened, endangered or declining species and their habitats. In this study, the distributions of species categorized as critically endangered (CR), endangered (EN), or vulnerable (VU) on the IUCN Red List were used as a variable for this criterion. Because there were a large number of coral species on the Red List and abundant data for their distributions, corals were analyzed separately from other species.

1) Distribution of threatened species

Distribution data for marine threatened species that are categorized as CR, EN, or VU on the IUCN Red List were obtained from OBIS, GBIF, and the literature. Species numbers for those threatened species were calculated grid by grid as an indicator for this criterion (Fig. S-1e). Note that risk assessments for fish and invertebrate groups are insufficient on the IUCN Red List at present, and this index is also greatly influenced by sampling effort. Data for long-distance migrators such as cetaceans, *Thunnus* spp. (tunas), seabirds, and sea turtles were excluded from the analysis because it is difficult to determine the importance of their presence to a specific site. Consequently, 11 marine mammals, 78 Chondrichthyes (shark and ray) species, and 48 other species were included as threatened species.

2) Prioritized areas for conservation of threatened coral species

Distribution ranges for coral reefs were obtained from IUCN Red List spatial data, OBIS and GBIF, and then further refined by using data for the global distribution of coral reefs [36–39]. Also used were unpublished data provided by S-9 research participants (H.Yamano) Priority areas for conservation that effectively conserved all threatened coral species were detected from the total number of times an area was selected in 100 replicate runs of complementary analyses using Marxan (Fig. S-1f) targeting a conservation area of 10% of the study area.

Criterion 4: Vulnerability, fragility, sensitivity, or slow recovery

Definition: Areas that contain a relatively high proportion of sensitive habitats, biotopes, or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.

This criterion focuses on the inherent sensitivity of habitats or species to disruption, and to their resilience to physicochemical perturbation. Information about such responses of organisms and ecosystems to environmental change is very scarce and difficult to evaluate at a global scale. The indices applicable to this criterion were 1) the distribution of species representative of slow growth and low recovery capability, and 2) enclosed seas with an M2 tidal constituent (principal lunar semi-diurnal which is the largest constituent of tide in most regions) ≤10 cm. Giant clams (*Tridacna gigas*) were considered as typical examples of slow-growing and slow-recovery species, and their distributions were used as indices for this criterion. For the second index, seawater exchange in an enclosed sea is often inefficient and there are high risks of water pollution and eutrophication. The M2 tidal constituent is generally used as a measure of insufficiency of seawater exchange, and an M2 tidal constituent ≤10 cm is considered to indicate high vulnerability [40,41]. This value was therefore used as an indicator of reduced exchange in enclosed seas.

1) Distribution of low-recovery species

Distribution data for giant clams (*Tridacna gigas*) were obtained from OBIS and GBIF (Fig. S-1g).

2) Enclosed seas with M2 tidal constituent ≤10 cm

Highly vulnerable sea regions with an M2 tidal constituent ≤10 cm were mapped by using data from the HAMTIDE model [42] and the International Center for the Environmental Management of Enclosed Coastal Seas (International EMECS Center) [43] (Fig. S-1h). For the Seto Inland Sea, the detailed data of Yanagi and Higuchi [44] were used separately. The proportion of the sea area with M2 ≤10 cm was evaluated for each grid.

Criterion 5: Biological productivity

Definition: Areas containing species, populations or communities with comparatively higher natural biological productivity.

This criterion is specified to identify regions that regularly exhibit high primary or secondary productivity, and therefore provide core ecosystem services and support higher trophic-level species. Because the production base differs between coastal and pelagic ecosystems, they should be evaluated separately. In coastal regions, the types of ecosystems themselves represent levels of productivity; therefore, the distributions of significantly productive ecosystems were directly mapped for this criterion. In offshore areas, primary production in most cases is based on phytoplankton, and chlorophyll-*a* concentration is used as a measure of productivity on a broad spatial scale.

1) Distribution of coral reefs, seagrass beds, seaweed beds, and mangroves

For coastal ecosystems, distribution areas were determined for coral reefs [36–39], seagrass beds [45,46], seaweed beds [47], and mangrove forests [43]. The total coverage of those ecosystems was calculated on a 1° grid (Fig. S-1i). Although estuaries are highly productive regions as well, they were not included in this study because it was difficult to take into consideration the influence of terrestrial nutrient input via the large number of rivers in the study area.

2) Offshore regions with high productivity

Because offshore productivity fluctuates widely with the seasons, the cumulative mean chlorophyll-*a* concentrations between 2008 and 2012 were calculated for a 1° grid by using data obtained from moderate resolution imaging spectrora diometer (MODIS) Aqua [49] (Fig. S-1j). Productivity was higher than that indicated by MODIS data in coastal regions and in the Yellow Sea because turbidity interferes with detection of chlorophyll. Those areas are still highly productive because of large inputs of terrestrial organic matter. When the anomalies caused by turbidity are taken into consideration, the seas off the northeastern coast of Japan and the southeastern coast of New Guinea are considered high production regions.

Criterion 6: Biological diversity

Definition: Areas containing comparatively higher diversity of ecosystems, habitats communities, or species, or with higher genetic diversity.

Because there is no single definition of biodiversity, there were several choices for diversity indices. In our study area, there was severe bias in the amount of data collected, and direct evaluation of biodiversity was not sufficiently accurate. One effective method to evaluate biodiversity with limited data is to estimate the expected number of species by considering rarefaction curves. Thus Hurlbert's Index, ES(10) [50], was used for this criterion.

1) Number of species estimated by using Hurlbert's Index, ES(10)

Before this analysis, terrestrial data were excluded by using mean high-tide levels. Avian species were excluded as well to avoid data for species likely to migrate out of the study area, or even from terrestrial areas. Thus the final number of species occurrence data used for the analysis was 1,122,630 (Table 1). Significant biases in both the number of species and specimens were observed (Fig. S-1k, Table l). For example, the numbers of both species and specimens were relatively small in the coastal regions of Russia, North Korea, Vietnam, Kalimantan, Sumatra, and Java and in the open ocean.

Hurlbert’s Index, ES(10), was calculated for each grid by using the above data (Fig. S-1m); grids with fewer than 20 samples were not included in the calculation.

<<Table.1 here>>

Criterion 7: Naturalness

Definition: Areas with a comparatively higher degree of naturalness as a result of the lack or low level of human-induced disturbance or degradation.

Naturalness can be considered to be represented by a low number of disturbances by human activities. Halpern et al. [9] evaluated 17 human impacts on the ocean at a global scale (Human Impact Model), and these data were used to show regions of relatively little human influence in this study. The limited nature of the data prevented the production of indicators that included local human impacts such as destructive fisheries practices, local coastal development, or illegal, unregulated and unreported (IUU) fishing. However, the use of this global indicator was considered valid in this region using population data.

1) Areas of less human impact

Naturalness was indirectly evaluated by identifying regions of relatively low human impact by using data from the Human Impact Model. The proportion of the sea area where the human impact score was small (5 or less) was calculated by grid (Fig. 1n). Because the Human Impact Model is based only on information available at a global scale and does not consider region-specific information, differences between the model and actual regional conditions were compared. Comparison with land population data revealed regions of high naturalness in less populated regions such as Borneo, New Guinea, and Northern Australia, suggesting that this analysis was reasonable to some extent and was well fitted to the criterion.

2.2.2 Standardization of data

The units and the range of values for the variables selected depended on the indices. It was therefore necessary to standardize the data for the integration. In accordance with the analytical methods and the draft training manual from EBSA regional workshops about the open ocean [51], criterion relevance was ranked into four categories: high (3 points), medium (2 points), low (1 point), and no information (0 points). The same point system was allotted to each variable to make the mean score equal to 2 points [19]. For criteria 1 and 3, which were evaluated by using multiple indices, the mean value was calculated after the original value of each index had been transformed into rank data from 1 to 3. Other criteria did not show overlap of the grids.

