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Identification of important marine areas around the Japanese Archipelago: Establishment of a protocol for evaluating a broad area using ecologically and biologically significant areas selection criteria

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ABSTRACT

After the adoption of the Aichi Target, data accumulation and evaluation regarding biodiversity have progressed rapidly. The use of ecologically and biologically significant areas (EBSAs) criteria to evaluate important areas enables the identification of effective and prioritized areas for ecosystem management. This includes strategic environmental assessment and discussions aimed at establishing protected marine areas based on scientific data. This paper reviews previous and current ideas as well as the methods used, for the identification of EBSAs. In particular, the following issues are addressed: problems associated with different types of marine ecosystems in the Japanese Archipelago, such as seagrass and seaweed beds, coral reefs, offshore pelagic plankton, and deep-sea benthic ecosystems; and problems associated with the integration of multiple criteria that are not totally exclusive. Several candidate variables accounting for each of the 7 criteria used to identify ecologically important areas are presented. Data availability is the most important criterion that allowed for the comprehensive evaluation of different types of ecosystems in the same localities. In particular, for coastal ecosystems such as seagrass, seaweed beds, and coral reefs, it is possible to carry out broad spatial comparisons using variables representing most of these 7 criteria. Regarding methods for the quantitative evaluation of each criterion and their integration, application of these methods to kelp forest ecosystems in Hokkaido, Northern Japan is presented as a case study.

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1. Introduction: progress of marine conservation by international policy makers

Biodiversity conservation is a crucial issue for the sustainable use of natural resources and security of human societies. Taking action to effectively halt the loss of biodiversity is the responsibility of the contracting party to the Convention on Biological Diversity (CBD)(CBD-COP 6 Decision VI/26 [1,2]). The Global Biodiversity Outlook 3 (GBO3 [3]) reports that the target agreed upon by the world's governments in 2002—"…to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level"—was not achieved. Habitats in coastal areas, such as mangroves, seagrass beds, salt marshes, and shellfish reefs, are declining continuously. The biodiversity of coral reefs is also declining significantly [3,4]. It is reported that including offshore marine areas, "…about 80 percent of the world marine fish stocks for which assessment information is available are fully exploited or overexploited," [3]. In response to this situation, the Aichi Target, which is to be achieved in the next decade, was adopted in the Tenth Meeting of the Conference of the Parties to the CBD (COP10/CBD; CBD decision X/29 in CBD Secretariat [5]; Yamakita [6]). The Target 11 Strategic Goal C was proposed to extend conservation areas, which are particularly important for biodiversity and ecosystem services, and encourages the nations of the COP to specifically conserve at least 17% of terrestrial and 10% of coastal and marine areas by 2020 [5]. Thus, consideration of the spatial aspect of coastal and marine ecological conservation is increasingly recognized.

Although the establishment of marine protected areas (MPAs) is the primary conservation strategy in many regions, merely setting up MPAs by broad sense definition[1] is insufficient to effectively improve the current state of marine biodiversity [9]. This is related to two important criteria required for MPAs. First is the ecological importance of each location, and the second is management effectiveness. The effort to improve management efficiency has already started. For example, IUCN proposed the classification of Protected Areas [8]. In the case of fisheries science, there is an effort to manage fisheries at the maximum sustainable yield considering the ecosystem [10]. Discussion of the ecological importance of the location is also underway, not only to discuss the biological potential of areas for establishing MPAs, but also regarding basic information to be used for ecological impact assessment (EIA) or strategic environmental assessment (SEA). In both cases, much information regarding habitats, ecological status, and biodiversity should be integrated, and the significance of the area should be assessed on the basis of scientific data and expert opinions. This is discussed further in Target 11.

Before the adoption of the Aichi Target, a protocol for identifying ecologically and biologically significant areas (EBSAs) was established by Canada's Department of Fisheries and Oceans (DFO) in 2004 to be used as a tool to promote the selection of marine areas where protection should be enhanced (reviewed in Dunn et al. [11]. In a workshop held in 2004, the DFO developed *a priori* criteria to select EBSAs and defined the following 5 criteria for understanding ecosystem structural and functional significance: (1) uniqueness, (2) aggregation, (3) fitness consequences, (4) resilience, and (5) naturalness [12]. In 2008, the 9th meeting of the Conference of the Parties (COP9/CBD; DEC/IX/20) adopted the following 7 scientific criteria for identifying EBSAs, which were modified from the DFO's criteria to enforce initiation of protection area in open waters and deep-sea habitats: (1) uniqueness or rarity; (2) special importance for life-history stages of species; (3) importance for threatened, endangered, or declining species and/or habitats; (4) vulnerability, fragility, sensitivity, and slow recovery; (5) biological productivity; (6) biological diversity; and (7) naturalness. In 2010, the COP10 noted that application of the EBSA criteria is a scientific and technical exercise, and that it has no obligation to consider MPAs directly. However, areas found to meet the criteria may require enhanced conservation and management measures, which can be achieved through a variety of means, including MPAs and EIA [13]. Six regional workshops on EBSAs convened by the Executive Secretary of the CBD have been held since 2011 and have covered the Western South Pacific, Wider Caribbean and Western Mid-Atlantic, Southern Indian Ocean, Eastern Tropical and Temperate Pacific, North Pacific, and South-Eastern Atlantic [14].

[1] MPA described here is based on the broad definition in Dudley 2008 which include "management area to protect particular species" and "traditional management practices" as examples. Narrow definition of MPA (i.e. no take marine reserve) is one out of six categories [7,8].

2. Correspondence on international policy by scientific communities

Following the progress for marine conservation by international policy makers, various scientific communities have also been developing ways to evaluate marine ecosystems on broad spatial scales. For the ecological categorization of marine areas, the Biogeographic Classification of the World's Coasts and Shelves, and Marine Ecoregions of the World (MEOW) are used in coastal and marine research [15]. The Global Open Ocean and Deep Seabed (GOODS) biogeographic classification has been established under the ultimate umbrella of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and its Intergovernmental Oceanographic Commission (IOC) [16]. Data regarding the presence of species registered in the Ocean Biogeographic Information System (OBIS) and Global Biodiversity Information Facility (GBIF) has greatly increased [17]. Satellite images, data from geographical information systems (GIS), and oceanographic ensemble data are updated frequently, and are becoming more organized. These data regarding species distribution models have become popular methods for studying marine biodiversity [18]. Attempts to improve these models are principal challenges, such as consideration of the effect of evolutionally aspects using geographical variables [19,20]. Along with the increase in spatial data and broad-scale studies on marine biodiversity, quantitative methods are used to fill gaps in spatial distribution and production. These use surrogates of a certain biodiversity index, and are currently in progress [21,22].