2.3 Selection of EBSA candidates

An area that meets at least one criterion can be regarded as an areas meets EBSA criteria. This principle will work in the case of the rating of specific location listed by experts. However, this selection condition is impractical in the case of our systematic approach targeting all over the study region. It selects too many areas by the rating process of each criterion. In this study, selection of EBSA candidates was carried out by multi-criterion analysis using the seven criteria. Two methods were compared: simple addition of ranking scores and analysis by using the conservation planning tool Marxan. Additionally, the number of criteria that ranked at the highest value and the mean ranking excluding cases with no information (i.e., the mean without zero values) were calculated for each grid. However, these additional methods were used only for a comparison of methodologies, because of the difficulty in selecting the same number of areas from only seven categorical values, and because of the inaccuracy caused by the lack of data.

In the simple addition of ranking scores, areas with scores in the top 10% were selected. In the complementary analysis, scores for each criterion were incorporated into a parameter to set weighting, and Marxan was run 100 times by setting up the target value to select 10% of the study area.

2.4 Analysis of the contribution of each criterion to EBSA candidates

To understand the influence of the values for the distribution of each criterion on the results of the integrated evaluation, the number of EBSA grids selected was compared for each criterion and for each method (summation and complementary analysis). The comparison also included the number of criteria that ranked at the highest value (number of the high criteria) and the means excluding zero values. Because the numbers of grids selected differed in these cases, the number of grids was multiplied by a correction factor so as to be same number of grids as the complementarity and summation in total.

2.5 Analysis of sensitivity of EBSA candidates

Because some of the data had bias or were less accurate for certain areas, species, or categories, the robustness of our results was examined scenario to modify the data after finalize the evaluation of all area. We considered the random errors in the values similar to the sensitivity analysis of missing values [52]. This scenario can also be used to consider the effects of future data updates, even for data that completely encompassed the study area. The following type of error was considered, and the appropriate integration method and amount of change caused by the error were also evaluated. In any of the seven criteria, a small error of evaluation (plus or minus 1) can occur at a random location (hereafter referred to as a "small error"). For this calculation, this type of random error was simulated 100 times and the integration was run for each replicate. When the values modified by the random errors exceeded the range of the ranking (i.e. less than zero or greater than five), the values were considered to be the minimum or maximum of the range. Although this truncation was not avoided it will practically happen by this scenario which modify the evaluation values after once finalize the evaluation of other area. Because it is desirable to compare the different integration methods, which output different ranges of values, this analysis was not used to select 10% of the area; instead, the results were ranked into five levels of importance for conservation, setting 3 as the mean value. Although ranking was not normally used for Marxan and zero values were included for summation for the purpose of selecting 10% of the area, here the ranking was considered both with and without zero values to observe the sensitivity. The differences in the evaluation with error and without error were then compared.

2.6 Gaps and overlaps of EBSAs and MPAs

The overlap between EBSA candidates in this paper and several kinds of registered marine areas for conservation purposes was assessed by examining the coincidence of EBSA candidates with latter existing registered areas. Areas meeting the EBSA criteria proposed by the result of the EBSA regional workshop (CBD EBSA) [53], Marine Protected Areas (MPAs) archived in the protected planet ocean which are based on data from the World Database on Protected Areas (WDPA) [54], UNESCO World Marine Heritage (WMH) [55], FAO Vulnerable Marine Ecosystems (VME) [56] and IMO Particularly Sensitive Sea Areas (PSSAs) [57] are used as the registered marine areas for conservation purposes. In the CBD-EBSA the deep sea was excluded for this calculation. All grids selected by summation and complementary analysis were used as EBSA candidates in this paper. Distribution data for MPAs were acquired from the World Database on Protected Areas (WDPA) [54], and all oceanic MPAs were used regardless of the substance or aims of their regulation.

3. Results

3.1 Comparison of assessed ranking and availability of data for the seven EBSA criteria

The number of grids evaluated differed by criterion (Figs. S-2, 1a). The highest percentage of grids evaluated was 100% for criterion 5, which used satellite images to evaluate offshore areas. For criterion 7, 64% of the grids were evaluated using a published integrated index [9]. Although this index itself evaluated 100% of our study area, only 64% of the grids were evaluated as having some importance under this criterion. Criteria 1 and 6, which were based on species occurrence data, could be used to evaluate 32% and 40% of the grids, respectively. Unevaluated grids were mainly in offshore areas. In contrast, criteria 2 to 4 could be used only to evaluate less than 18% of the area. This is because of a lack of data on life histories and specific species in the study area.

<<Fig.1 here>>

3.2 EBSA selection by using multi-criteria analysis

Summations of the ranking of the seven criteria mainly showed higher values in coastal areas (Fig. 2a). Although the 10% selected from the summation and the complementary analysis matched in several areas, there were apparent differences around the Sea of Japan and the Gulf of Thailand and in coastal areas from the Korean peninsula to Vietnam (compare Fig. 2c to 2d).

<<Fig.2 here>>

The differences in results from different methods were examined in more detail by comparing the coverage of the highly evaluated grids in each criterion. After the integration and selection of 10% of the area, fewer grids were selected from among highly evaluated grids in each of the seven criteria (Figs. 1b, 2 [compare 2b to 2a and 2d to 2c]). For criteria 1, 5, 6, and 7, fewer than 31% of the highly evaluated grids were selected after the integration by complementarity analysis. For integration using summation, fewer than 37% were selected under criteria 4, 6, and 7.

Over 52% of the highly evaluated grids were selected under criteria 2, 3, and 4 by the complementarity analysis, and were selected under criteria 1, 2, 3, and 5 by summation. In most cases (with the exception of criteria 2 and 4) integration by summation showed a higher number of grids for each criterion. However, without integration using the complementarity analysis, the locations selected by criterion 4 were completely lost; these locations were selected with high frequency in the complementarity analysis. The other two methods gave relatively low percentage inclusion of highly evaluated grids (under 47% by counting the number of "high" rankings under the seven criteria, and under 41% using the mean ranking without zero values).

The trend of contributing grids for each criterion differed, especially in the case of criterion 4 (Fig. 3). The highest positive correlation was observed between criterion 4 and criterion 2 (Spearman's rank-order correlation $r = 0.47$). The highest negative correlation was observed between criteria 4 and 1 ($r = –0.23$). Thus, criterion 4, which ranked areas based on enclosed seas and giant clams, differed, or partially showed an opposite trend, from the distribution of the important rare species *Latimeria menadoensis* (criterion 1) and showed similar trends similar to those of the nesting sites of sea turtles (criterion 2). Criterion 1 showed higher correlation with criteria 5 and 6 compared with the other criteria. Thus the presence of a rare species showed trends in spatial distribution similar to those of biodiversity and productivity.

<<Fig.3 here>>

3.3 Analysis of the accuracy of integrated EBSA results

In the case of small errors (Table 2), complementarity and summation of the maximum were robust. This was especially true for the case in which zero values were included for the ranking. Because the target of selecting 10% of the area was set before running Marxan, numerous non-selected areas with zero values were produced. This had the effect of skewing the results toward the positive. To examine the detailed structure of the change in the selected areas, the ranking without zero values was also determined. In this case the result of the ranking ranged from –4 to +4 and the variance was higher than the summation.

<<Table.2 here>>

In contrast, the summation ranked including grids without information showed a difference of ±1, and almost 20% of the grids were modified by the random error. Although the variation was higher in the summation, the change in the results of the ranking without zero values was lower than in the complementarity analysis. This means that, when complementarity is used, the highly (or lowly) ranked grids will vary more than in summation.

Compared with these mainly targeted integration methods, the average without zero values showed higher variations in the change. The average change did not converge on 0 and was closer to 1. This occurred because of the distribution of the zero data, which were excluded for calculation of the mean. Counting of the maximum values showed a pattern of changes similar to the summation, but the variation was higher. Part of this variation was caused by the higher number of zero values included compared with in the summation.

3.4 Gap and overlap between EBSA candidates of this paper and existing registered areas for conservation purposes

The total area of EBSA candidates of this paper selected by summation and complementary analysis reached 14.4% of the study area. Overlap ratio of EBSA candidates and five different types of registered areas are listed in Table 3 and Fig. S-3.

<<Table 3 here>>

The MPAs cover 397,813 km^2, 1.1% of the study area. Among the EBSA candidates 4.3% overlap with MPAs. Mismatches are concentrated in the coastal regions of Papua New Guinea, the area between the northern coasts of Australia and the Tanimbar Islands of Indonesia, and the Sea of Japan. The site by site differences following CBD-EBSA locations are summarized in the next section.

On the other hand, 56.4% of MPA areas overlap EBSA candidate of this research. The main examples are the Great Barrier Reef Marine Park (Australia), the Raja Ampat National Park at the western tip of New Guinea (Indonesia), and the Berau Marine

Protected Area on the east coast of Kalimantan (Indonesia). A large part of MPAs which did not overlap with EBSA candidates was due to MPAs such as the Islands Unit of the Marianas Trench Marine National Monument (246,608 km^2, USA), the Savu Marine National Park (49,678 km^2, Indonesia), and the Setonaikai National Park (628 km^2, (Japan). The total area of these MPAs accounts for a large portion of the MPAs not overlapped by EBSA candidates.

UNESCO World Marine Heritage (WMH) covered 96,045 km^2 in this study region. Only 1.8% of the areas in the EBSA candidate overlapped with WMH. On the other hand, 97.7% of WMH overlapped with EBSA candidate in this paper. The largest WMH site is Great Barrier Reef and all areas overlapped with EBSA candidate in this research area. On the other hand, Tubbataha Reefs Natural Park in the Philippines and Shiretoko in Japan did not overlap.

FAO Vulnerable Marine Ecosystem (VME) covered 3,519,400 km^2 area in this study region. EBSA candidate overlapped with VME was only 0.2% and 0.3% of VME overlapped with EBSA candidate in this research area. Northwestern Pacific Ocean VME slightly overlapped with EBSA candidate. In addition, area selected by VME was the outwith the scope of EBSA regional workshop in the seas of east Asia.

IMO Particularly Sensitive Sea Areas (PSSAs) covered 150,700 km^2 in this study region. EBSA candidate overlapped with 2.8% of PSSAs. Torres Strait is the only PSSA in the southeast Asia and 95.9% of area overlapped with EBSA Candidate. Torres Strait was the outwith the scope of EBSA regional workshop in the seas of east Asia.

Selected EBSA candidate of this paper overlapped with 12.5% of CBD-EBSA which raised from the result of regional workshop in the seas of east Asia (Table 4). On the other hand, CBD-EBSA overlapped with 34.5% of EBSA candidate. Sulu-Sulawesi Marine Ecoregion is the largest area meeting the EBSA criteria and overlapped with 50.5% of EBSA candidate, whereas Redang Island Archipelago, Adjacent Area, Nino Konis Santana National Park and Atauro Island and Benham Rise did not overlap.

<<Table 4 here>>

4. Discussion

4.1 Possibility of EBSA quantification throughout E–SE Asia

Seven criteria were quantitatively evaluated across the Asia-Pacific Region. Data for species distributions in databases and in the literature, and remote-sensing and GIS data, were useful for this evaluation. This was especially true for criterion 5, which estimated productivity throughout the study area by using satellite images and databases. Even in this case, higher resolution data that considers more variables, such as river discharge, are needed as a next step for evaluating coastal areas.

With the exception of satellite images and models of human impacts, it was not possible to obtain comprehensive data for EBSA evaluation over a broad area. There were huge gaps in the amount and kinds of data among regions and taxa. For example, the result of the evaluation of criterion 4 affected the results of the integration of the seven criteria. Criterion 2 also showed data limitations in several coastal and offshore areas. Increased efforts to obtain data, to accelerate sampling efforts, and to predict species distributions are needed to solve this problem.

For some criteria, the choice of index or species groups also affected the result. For example, the offshore seafloor and species that migrated over wide areas were not included in this study because of a lack of data and difficulty in habitat specificity, respectively. This obviously affected the results of criterion 3, which did not include species on the IUCN Red List that migrate long distances (whales, tunas, birds, turtles). Defining the important locations for such species also adds confusion to criterion 2.

The criteria used in this trial evaluated EBSA candidates successfully to a point, but the obvious lack of data for criteria 2 to 4 affected the evaluation in several locations. There are two solutions to this problem. One is better treatment of data, for example, by indication, calibration, and prediction of data limitations. The other is obtaining better agreement among experts. Although expert opinions were used for the selection of indices for each criterion here, more objective and transparent ways are available. For example, the use of the Delphi method has been proposed to lead to agreement among multiple experts [58].

4.2 Optimal integration of criteria

The appropriate way to consider the seven EBSA criteria is still under discussion (see CBD’s EBSA draft training manual [51]). Multiple criteria were experimentally integrated in this study and showed how it is possible to use complementarity and summation (in that order of priority) to evaluate their importance using EBSA criteria.

Our comparison of summation and complementarity analysis revealed a large difference in the treatment of criterion 4, which showed a trend different from those of the other criteria. In the case of complementarity analysis, it is possible to consider criteria that are not selected in a majority of grids. Therefore, it is better to select EBSAs by eliminating unexpected bias toward the majority of trends in criteria (i.e. complementarity is more appropriate for this purpose as far as considering such criteria).

Robustness of the data was high in these two major analyses. Although there was not a high degree of variation for the purpose of selecting a certain portion of the area (10%), complementarity analysis showed higher variation of ranking among the areas selected. This may be associated with the characteristics of the analysis, because complementarity selects a different site for each run of the analysis even if the evaluated criterion values are the same.

Considering the coverage of highly evaluated grids for each criterion and the robustness to incomplete data, use of complementarity is recommended for selecting important areas in terms of the targeting of each criterion equally, even if there are different trends or trade-offs in different criteria. Complementarity was also useful under conditions of incomplete data as far as selecting a certain percentage of the area. However, if the goal is to rank all areas by equal weighting to all criteria then summation is appropriate. In this case summation can be robust for incomplete data, especially when some variables have similar trends.

The importance of each criterion to the integrated EBSA evaluation was highly affected by data limitations. For example, the lower importance of criteria 1 and 3 provided in section 3.2 in the Results is explained by the effect of missing data. It can be debated whether to use a value of zero for the grids not evaluated or to eliminate zero values from the analyses (which is similar to the use of average rank for the grids). The use of zero values clearly reduced the rank of EBSA after summation. However, summation was more robust than the result without zero values (average). In addition, there are benefits to showing data-limited areas on integrated maps when an absence of information is shown as zero. Governments in incomplete or less-thoroughly evaluated areas probably realize the necessity of improving data so long as they think that a lower rank is not good. It is important to show such maps together with the policies used to encourage increased data-collection efforts and improve data quality. However, by showing the same maps to developers without summarizing the results according to government boundaries it is also possible to use them to conveniently destroy areas with fewer data.

4.3 Comparison of present-day registered areas and selected EBSA candidates.

For the registered areas that did not overlap with EBSA candidates, explanations for the discrepancies were divided into three types: i) the present-day registered areas was selected by using EBSA-related indices but variables different from those used in the EBSA selection; ii) there was insufficient analytical resolution or lack of data; and iii) the present-day registered areas was selected by using indices unrelated to the EBSA criteria.

For the MPA, the background for discrepancies are examined as follows. The Island Unit of the Marianas Trench Marine National Monument is assigned to the first type of reason for discrepancies. Because this MPA was selected for its characteristic ecosystems created by volcanic activities and coral reefs and high biodiversity [59], our elimination of seafloor areas is very likely the reason why it was not selected using the EBSA criteria.

The Savu Sea Marine National Park is assigned to the first and second types of reasons for discrepancies. This MPA was selected for its importance as a migration corridor for large marine animals and as a refuge for marine species in response to climate change, and because of its extremely high primary productivity [60]. Thus the elimination from consideration of threatened long-distance migrators, and a lack of geographically-related physical data such as those concerning currents and nutrients, are possible reasons for the discrepancies.

The Setonaikai National Park was selected on the basis of criteria unrelated to EBSA criteria, such as the aesthetics of a calm inland sea with many islands, and cultural scenery harmonious with nature [61]. This is likely the reason for the discrepancy and is assigned to the third type of reason.