Using these data, the number of empirical case studies on the application of the EBSA protocol have been increasing recently [23,24]. For example, Taranto et al. [25] proposed a framework for applying the EBSA criteria to locate ecologically and biologically significant seamounts and assessed the relevance of individual seamounts using 10 indicators. Meanwhile, McKinnon et al. [26] examined the application of the EBSA identification process for tropical marginal seas and concluded the process is an important and tractable step for sustainable management. Bundy et al. [27] demonstrated local ecosystem knowledge provided advice for ecosystem approaches for inshore coastal management using the EBSA concept. These studies have used several criteria of EBSA and have successfully detected specific areas with highly important characteristics.

In the case of the management discipline and establishment of MPAs, including the sociological and/or political aspects, methods for supporting spatial planning are also in development using spatial planning tools and GIS. In particular, prioritization using complementary analysis is a popular optimization tool for maximizing the number of species protected in the smallest protected area [28,29]. One of the most commonly used software programs is Marxan [30], which was initially developed to select MPAs in the Great Barrier Reef. Using Marxan, Levy et al. [31] examined a method for marine conservation planning in the Indo-west Pacific area while incorporating climate change modeling; they proved it is possible to use Marxan and incorporate temperature dynamics for broad-scale conservation area planning. This type of optimization is useful not only for optimization of MPA establishment considering species distribution and sociological weight, but also for the integration of different types of data such as environmental data or other surrogates, including the different criteria used in EBSA extraction.

In the case of Japan, the Ministry of the Environment has been running several projects to reach the Aichi Targets after the COP10/CBD in Nagoya. A scientific project for the quantitative evaluation of biodiversity loss and making predictions for marine ecosystems has been started as a part of the research program entitled, "Integrative Observations and Assessments of Asian Biodiversity," as the Strategic Projects S9 of the Environment Research and Technology Development Fund conducted by the Ministry of the Environment, Japan [32]. In addition, the Ministry organized an advisory commission to select important marine areas on the basis of integrated information on marine environments around Japan [33]. The committee employed 8 criteria to select important areas, 7 of which are based on the CBD EBSA criteria, and applied all of them to the marine areas of the Japanese coast and offshore regions within Japan's exclusive economic zone.

In the first half of this article, progress in the quantification of each EBSA criterion in 5 different ecosystems in the Japanese Archipelago is reviewed. In the second half of this article, a simple method for integrating the 7 different criteria and different ecosystems is proposed, and an example is provided. Finally, we discuss the possible EBSA extraction process whilst simultaneously evaluating all criteria across the whole scope region and across different ecosystems, which has yet to be accomplished.

3. Quantification of EBSA criteria for major marine ecosystems in Japan

The marine project of the S9 research program evaluated the CBD EBSA criteria to verify the capability of quantitative evaluation for Japanese marine environments. The following 5 important marine ecosystems have been selected for this examination: seagrass beds, seaweed beds, coral reefs, offshore pelagic waters, and deep-sea vents and seeps. The descriptions of indicator for each criterion can be found below and are summarized in Table 1. The quantitative variables for each CBD EBSA criterion were considered on the basis of the definitions in COP decision IX/20, annex I.

3.1. Criterion 1: uniqueness or rarity

This criterion is defined as, "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,"[5]. This criterion is used to identify the occurrence of unique organisms such as endemic species as well as sites or habitats with unique assemblages of marine organisms (such as geomorphology).

In this research program, only biological aspects and a corrected list of species were used for evaluation. However, it was difficult to obtain reliable information on the distribution of endemic species in many taxa. Thus, alternative approaches to select sites with unique community structure and/or population genetic structures of key species are considered. In the case of kelp forests in Hokkaido, similarity in kelp community structure was determined, and areas with higher dissimilarity from other sits were ranked higher according to this criterion. For seagrass beds in Japan, information on the center of the distribution of endemic seagrass species around the Japanese Archipelago, distribution of species in limited numbers in present habitats (e.g., red list species) and with respect to the genetic distance of some seagrass species, or sites with morphologically unique seagrasses were available to select sites according to this criterion. In the case of coral reefs, 2 groups of islands, which are the habitats of several endemic species, can be used as an alternative index. For deep-sea ecosystems, complementary analysis of species composition can be used to select sites with unique combinations of vent and seep communities [34]. For offshore pelagic ecosystems, the uniqueness and rarity in the ocean physical/current system must be evaluated because of the limited information about this criterion with respect to pelagic plankton species.

The most useful information for the quantification of criterion 1 is an endemic species list. However, accumulated information on the distribution of endemic species is insufficient in Japanese waters, especially for offshore pelagic and deep-sea areas. To overcome this bias, it is important to clarify the relationships between research efforts and the distribution of endemic species. In addition, biased distribution of endemic species may occur as a result of the duration, speed, or location of evolution. Additional research is required on these topics. Typical scale mismatch can occur when using different sources of information on endemic species. For example, a globally defined endemic species may occur at many sites within a certain region. If the study area is limited to this region, the species cannot be used as an indicator of this criterion. In contrast, some globally common species may be rare in some regions. In such cases, the distribution of species in the focal area can be used as an index for this criterion if the research area in confined to the specific region.

3.2. Criterion 2: special importance for life-history stages of species

This criterion is defined as, "areas that are required for a population to survive and thrive," [5]. This criterion is intended to identify the areas required for the survival, reproduction, and critical life-history stages of individual species, such as breeding sites, nesting grounds, spawning areas, and way stations of mobile species. Alternatively, this criterion can be evaluated by considering the metapopulation structures of major marine species. Source populations revealed by molecular genetics analyses should be ranked higher than sink populations for this criterion. Furthermore, recent developments in the bio-tracking of animals can be used to evaluate this criterion by indicating which specific locations within the area are important for the total life history of the target species [35].

This study investigated whether there is information regarding the use of certain habitats by key mobile fauna as well as the genetic connectivity of fundamental species. For the kelp community in Hokkaido, fishery catch data on 7 key species by the local government can be used as an alternative index of this criterion. In the case of coral reef ecosystems, sites in the upper stream side of ocean currents were considered the source population; thus, these sites were given high scores for this criterion. However, these types of data are currently unavailable for seagrass bed, offshore pelagic, and deep-sea ecosystems; thus, it is difficult to use this criterion for EBSA selection for these ecosystems. Even in references regarding this criterion [35], the application of this criterion in the deep sea was considered difficult in many cases.

As a result, criterion 2 is difficult to be employed in most ecosystems because of a lack of data. This occurred in the case study on EBSA selection on a wider Asian regional scale (Uchifune

Table 1
Candidate indices for each EBSA criterion and their applicability to major marine ecosystems around Japan.