Lastly, the Tubbataha Reefs Natural Park in the Philippines is assigned to the first and second type of reasons for discrepancies. This MPA is an important breeding ground for seabirds and sea turtles [62]. Bird data were excluded from our analyses, however, and marine IBA data were not available. Data on the nesting sites of sea turtles in the Tubbataha Reefs Natural Park are still not available on the database of the

Global Distribution of Marine Turtle Nesting Sites [34]. These are possible reasons for the discrepancies concerning this Park.

In the case of WMH, largest WMH site (Great Barrier Reef) was overlapped with EBSA candidate. Because total area of WMH is small (96,044km^2), higher percentage of WMH was overlapped with EBSA candidate. Even by the comparison of counting the number of the registered area, EBSA candidate covered seven of the nine WMH sites. Among sites not overlapping, Tubbataha Reefs Natural Park in Palawan in the Philippines is considered relatively pristine and possessing high biodiversity. However, scientific data in the global database was not enough to evaluate this area.

Criteria used in VME were similar to EBSA criteria. However, almost of all the VME area did not overlap with EBSA candidate in this research area. Typical VME in this research area are bottom fishing outside of the footprint managed by the South Pacific Regional Fisheries Management Organisation (SPRFMO) and Northwestern Pacific Ocean managed by the North Pacific Fisheries Commission (NPFC). These are mainly targeted to manage deep sea and bottom fishing in the high seas. Even using similar evaluation criteria, the difference of the focused variables and lack of data in the high seas showed a large gap between EBSA candidates and areas of VME. Thus first and second types of gaps are observed in VME. Along with VME some PSSAs criteria are also similar to EBSA criteria. Although only a single site of PSSAs (Torres Strait) is presence this research area, it meets EBSA criteria of biological diversity, naturalness and importance for threatened species. Because of this similarity, Torres Strait PSSAS highly overlapped the EBSA candidate.

By comparison with the CBD EBSA, the largest CDB-EBSA site Sulu-Sulawesi Marine Ecoregion situated in the Coral Triangle overlaps half of the EBSA candidate area. On the other hand, Benham Rise which is a relatively pristine and undersea plateau off the eastern coast of Luzon Island was not included in our systematic EBSA candidate. It also represents not only offshore mesophotic coral reef biodiversity but also the spawning area of the Pacific bluefin tuna, *Thunnus orientalis*. Such an area will be considered as suitable for addition by expert opinion, because of the lack of data and combination of the consideration of seafloor geology and surface ecosystems.

These types of information gaps are also observed by the lack of domestic data of some countries. As mentioned in the Introduction, the Ministry of the Environment of Japan collected higher resolution data and applied a systematic approach [63]. They also asked experts to add opinions and modified the result of the systematic approach. Based on these results important marine areas from the view point of biodiversity were approved by the government official before the regional workshop and partially submitted to the reginal workshop.

The same situation was also observed in the Nino Konis Santana National Park in East Timor. Although the presence of the several sharks, coral trout (Plectropomus species), and the highly threatened Napoleon wrasse (*Cheilinus undulatus*) are known in this area, the global data did not shown high diversity. Especially in consideration of Red List species distribution extraction of domestic data will be needed and will not be easy to treat beyond the national scale using the systematic approach.

Our analysis in E-SE Asia intentionally did not use purely domestic datasets of specific countries to avoid bias. This result suggests that it will be important collect local data in E-SE Asian region. It also suggests that increasing data coverage will increase the area meeting the EBSA criteria.

These examples show that discrepancies between EBSA candidates and registered areas are caused by differences in either criteria, indices, variables, or data used for the site selection, and that closely examining the background of each gap may guide future data collection and selection of indices and variables. Although data for wide-ranging migratory species were not included in EBSA selection in this study, such data about the main conservation targets of many MPAs should be made usable by overcoming the problem of spatial evaluation by considering predictive modelling.

EBSA candidates that did not overlap with existing registered areas at all are potentially important areas for conservation, but at the same time the accuracy and adequacy of the data used for their selection should be considered, especially at this early stage. For example, the selection of most of the Sea of Japan was apparently influenced by the result from criterion 4.

5. Conclusions

Although there are several challenging tasks both to increase the amount of data and improve data quality for the near future, the conclusion is that it is possible to evaluate each EBSA criterion quantitatively overall, over a broad area, of the Asian Pacific. The use of complementarity with our dataset was the best, and summation was also informative, for evaluating the seven EBSA criteria in an integrative way. Our comparison of the present registered areas for conservation and selected EBSA candidates highlights the need to use similar indices for area selection in each country, the need for more data about characteristic species (especially large species and migratory species), and the lack of consideration of some aspects of important areas in the EBSA criteria (e.g. scenery and ecosystem services). The insights from this study suggest the importance of not only data quantity and resolution but also of philosophy in selecting indicators for important areas.

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Figure Legends

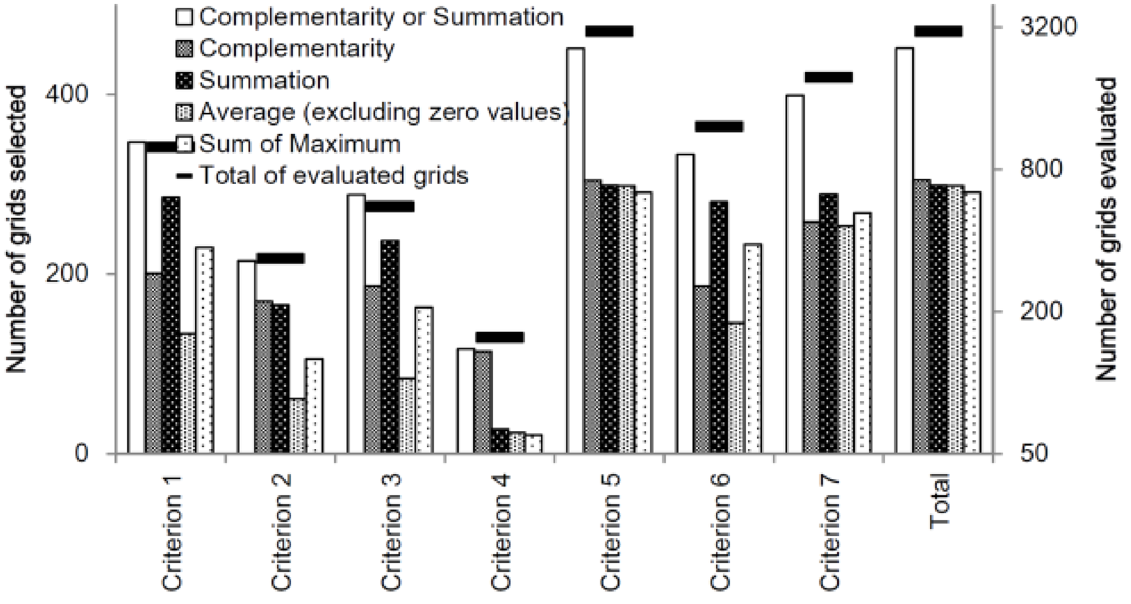
Fig. 1. Comparison of numbers of grids that contributed to integrated results among criteria and between summation and complementary analysis. (a) Number of grids evaluated. (b) Number of grids ranked as “High”.

Fig. 2. Integration of seven criteria. (a) Integration by summation. (b) Number of “high” evaluations for each grid. (c) Same as (a), with 10% of the study area selected. (d) Integration by complementary analysis with 10% of the study area selected.

Fig. 3. Correlation matrix of seven criteria. Spearman’s ranked correlation was used for the calculation. The upper right half shows the correlation coefficients *r* for each pair of criteria. The lower left half presents scatter plots and smoothed lines for each pair of criteria, and the graphs along the diagonal are histograms of the evaluated values (ranked low = 1 to high =3) for each criterion.

Fig. 1

a


Complementarity or Summation
Complementarity
Summation
Average (excluding zero values)
Sum of Maximum
Total of evaluated grids
Number of grids selected
Number of grids evaluated
0
200
400
50
200
800
3200
Criterion 1
Criterion 2
Criterion 3
Criterion 4
Criterion 5
Criterion 6
Criterion 7
Total

b

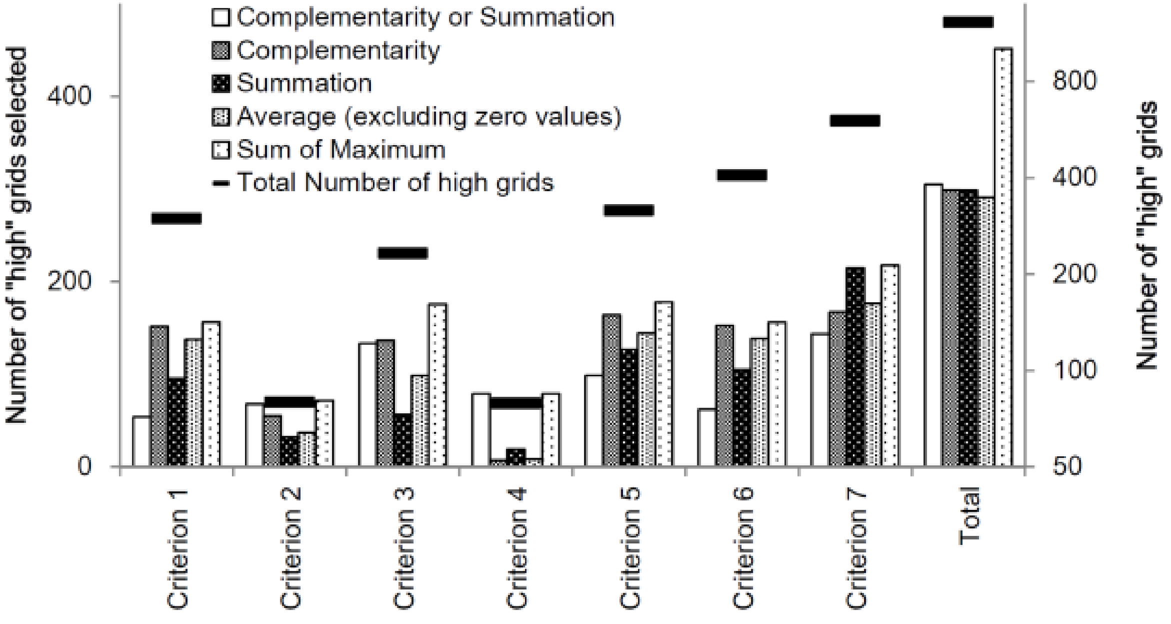

Complementarity or Summation
Complementarity
Summation
Average (excluding zero values)
Sum of Maximum
Total Number of high grids
Number of "high" grids selected
Number of "high" grids
0
200
400
50
100
200
400
800
Criterion 1
Criterion 2
Criterion 3
Criterion 4
Criterion 5
Criterion 6
Criterion 7
Total

Fig. 2

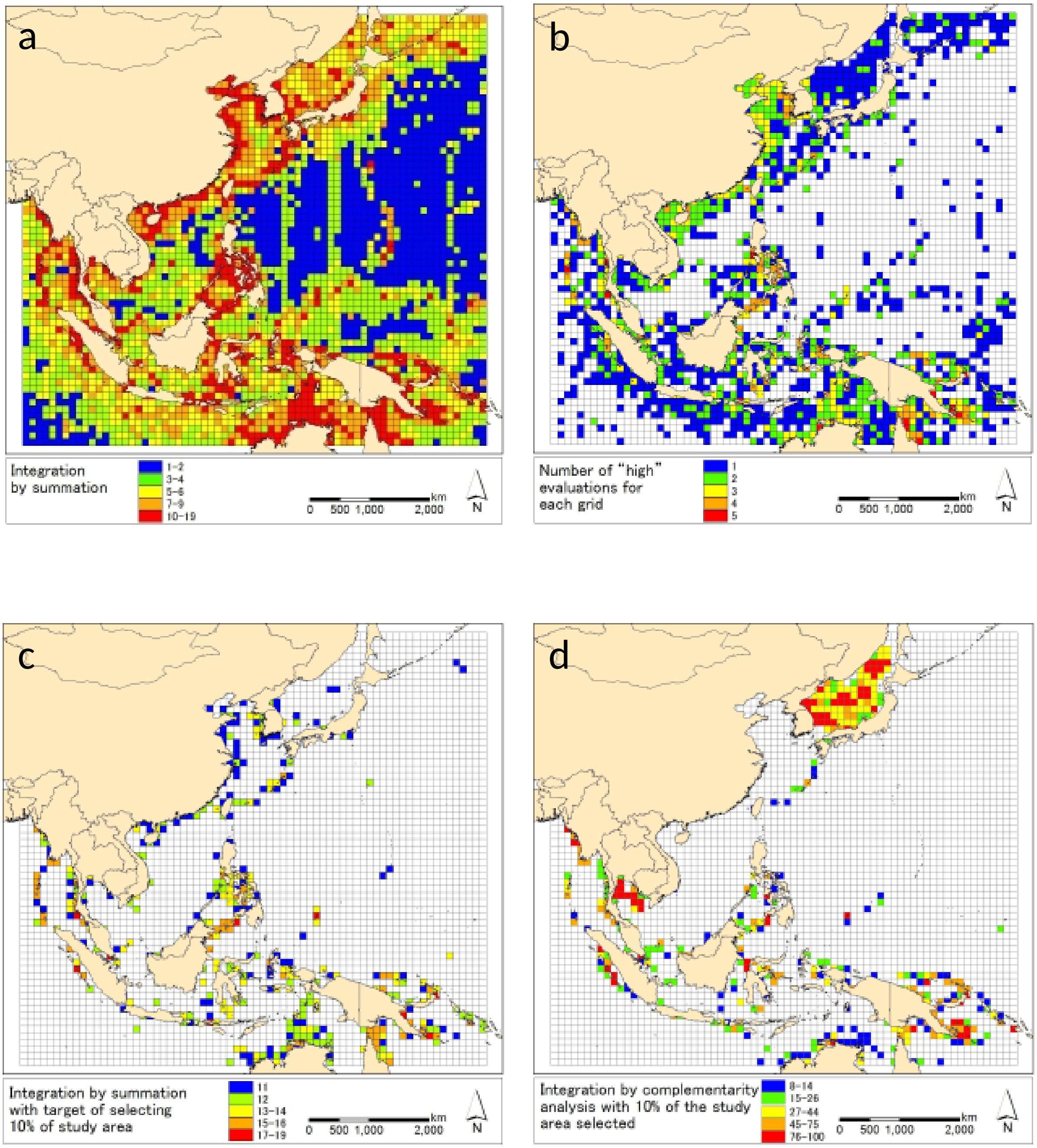
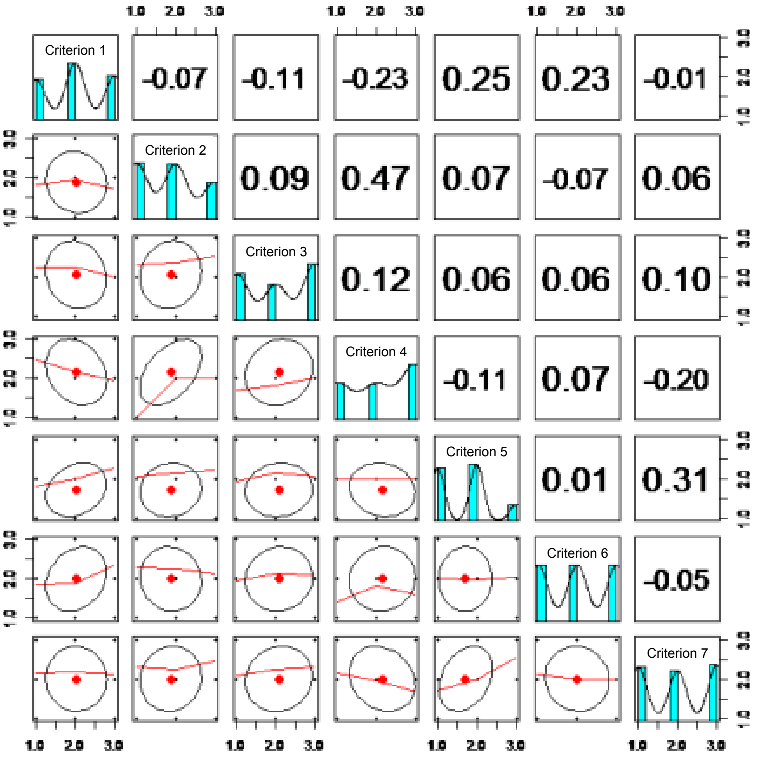

a
Integration by summation
1-2
3-4
5-6
7-9
10-19
0 500 1,000 2,000 km
N
b
Number of "high" evaluations for each grid
1
2
3
4
5
0 500 1,000 2,000 km
N
c
Integration by summation with target of selecting 10% of study area
11
12
13-14
15-16
17-19
0 500 1,000 2,000 km
N
d
Integration by complementarity analysis with 10% of the study area selected
8-14
15-26
27-44
45-75
76-100
0 500 1,000 2,000 km
N