Candidates for quantitative indices for each criterion	Data availability/Plausibility of the quantitative indices in Japan				
	Kelp Forest	Seagrass bed	Coral reefs	Offshore pelagic	Deep sea
Criteria 1					
Distribution of endemic species	n/a	some	some	n/a	limited
Unique species assemblage structure	available	limited			available
Unique genetic structure of key species	n/a	some			
Criteria 2					
Data on habitat use by important species	n/a	n/a	n/a	n/a	n/a
Data on fisheries statistics of important species	available	n/a	n/a	n/a	n/a
Animal tracking data	n/a	n/a	n/a	n/a	n/a
Molecular genetic data to specify source and sink populations					
Ocean current data to specify source and sink populations			used		
Criteria 3					
Occurrence in endangered species red lists	available	available	available	n/a	n/a
Criteria 4					
Data on long-term changes in habitat area	available	some	available	some	some
Indicator species information	n/a	n/a	some	n/a	n/a
Criteria 5					
Data on primary productivity	limited	available	limited	n/a	n/a
Area or coverage as a proxy of productivity	available	available	available	n/a	available
Secondary or higher trophic level productivity	some	some	available	available	available
Satellite images (e.g., ocean color)	some	some	some	available	n/a
Criteria 6					
Species richness and other diversity indices	available	available	available	available	available
Criteria 7					
Human population data	available	available	available	n/a	n/a
Data on coastal development	available	available	available	n/a	n/a
Level of protection as natural reserves	available	available	available	n/a	n/a
Fisheries data	some	n/a	some	available	n/a
Industrial use (e.g., marine mining)	limited	limited	limited	n/a	available

et al. under review). This criterion does not need to include quantitative data from across the entire ocean, considering the underlying concept that includes qualitative information regarding breeding areas that are already known. However, basic data collection on habitat use by major mobile species in Asian waters during their life histories, such as use of spawning grounds, is insufficient. Fisheries statistics can be used as substitutes for stock data regarding the kelp community. Although the availability of fine-scale reliable data is limited, rough spatial resolution, such as regional analysis, is better to avoid conflict between conservation and fisheries in this case. Research on animal tracking by bio-logging to investigate the movement of marine organisms has recently been increasing [37]. Data sharing and gathering after initial publication are useful to when utilizing these types of data for selecting important sites with respect to the life history of certain species.

3.3. *Criterion 3: importance of threatened, endangered, or declining species and/or habitats*

This is criterion is defined as an "area containing habitat for the survival and recovery of endangered, threatened or declining species or area with significant assemblages of such species," [5]. This criterion targets threatened, endangered, or declining species and their habitats for consideration. As discussed for criterion 1, the selection of endangered species depends on the individual study areas. If the research target is limited to certain areas (e.g., within the Japanese coast as in the present study), locally endangered species should be used even if they are still abundant in other regions worldwide.

The present research program used the area and the species number of endangered species listed in the IUCN red list as well as the endangered species list of the Ministry of the Environment of Japan. In the case of kelp forest ecosystems, the distributions of 5 kelp species listed in the Ministry of the Environment red list were used to rank the sites according to this criterion. For seagrass bed and coral reef ecosystems, both the Ministry of the Environment endangered species list and the IUCN red list can be used. However, these lists do not include any endangered species among offshore deep-sea chemosynthetic benthic organisms or oceanic plankters. Therefore, additional information on engendered species is required to apply this criterion.

Unlike other EBSA criteria, it is possible to apply the same indices for different ecosystems. To do this, the spatial extent where the status of each species is defined should be compared and adjusted among different sources. For endangered marine species, there may be some undiscovered sites. The use of species distribution models to predict sites where these species might be present may be difficult for endangered species because of small sample sizes. Methods for assessing accuracy and uncertainty must be developed to utilize this criterion across different ecosystems.

3.4. *Criterion 4: vulnerability, fragility, sensitivity, and slow recovery*

This criteria is defined as, "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," [5]. This criterion determines the inherent sensitivity of habitats or species to disruption, and estimates resilience to physicochemical perturbation. The slowly reproducing species are potentially at high risk to impacts. The vulnerability of benthic ecosystems in relation to bottom-contact fisheries has been assessed by the intensive survey of the Food and Agriculture Organization of the United Nations (2008, 2013).

Thus, this criterion is applied to slow-recovering, sensitive, or fragile ecosystems. In this research program, the rates of decrease and recovery rates of fundamental species were considered. In the case of kelp forest ecosystems, changes in the kelp forest area from 1996 to 2009 were analyzed for each local government unit in Hokkaido. The score of this criterion was defined on the basis of this analysis. Recovering the coverage rate from breaching events can also be used to rank sites for coral reef ecosystems. However, similar long-term data are not available for seagrass, pelagic plankton, or deep-sea ecosystems. It is possible to evaluate this criterion by analyzing remote sensing data of seagrass bed distribution, the distribution of species in the plankton community sensitive to environmental change, and evaluating trends in the diversity and biomass of benthic species for deep-sea ecosystems.

For criterion 4, the dynamics of a given ecosystem must be evaluated temporally after any impacts on the ecosystem. However, realistically monitoring an ecosystem after any impact and assignment to a management area after several years of monitoring will be too late. Some large events can destroy or alter overall ecosystems (e.g., [38,39]). Alternatively, in cases in which long-term data are unavailable, indicator species that inhabit only sensitive areas and/or directly represent vulnerability (e.g., long lifespan) can be used. Such indices can be applied to EBSA selection in Asian regions where long-term data are unavailable [36]. In addition, sensitivity area maps for various purposes such as accidental oil spills; if they exist, the data can be directly utilized as a part of the evaluation process of this criterion.

3.5. Criterion 5: biological productivity

This criterion is defined as an "area containing species, populations or communities with comparatively higher natural biological productivity," [5]. This criterion is focused on identifying highly productive regions that support abundant producers and consumers. In marine ecosystems, primary producers include not only photosynthetic organisms, but also chemosynthetic organisms that drive the ecosystems in hydrothermal vents and methane seeps.

Highly productive areas such as fronts of upwelling currents or river mouths are considered major candidates. In this research program, the primary productivity of fundamental species is quantified by direct/indirect measurements as well as fisheries statistics (e.g., for kelps). Furthermore, productivity can be represented by the area of distribution in the case of kelp beds by assuming positive relationships with area and productivity. In the case of seagrass ecosystems, productivity can be calculated according to area and primary production using a model used in previous studies. The scale of the development of a reef can be used to represent productivity in coral reef ecosystems. In the offshore pelagic plankton community, chlorophyll A concentration can be estimated using satellite images and used as proxy for productivity. Zooplankton biomass obtained by several research cruises can also be used as a good indicator of productivity. In the deep sea, the biomass of *Calyptogena* clams and *Bathymodiolus* mussels living symbiotically with chemosynthetic bacteria are candidates for representing productivity.