Fig. 3



Criterion 1
-0.07
-0.11
-0.23
0.25
0.23
-0.01
Criterion 2
0.09
0.47
0.07
-0.07
0.06
Criterion 3
0.12
0.06
0.06
0.10
Criterion 4
-0.11
0.07
-0.20
Criterion 5
0.01
0.31
Criterion 6
-0.05
Criterion 7
1.0
2.0
3.0

Tables

Table 1. Number of species occurrence data obtained from each data source

Data source[a]	**Number of individuals**	
	All	**Species known**
OBIS	991,532	726,914
GBIF	819,144	392,822
NaGISA	2,928	866
Literatures	2,716	2,028
Total	**1,816,320**	**1,122,630**

[a]OBIS, Ocean Biogeographic Information System; GBIF, Global Biodiversity Information Facility; NaGISA, Natural Geography in Shore Areas; List of literatures are attached in the supporting materials

Table 2. . Sensitivity of ranking to random error (±1). The integration results were ranked into 5 classes and the differences between the original rank and the rank after adding random error was calculated (i.e. a difference range from –5.0 to +5.0). The values in the table are the numbers of grids (mean and standard deviation [sd]) with each difference in ranking calculated for each integration method from 100 replicates. s

	Difference between ranks from original data and from data produced with random error										
	–5.0	**–4.0**	**–3.0**	**–2.0**	**–1.0**	**0.0**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**
Complementarity mean*	0.0	0.0	0.0	0.0	0.0	4513.0	37.0	0.0	0.0	0.0	0.0
Complementarity sd*	0.0	0.0	0.0	0.0	0.0	163.1	163.1	0.0	0.0	0.0	0.0
Complementarity without0 mean	0.0	1.0	23.0	104.7	379.4	3815.0	198.8	24.4	3.6	0.3	0.0
Complementarity without0 sd	0.0	1.0	6.4	40.2	88.9	91.7	27.9	19.1	4.4	0.6	0.0
Summation mean*	0.0	0.0	0.0	0.0	346.7	3823.7	379.6	0.0	0.0	0.0	0.0
Summation sd*	0.0	0.0	0.0	0.1	27.1	22.1	29.2	0.1	0.0	0.0	0.0
Summation without0 mean	0.0	0.0	0.0	4.7	400.8	3628.2	513.7	2.6	0.0	0.0	0.0
Summation without0 sd	0.0	0.0	0.0	2.2	16.1	25.6	18.9	1.4	0.0	0.0	0.0
Average(exclude 0) mean	0.0	0.0	1.5	20.7	228.4	1241.9	1238.0	560.6	123.7	2.3	0.0
Average(exclude 0) sd	0.0	0.0	4.1	25.1	135.1	278.1	240.2	157.9	48.6	6.9	0.0
Average(exclude 0) without0 mean	0.0	0.0	1.5	20.7	228.4	1241.9	1238.0	560.6	123.7	2.3	0.0
Average(exclude 0) without0 sd	0.0	0.0	4.1	25.1	135.1	278.1	240.2	157.9	48.6	6.9	0.0
Count of high mean	0.0	0.0	0.0	0.0	325.6	3990.2	217.6	14.1	2.4	0.1	0.0
Count of high sd	0.0	0.0	0.0	0.0	60.1	203.0	196.2	56.0	9.6	0.5	0.0
Count of high without0 mean	0.4	6.0	41.5	175.2	571.6	3221.6	487.3	43.7	2.7	0.1	0.0
Count of high without0 sd	0.6	2.8	11.7	31.0	35.0	24.5	46.3	22.6	1.9	0.3	0.0

* Method of ranking used to select 10% of the area

Table 3. Gaps and overlaps between EBSA candidates and existing registered areas for the conservation purposes.

	Marine Protected Areas (MPA)	World Marine Heritage (WMH)	Vulnerable Marine Ecosystem (VME)	Particularly sensitive sea areas (PSSAS)	Areas meeting EBSA Criteria (CBD EBSA)*
Total area of each management area in our scope region (km2)	397814	96045	3519400	150700	3138194
EBSA candidate overlap ratio with each management area	4.3	1.8	0.2	2.8	12.5
Management area overlap ratio with EBSA candidate	56.4	97.7	0.3	95.9	34.5

*For the CBD EBSA their scope was limited in the areas considered in regional workshop

Table 4. Gaps and overlaps between CBD-EBSA and EBSA candidates by the result of this paper. Gaps and overlaps with MPA and WMH were also showed to compare their differences.

	Areas meeting EBSA criteria (CBD EBSA)	Area (km²)	EBSA Candidate (%)	MPA (%)	WMH (%)
1	Hainan Dongzhaigang Mangrove National Natural Reserve	156	18.0	2.4	0
2	Shankou Mangrove National Nature Reserve	278	43.7	10.0	0
3	Nanji Islands Marine Reserve	295	34.0	0	0
5	Muan Tidal Flat	41	63.1	40.0	0
6	Intertidal Areas of East Asian Shallow Seas	9684	12.6	3.1	0
7	Lembeh Strait and Adjacent Waters	2726	83.2	0.1	0
8	Redang Island Archipelago and Adjacent Area	7424	0	0	0
9	Southern Straits of Malacca	30353	66.7	10.5	0
10	Nino Konis Santana National Park	1603	0	30.2	0
11	The Upper Gulf of Thailand	14542	64.4	0	0
12	Halong Bay-Catba Limestone Island Cluster	3658	57.8	18.4	12.9
13	Tioman Marine Park	936	85.1	1.4	0
14	Koh Rong Marine National Park	850	87.2	0	0
15	Lampi Marine National Park	1164	78.6	1.4	0
16	Raja Ampat and Northern Bird's Head	105540	54.3	8.9	0
17	Atauro Island	427	0	23.9	0
18	Sulu-Sulawesi Marine Ecoregion	351098	50.5	7.0	0.2
19	Benham Rise	38795	0	0	0
2	Eastern Hokkaido	6158	0	5.2	3.5

0					
21	Southwest Islands	17353	78.4	9.0	0
22	Inland Sea Areas of Western Kyushu	6352	6.3	5.7	0
23	Southern Coastal Areas of Shikoku and Honshu Islands	14675	34.9	11.6	0
24	South Kyushu including Yakushima and Tanegashima Islands	4154	36.8	4.5	0
25	Ogasawara Islands	2822	39.7	6.2	2.5
26	Northern Coast of Hyogo, Kyoto, Fukui, Ishikawa and Toyama Prefectures	11496	66.3	15.1	0
31	Convection Zone East of Honshu	160297	0	0	0
32	Bluefin Tuna Spawning Area	150041	42.5	0.7	0
34	Kuroshio Current South of Honshu	174199	12.7	0.2	0
35	Northeastern Honshu	7668	0	16.9	0
Total		1124787	34.5	4.2	0.1