Data on productivity are generally available for most types of ecosystems. Spatial estimation of the variation of primary productivity is also possible using remote-sensing and GIS techniques. Among habitat comparison methods, the integrated use of quantitative indices for this criterion is plausible. Nevertheless, further studies on the accuracy of the estimation of productivity as well as methods for the extrapolation and evaluation of geographical variation are required for more precise evaluation.

3.6. Criterion 6: biological diversity

This criterion is defined as an "area containing comparatively higher diversity of ecosystems, habitats, communities, or species, or higher genetic diversity," [5]. There is no scientific consensus regarding the definition of biological diversity or biodiversity [40,41]. Therefore, this criterion must be considered according to multiple aspects including the absolute number of elements such as richness, popular biodiversity indices representing relative abundance (e.g., evenness), and differences in variables (e.g., taxonomic distinctness). In this research program, species richness and diversity indices are calculated on the basis of the database on species occurrence in major ecosystem types. This time, the species diversity of focal fundamental species was considered. For example, for kelp forest ecosystems, the number of kelp species can be used to rank this criterion for kelp beds. In the cases of seagrass and coral reef ecosystems, both the diversity index and number of species can be used. In pelagic plankton ecosystems, the number of zooplankton species in a certain taxon (e.g., copepods) can be used, because there are a sufficient number of samples to provide accurate estimates. The number of benthic species can also be used for deep-sea ecosystems.

Thus, simple and common indices such as species richness (i.e., the number of species) can be used for different ecosystem types. The next step is to develop better indices considering the evenness of species distribution as well as phylogenetic relatedness. This is especially important for comparisons among different ecosystems because of large differences in lifetimes and speed of evolution [42]. More importantly, problems associated with the effects of research efforts on the estimation of species diversity should be considered as in the case of criterion 1 (Nakajima et al. 2015).

3.7. Criterion 7: naturalness

This criteria is defined as an "area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation," [5]. This criterion is a relative measure in that "pristine conditions" are most important and should be preserved as best as possible.

In this research program, data such as the area of natural reserves, ratio of natural to artificial coastline, and human population size per catchment area are available and can be used for coastal ecosystems like kelp forests, seagrass beds, and coral reefs. On the other hand, offshore pelagic plankton and deep-sea benthic ecosystems, of which we are not yet able to determine the direct effect on fisheries, are mostly regarded as relatively natural; therefore, it is difficult to find relevant data showing variations in "naturalness." For offshore pelagic ecosystems, data recorded from fisheries can be used, although the available species are limited. Distance from the coast can also be used as a rough approximation of fishing intensity. For deep-sea ecosystems, depth can be used as an approximation of fishing effort. The possible exploitation of deep-sea energy and mineral resources must also be considered, because deep-sea research that is based on long-term observations is insufficient to analyze the dynamics of unique ecosystems such as hydrothermal vents [43].

In theory, criterion 7 must be identified by quantifying human activity and its impacts on ecosystems. Available quantitative indices are mostly from the statistics of the Japanese government. In order to apply these indices to other countries in Asia, satellite images such as nighttime images of artificial light density and changes in coastline structures can be used to measure spatial and temporal variations in human impacts. Globally, the human impact model [44] can be used as an index of naturalness. For the open ocean, the use of fisheries statistics should be considered.

4. Summary of the quantification of EBSA criteria

In summary, this paper reviewed the methods used to quantitatively evaluate 7 criteria of 5 major marine ecosystems around Japan. Although EBSAs are criteria for evaluating the significance of subjectively decided areas, it is possible to include multiple criteria for the selection of EAs/EBSAs for different ecosystem types. However, the available data still vary between these criteria and the target ecosystems (Table 1). In most cases, the distribution data of fundamental species represents the major data source for quantification. Remote-sensing data and species occurrence data by field observations are also very useful for this purpose.

Nevertheless, there is a serious lack of data for some categories. For example, data on mobile fauna are insufficient to make quantitative indices for criterion 2. Data on the temporal dynamics of ecosystems (criterion 4) are difficult to obtain in some ecosystems. As this project has primarily focused on fundamental species such as kelps, seagrasses, and corals, fisheries data cannot be used to directly measure most of these species, which are non-commercial, except for major kelps. In addition, some of the literature describing local biodiversity and ecosystem conditions is based on so-called "gray literature," which contains unreliable data. Nevertheless, without peer-reviewed scientific data, these data sources have to be relied on while taking their accuracy into account. In such cases, it is worthwhile to prepare alterative indices or surrogate parameters from other sources to evaluate data certainty.

5. Case study: integration of different criteria in kelp forest ecosystems in Hokkaido

As an example, the quantitative evaluation of each EBSA criterion, and their integration, was applied to Laminariales kelp forests around Hokkaido in Northern Japan. Each criterion was evaluated using quantitative values explained in the second section of this paper. The evaluation was made for the coastlines of each local governmental unit (LGU) where the rocky subtidal shores exist, which included 55 municipalities in 2004. The variables used are as follows: (1) the average dissimilarity of the kelp community for criterion 1, (2) fisheries yield for 7 commercially important species known to use kelp forest as major feeding habitats and/or spawning sites for criterion 2, (3) the numbers of 5 kelp species listed in Red Data Book of Japan [45] for criterion 3, (4) temporal changes in the kelp forest area between 1978 and 2009 for criterion 4, (5) the area of kelp forest used as a proxy for biological productivity for criterion 5, (6) species richness of kelp species for criterion 6, and (7) whether or not the coastline is registered as a national or prefectural park. All of these data were categorized as good (rank 3), moderate (rank 2), or poor (rank 1). Each LGU and all 450 5×5-km grids covering the entire coastline of Hokkaido were ranked, except for criterion 7, in which a rank was directly given for each grid. The integration of different criteria and final output of the map were based on the 5×5-km grids. The detailed methods and data sources can be found in Appendix I.

Because each indicator examined in the previous paragraph has a different statistical distribution and units, standardization was used to transform the original data into categorical ranks. Among several types of categorizations [46,47], quantile classification was used to rank the data as high, medium, and low. The first, middle, and final thirds are assigned ranks 1, 2, and 3, respectively. Thus, each of the 3 ranks has the same numbers of sample and has a uniform distribution. The method of employing quantile classification using the R program [48] is described in Appendix II. NA values, empty values, and zero values were considered no information and omitted in advance.

There are 2 types of method used to integrate multiple indicators that represent different criteria. One method is to consider the contribution of each criterion equally (i.e., unweighted integration), and the other is to weight criteria based on their significance. For the former, the average values for each criterion (i.e., arithmetic mean) and the geometric mean are used. Three different types of integration methods were considered to be weighted: (1) the use of the maximum value, (2) the sum of 3 axes of ordinated data by principal component analysis (PCA), and (3) complementation analysis. When the maximum value is used, it is possible to select all important locations for at least one criterion. This integration meets the fundamental definition of EBSA because these locations meet at least one criterion. When the distribution of categories can be assumed to be continuous with some normality and linearity, ordination using PCA can be used. This is weighed to each criterion without being dependent on the condition of the location. For the integration considering their complementarity, Marxan is used [30,49]. This software uses an optimization method by simulated annealing. Complementation analysis by Marxan was originally used to prioritize the protected area by maximizing the number of species to be conserved while minimizing the number of sites. Because Marxan solves the proximity of the combinational optimization problem, it can also be used to evaluate suitable locations to maximize the total points of the 7 different criteria within a limited number of selected sites. For this example, Marxan was run 100 times, and the number of times each site was selected as important was presented. The R code for these methods can be found in Appendix II.

The values that are not evaluated (i.e., missing values or so-called "null data") can sometimes influence the integration results. In the case of the equally weighted method, the omission of null data and the inputting of an arbitrary value (i.e., 0 or 1) are considered. Because this analysis does not intend to rank sites lacking some lower values, the omission of null data can be adapted. In the geometric mean method, a value of 1 is assigned to the null data. In the case of PCA analysis, null data in the original dataset should also be ordered into the new axis.

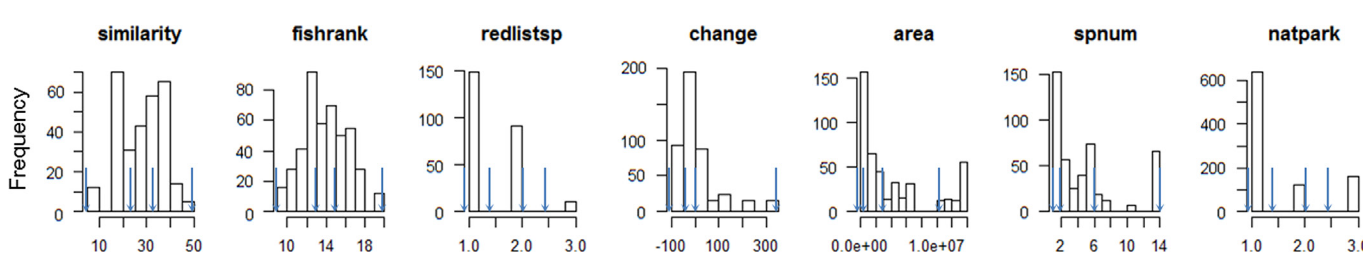

Fig. 1. Original frequency distribution of the data of the 7 criteria (Cr.). Cr. 1 (similarity): average similarity in the kelp community, Cr. 2 (fish rank): average rank of 8 fish/shellfish catch, Cr. 3 (area): kelp bed area in each city, Cr. 4 (change): ranked changes in areas from 1996 to 2009, Cr. 5 (spnum): productivity represented by number of kelp species, Cr. 6 (redlistsp): average of ranked endangered kelp species, Cr. 7 (natpark): ratio of national parks. Values classified into 3 ranked categories by the quantile method are indicated by arrows.

As a result, the frequency distribution of the original data varied greatly by criteria (Fig. 1). The maps showing the rank distribution indicated similar regional patterns among some criteria such as higher ranks of fishrank area spnnum in the Pacific side of the eastern peninsula (Fig. 2). Transformation to the 3 levels of rank data dampened the skew of the frequency distributions of most variables (Fig. 1).

As some of the variables exhibited similar spatial patterns of variation, PCA was conducted to ordinate some variables (Fig. 3; Table 2). The results show that the rankings of 6 criteria are similar to each other, except for the variable for criteria 1 (i.e., similarity), which exhibited a different pattern (Fig. 3).

The results of the integration of the 7 criteria were similar for all methods (Figs. 4 and 5). The variation was greatest for the method using PCA followed by (in descending order) those using Marxan, geometric mean, arithmetic mean, and maximum rank. In the case of the maximum rank method, 3-rank classification was possible and exhibited a high frequency of maximum values. The values were higher in eastern and northern Hokkaido; thus, these regions are considered important for the conservation of kelp forests in Hokkaido.

6. Discussion

Here, a method for selecting EBSAs on the basis of quantitative variables representing 7 different criteria was developed. The method is based on reliable scientific information and is applicable to various types of marine ecosystems and regions if there are data regarding spatial and temporal variations in the diversity and abundance of marine organisms, physicochemical environmental conditions, human use of marine resources, and regulations. However, there are several challenging problems at each phase of the EBSA extraction and prioritization procedure, including the selection of proper variables for each criteria, data standardization, and integration of different criteria.

When establishing quantitative indices for each criterion, it is difficult to apply the same indices across different types of marine ecosystems, ranging from coastal to offshore and from shallow subtidal to deep sea. This was especially true for criteria 2 and 4, because they are dependent on characteristics of biological communities (e.g., the turnover rate of community structure for criterion 4) and the life histories of major component species (e.g., the specific utilization of habitats for reproduction and nursery for criterion 2), which vary greatly with respect to ecosystem type and environmental condition. The discrepancies in selected variables among ecosystem types lead to difficulties in ranking sites for prioritization of EBSA using the same measures; therefore, this was not attempted in the present study. Because one of the applications of EBSA extraction is to designate 10% of all marine habitats as MPAs to meet the Aichi Target, one solution is to select highly prioritized EBSAs separately for each ecosystem type by setting a percentage area of

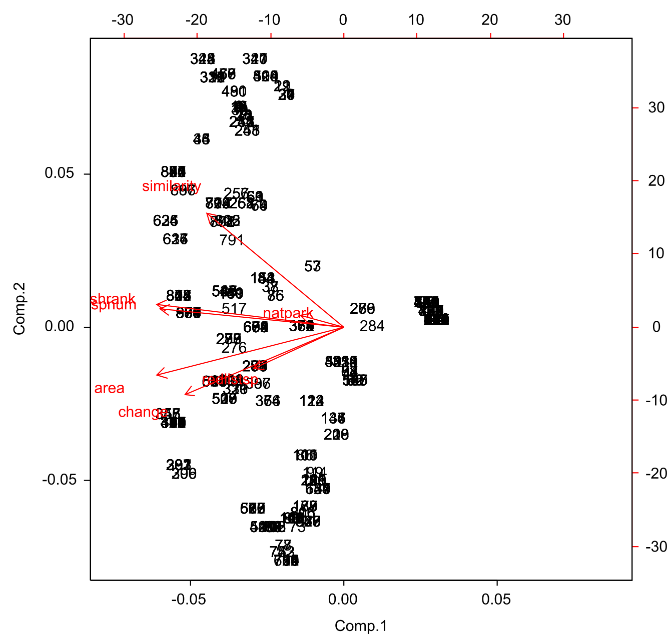

Fig. 3. Relationships among variables using PCA.