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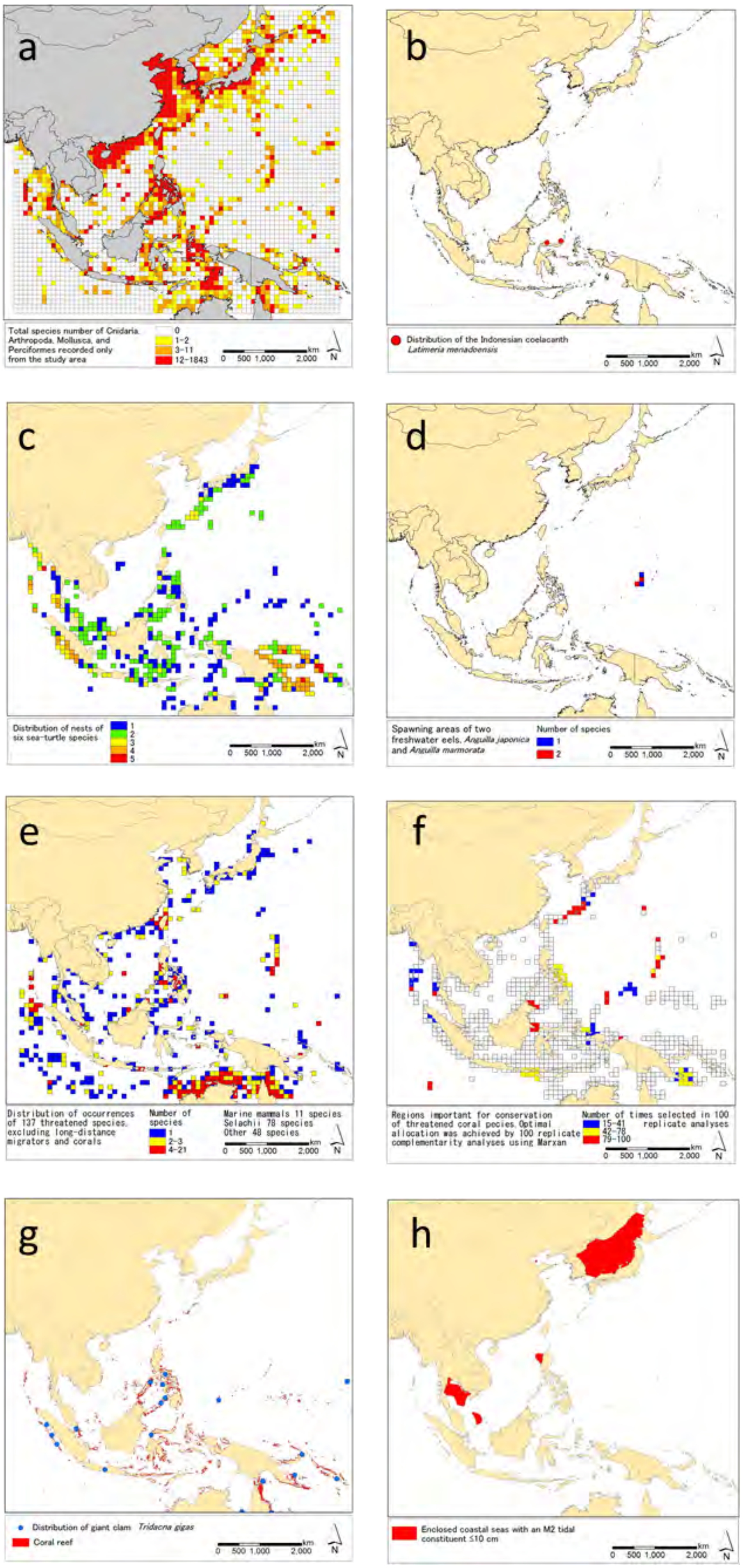
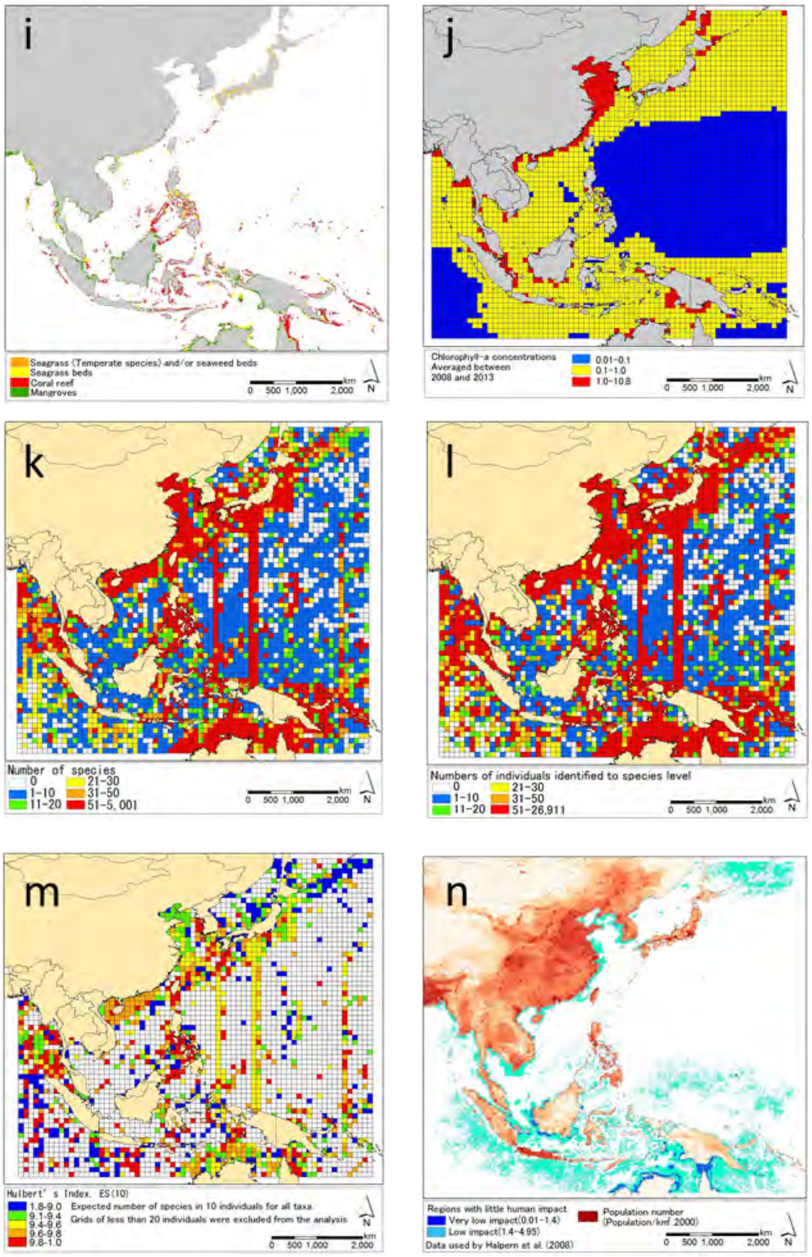
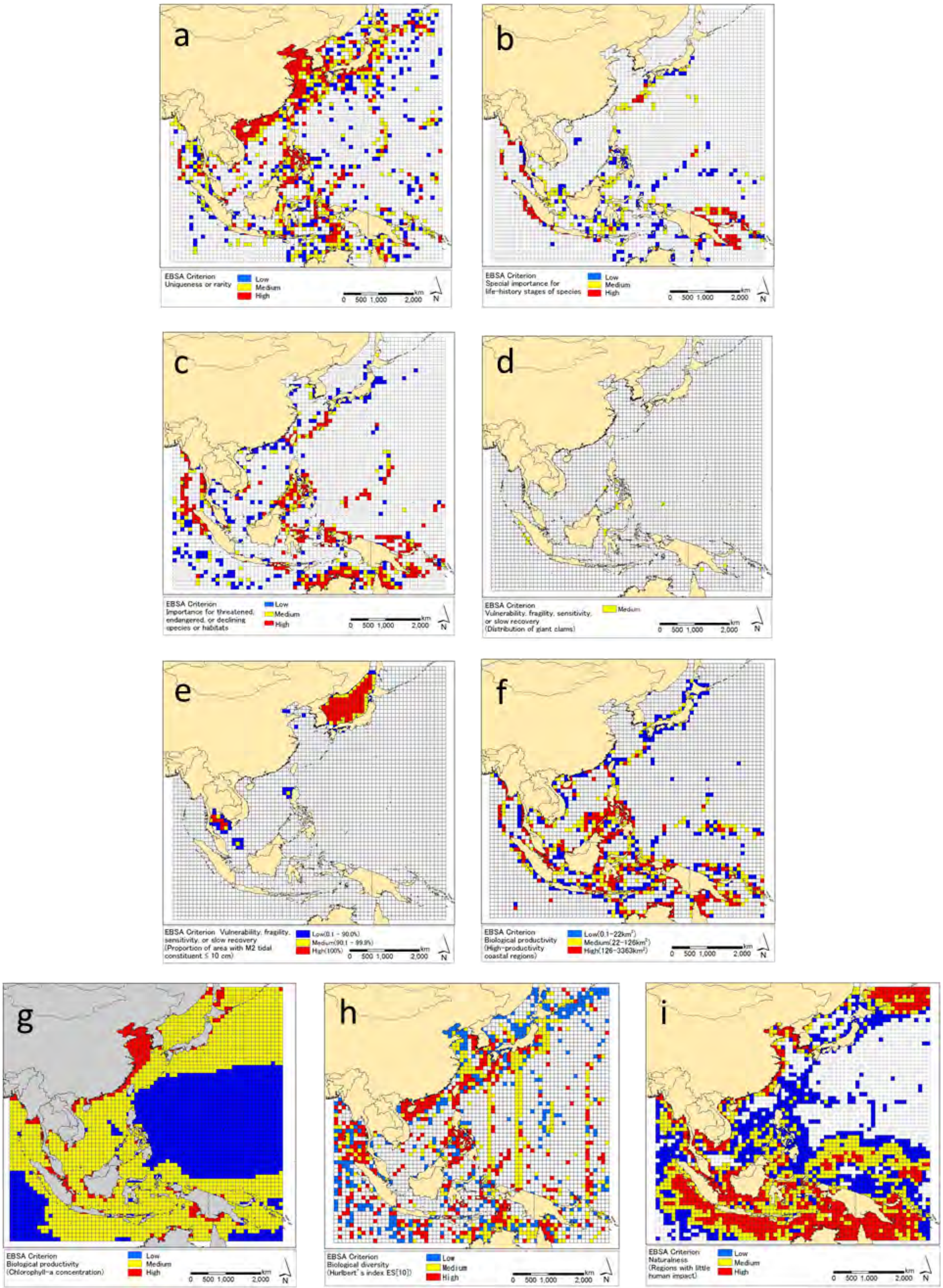
Supplementary Fig S-1.