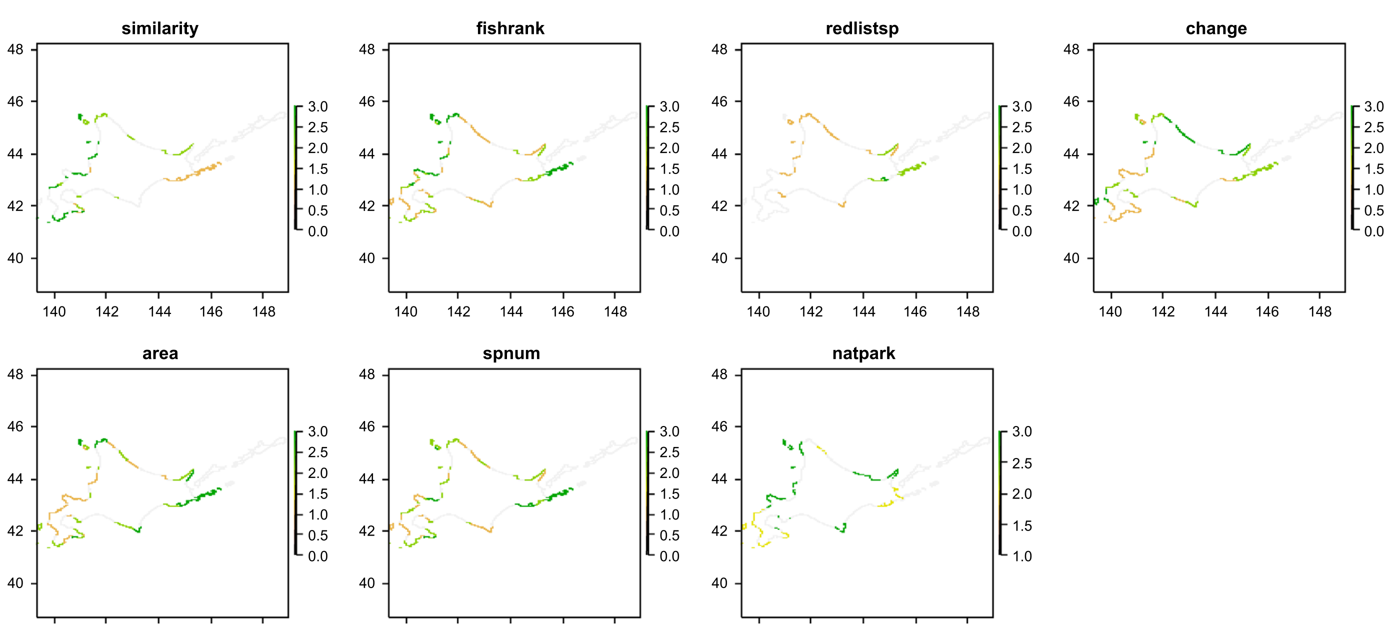

Fig. 2. Spatial distribution of the classified data. Unevaluated areas are indicated by 0. Cr. 1 (similarity): average similarity in the kelp community, Cr. 2 (fish rank): average rank of 8 fish/shellfish catch, Cr. 3 (area): kelp bed area in each city, Cr. 4 (change): ranked changes in areas from 1996 to 2009, Cr. 5 (spnum): productivity represented by number of kelp species, Cr. 6 (redlistsp): average of ranked endangered kelp species, Cr. 7 (natpark): ratio of national parks.

Table 2
Matrix of variable loadings of the result of the PCA.

	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5	Comp. 6	Comp. 7
similarity	−0.35	0.75	−0.04	−0.38	0.12	−0.24	0.31
fishrank	−0.47	0.15	−0.03	0.42	−0.41	0.60	0.23
redlistsp	−0.23	−0.28	−0.17	0.17	0.78	0.13	0.43
change	−0.40	−0.45	0.16	−0.73	−0.12	0.24	0.00
area	−0.47	−0.32	−0.03	0.26	−0.27	−0.71	0.14
spnum	−0.46	0.12	−0.19	0.10	0.28	0.03	−0.80
natpark	−0.11	0.07	0.95	0.19	0.20	−0.02	−0.06
SS loadings	1	1	1	1	1	1	1
Proportion Var	0.143	0.143	0.143	0.143	0.143	0.143	0.143
Cumulative Var	0.143	0.286	0.429	0.571	0.714	0.857	1

*Cr. 1 (similarity): average similarity in the kelp community, Cr. 2 (fish rank): average rank of 8 fish/shellfish catch, Cr. 3 (area): kelp bed area in each city, Cr. 4 (change): ranked changes in areas from 1996 to 2009, Cr. 5 (spnum): productivity represented by number of kelp species, Cr. 6 (redlistsp): average of ranked endangered kelp species, Cr. 7 (natpark): ratio of national parks.

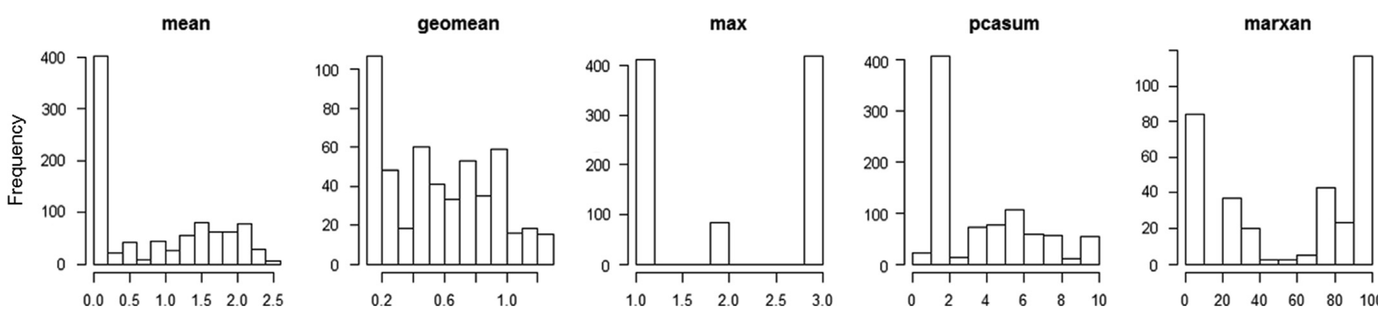

Fig. 4. Results of the integration of the 7 EBSA criteria using different 5 methods: arithmetical mean, geometric mean, maximum, average of the 3 axes of PCA, and selected counting of complementary analysis.