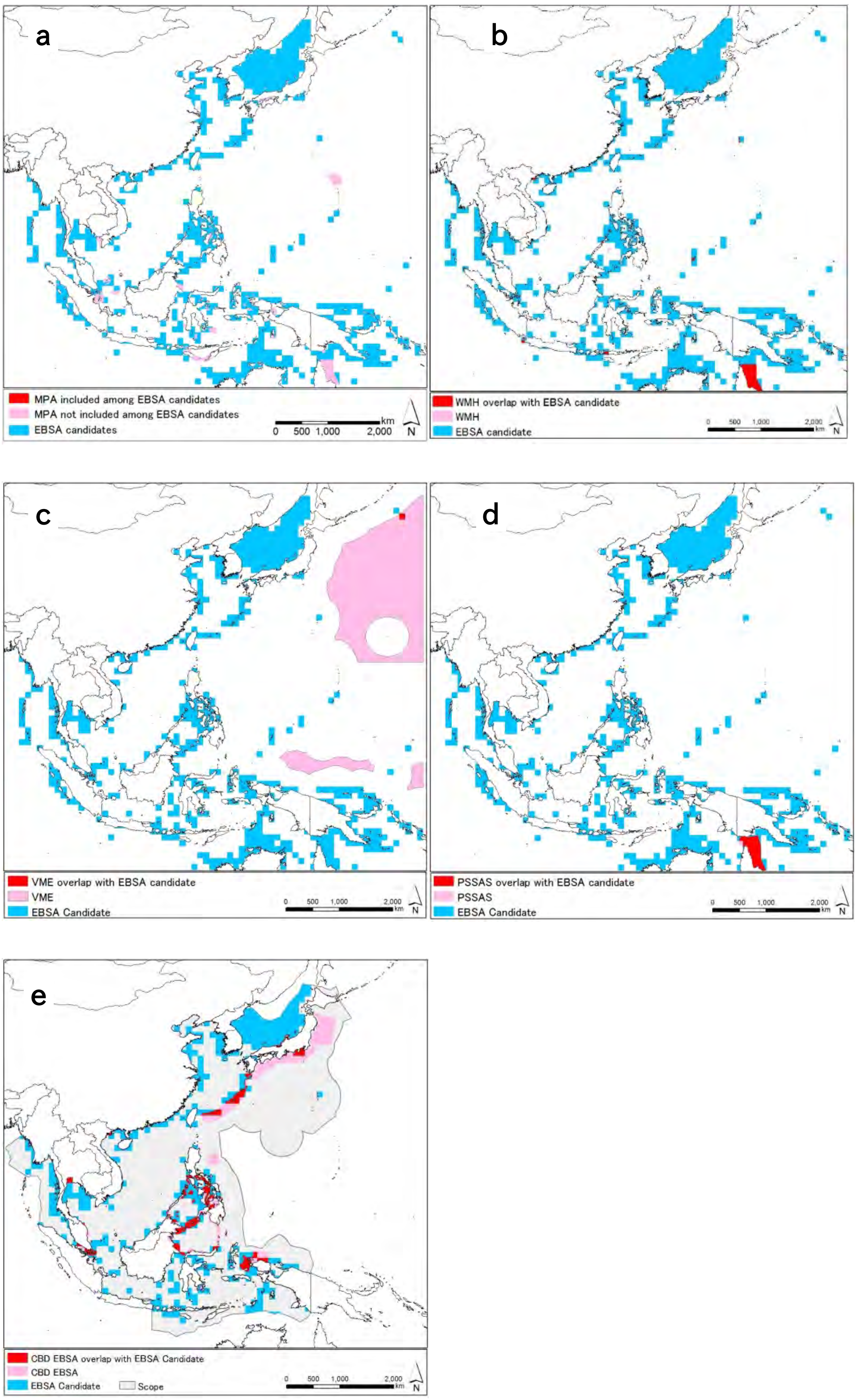
GIS maps created for each index. (a) Total species number of Cnidaria, Arthropoda, Mollusca, and Perciformes recorded only from the study area. (b) Distribution of the Indonesian coelacanth *Latimeria menadoensis*. (c) Distribution of nests of six sea-turtle species. (d) Spawning areas of two freshwater eels, *Anguilla japonica* and *Anguilla marmorata*. (e) Distribution of occurrences of 137 threatened species, excluding long-distance migrators and corals. (f) Regions important for conservation of threatened coral species. Optimal allocation was achieved by 100 replicate complementary analyses using Marxan. (g) Distribution of giant clams which lives in coral reef (distribution of coral reef was also showed to inform their habitat). (h) Enclosed coastal seas with an M2 tidal constituent ≤10 cm. (i) Distributions of coral reefs, seagrass, and seaweed beds, and mangroves. (j) Chlorophyll-a concentrations averaged between January 2008 and October 2013. (k) Numbers of species in accumulated data per 1° grid. (l) Numbers of individuals identified to species level in accumulated data per 1° grid. (m) Hurlbert's Index, ES(10), for all taxa. (n) Regions with little human impact, based on data used by Halpern et al. (2008) [9].

Supplementary Fig S-2.



Three-rank (low, medium, high) evaluation of each EBSA criterion. (a) Criterion 1 (integrated value). (b) Criterion 2 (integrated value). (c) Criterion 3 (integrated value). (d) Criterion 4 (distribution of giant clams). (e) Criterion 4 (enclosed coastal seas with an M2 tidal constituent ≤10 cm). (f) Criterion 5 (high-productivity coastal regions). (g) Criterion 5 (chlorophyll-*a* concentration). (h) Criterion 6 (Hurlbert's index, ES[10]). (i) Criterion 7 (regions with little human impact).

Supplementary Fig S-3.



Overlay of the EBSA candidate of this paper and other registered areas for the purpose of conservation. a) Marine Protected Areas(MPAs). b) UNESCO World Marine

Heritage(WMH). c) FAO Vulnerable Marine Ecosystem (VME). d) IMO Particularly sensitive sea areas (PSSAS). e) CBD-EBSA raised by regional workshop.

Supplementary Table 1. Additional literature used for data input.

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