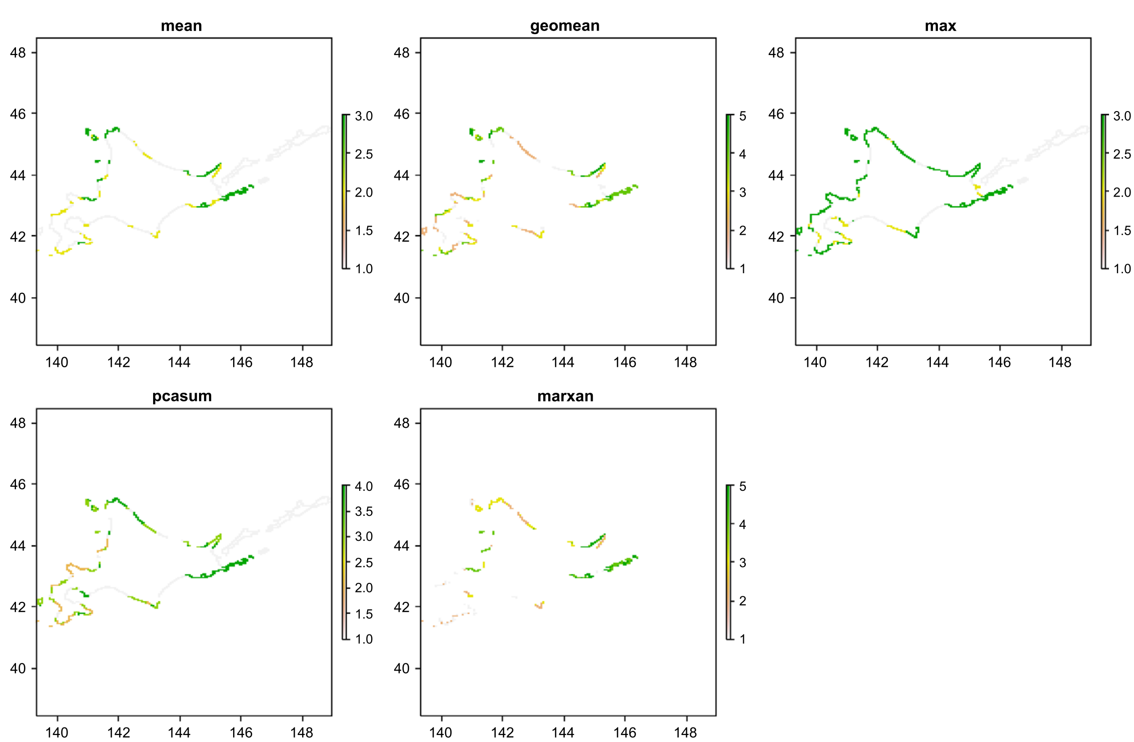

Fig. 5. Spatial distribution of the values classified into 5 categories using the results of the integration of the 7 EBSA criteria using 5 different methods: arithmetical mean, geometric mean, maximum, average of the 3 axes of PCA, and selected counting of complementary analysis.

more than 10% for each type and then combining them at the final stage. Next, other criteria that are not included in the EBSA criteria (such as representativeness) can be introduced, and MPA candidates can be selected with consideration of the sociological and/or political situation. However, the problem with this method is that each ecosystem type is assumed to be independent. Nevertheless, it is being increasingly recognized that interactions among different habitat types (e.g., between coral reefs and seagrass beds in the tropics, and seagrass and algal beds in temperate coastal areas) enhance biodiversity and ecosystem functions at the seascape level (reviewed in Yamakita and Miyashita [20]). The method for selecting significant areas on the basis of such ecosystem connectivity should be investigated in future studies.

Selected variables for each criterion, including categorical and continuous variables, exhibit different types of data distribution. Therefore, data standardization is a prerequisite for the integration of different criteria. Transformation to a standard normal distribution was classically recommended because it enables robust statistical analyses [50]. Nevertheless, this cannot be used to include categorical data as those for criteria 7 in kelp forest ecosystem of this paper as example. In such cases, the transformation to rank data is the most practical as well as the most understandable for decision makers who are non-experts. However, much information would be lost when transforming continuous data into categorical data. Recent progress in statistics, such as derivatives of the generalized linear model and hierarchical Bayes model, has enabled multivariate analyses without the transformation of original data; applications of such models should be investigated further.

The examples presented herein show that different methods for the integration of criteria can lead to different final results for EBSA extraction and prioritization. It is important to note that the data distribution of some criteria exhibit similar trends, as shown in the PCA for the kelp ecosystem example, in which 6 of the 7 criteria exhibited collinearity. Although the 7 criteria are based on independent concepts, in reality, they are related to each other [35]. For example, an endemic species selected as a candidate for criteria 1 (uniqueness or rarity) can also be endangered species, which should be used for criteria 3. In such cases of high collinearity among different criteria, additive integration such as the use of arithmetic means could give more weight to these criteria (i.e., higher values at sites with the presence of endemic/endangered species) compared to other methods of integration aiming to resolve this issue, such as the use of PCA and Marxan, which summarize axes and compare the overlap of important areas. According to the principles of the EBSA criteria, any site considered important for least one criterion can be considered a candidate EBSA [35]. Thus, integration methods considering the maximum and complementarity of different criteria may be concordant with this principle.

However, the adequacy of the weighting of variables for integration can be subjective depending on the opinions of stakeholders in the case of the selection of MPAs from among prioritized EBSAs. Consensus building among researchers regarding the prioritization of EBSAs based on scientific knowledge, such as the relative importance of a given endemic species, also should be discussed for the advanced prioritization of EBSAs. From this aspect, the use of complementary analysis taking into account spatial structures and subjective weights is promising for consensus building.

Another important problem that must be solved is the treatment of zero data, i.e., no data availability. It should be strictly clarified whether zero values in original data mean low scores with supporting information or sites with no information; in the case of the latter, there are some methods for interpolating missing values. The simplest method is to assign the average value of the whole dataset. However, this procedure can cause some biases if data unavailability is associated with the nature of some criteria. For example, data deficiency due to less research effort likely occurs in areas with poor accessibility, which may be pristine and less-impacted sites. In such cases, the actual ranking for biological diversity and naturalness would be above the average of the available data. Various techniques for inter- and extrapolating missing data using information from other sites on the basis of spatial information such as GIS were recently developed [51,52]. Species distribution models and other spatial predictions can be used to fill data gaps to more comprehensively evaluate EBSAs [53].

Finally, the adequacy of EBSAs extraction and prioritization results should be validated using other independently obtained data sources. In the case of this paper, because all available data were examined and incorporated to extract and prioritize EBSAs around the Japanese coast, it was difficult to obtain independent quantitative data for validation beforehand. Thus, cross-validation using some of the collected data is an alternative method for testing the robustness of the results. Furthermore, hearing the comments and opinions of experts regarding biodiversity and the ecosystem status of each site through interviews and questionnaires on obtained results would be worthwhile for validating the entire EBSAs extraction and prioritization process.

7. Conclusion

This paper reviewed the previously used and ongoing processes for EBSA extraction and evaluation of EBSA criteria worldwide, with particular emphasis on Japan. This paper also presented a new approach for extracting and prioritizing EBSAs according to quantitative scientific information for the 7 criteria. The proposed procedure is applicable to various marine ecosystems. In coastal areas in particular, broad spatial comparison is possible using most of the 7 criteria. In addition, quantitative data are not widely available, especially for higher-level consumers; such data are important for evaluating some criteria such as criteria 2 and 4. Furthermore, This paper presented some quantitative methods for integrating different categories of variables; the results vary depending on how each category is weighted with respect to interrelatedness. Although some challenges remain, especially regarding statistical and practical accuracy, the method proposed herein can be useful for selecting important marine areas to meet the Aichi Target.

Acknowledgments

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Appendix A. Selection and ranking of variables representing EBSA criteria for kelp forest ecosystem in Hokkaido, Japan

The occurrence data on Laminariales species around the coast of Hokkaido were collected from the SAP specimen database in the Hokkaido University Museum and occurrence records listed in the literature. They were stored in the Biological Information System for Marine Life (BISMaL) database for further analysis (GODAC/JAMSTEC 2009 [54]). A total of 35 species were found to occur in at least one location on the Hokkaido coast. From the database, the occurrence of each kelp species was recorded for the coastline of each local governmental unit (LGU; consisting of 55 municipalities in 2004) where rocky subtidal shores exist.

Criterion 1 (uniqueness of sites)

The similarity of kelp species composition was analyzed using the Bray–Curtis dissimilarity index for each pair of LGUs, and the average dissimilarity was calculated for each LGU with the occurrence of more than one kelp species. The average value (i.e., percentage similarity) ranged from 6.5% to 45.3%. Criterion 1 was scored as follows: LGUs with an average similarity $<25\%$, 25–40%, and $>40\%$ were scored 3, 2, and 1, respectively. LGUs with only one kelp species, which were excluded from the similarity analyses, were also given a score of 1.

Criterion 2 (special importance for life-history stages of species)

The fisheries yields for 7 commercially important species (*Hexagrammos* spp. and *Sebastes* spp. [rockfishes], *Clupea pallasii* [herring], *Arctoscopus japonicus* [sailfin sandfish], *Haliotis discus* [abalone], and *Strongylocentrotus intermedius and S. nudus* [sea urchins]), which are known to use kelp forests as major feeding habitats and/or spawning sites, were obtained for each LGU based on the statistics given by Hokkaido Prefecture (Marine Net Hokkaido 2014 [55]). The average yields between 1991 and 2001 were obtained for each species, and scored from 1 to 3 so that the total average was between 1.6 and 2.0; then, the scores of all 7 species were averaged.

Criterion 3 (importance for threatened species)

The occurrences of the following 5 kelp species listed in *Threatened Wildlife of Japan, Red Data Book of Japan* (Ministry of the Environment 2000) were examined on the basis of the BISMaL kelp database: *Alaria angusta* (VU), *Cymathaere japonica* (NT), *Saccharina cichorioides* (NT), *S. longipedalis* (NT), and *S. yendoana* (NT). The numbers of these threatened species at each LGU coastline were recorded. LGUs with no occurrence, 0 species, 1 species, and 2–3 species were scored 0, 1, 2, and 3, respectively.

Criterion 4 (vulnerability)

Temporal changes in kelp forest area between 1978 and 2009 were estimated for each LGU based on the GIS data on kelp forest distribution by KK Toyo Aerosurvey Co. Ltd. (1980) [56] and Hokkaido Prefecture (unpublished data in 2009). The percentage change ranged between −100% (total disappearance) to 348%. LGUs with greater loss of kelp forest during these 30 years were ranked higher, because these sites were regarded as more vulnerable to environmental stresses. LGUs with −100% to −60%, −60% to −1%, and 0% or positive change were ranked 3, 2, and 1, respectively.

Criterion 5 (biological productivity)

The primary productivity of kelp forests at each LGU was represented according to the area of kelp forest by Hokkaido Prefecture (unpublished data in 2009). The value ranged from 0.9 to 1353 ha. LGUs with >500, 50–500, and <50 ha were scored 3, 2, and 1, respectively.

Criterion 6 (biological diversity)

The species richness of Laminariaceae was determined for each LGU on the basis of the BISMaL database, ranging between 1 and 14. LGUs with >4, 3 or 4, and 1 or 2 species were scored 3, 2, and 1, respectively.

Criterion 7 (naturalness)

This criterion was determined on the basis of the whether or not a coastline is registered as a national or prefectural park. Areas registered as a national park (either national park or semi-national park), Hokkaido prefectural park, and neither were scored 3, 2, and 1, respectively. The scores were assigned for each 5 × 5-km grid rather than LGU for this criterion.

Appendix B. R code for determining rank separation and integration of different categories used in the text

This code was evaluated in R 2.15.1 Windows 7 × 64.

```
############################
# *A function to calculate the rank of
# quantile classification.
# Each class contains equal number of data
# and ranked from the smaller number to large number.
#
# written by Takehisa Yamakita 2013/12/30 ver.1.0
#
classintv.rank.df <- function(
  file=read.csv(file.choose()),
  classnum=3,use0=F,sty="quantile"
){
  require(classInt)
  x.res <- file
  if(is.data.frame(x.res)==F){
    cat("error please use dataframe")
  }
  for(i in 1:length(colnames(x.res))){
    a <- x.res[,i]
    # remove na
    x.TFna <- is.na(a)
    a <- a[!x.TFna]
    # treatment of 0
    if(use0==F){
      x.TF0 <-(a==0)
      a <- a[!x.TF0]
    }
    if(length(a)>0){
      cls1 <- classIntervals(
        a, n=classnum, style=sty
      ) # styles in classIntervals can be used
      cls2 <- factor(cut(cls1$var,breaks= c(
        unique(cls1$brks)[1]-1,unique(cls1$brks)[-1]
      ) ))# put -1 to avoid drop minimum value
      cls3 <- as.numeric(cls2)
      # treatment of 0
      if(use0==F){
        x.res[!x.TFna,i][!x.TF0] <- cls3
      }else{#removed na
        x.res[!x.TFna,i] <- cls3
      }
    }
  }
  return(x.res)
}
#
## **Usage examples
#  x <- data.frame(
#    id=1:5,cr1=runif(5),cr2=rnorm(5),cr3=rlnorm(5),
#    cr4=rexp(5,1),cr5=0:4,cr6=c(1:4,NA),cr7=rep(0,5)
#  )
#  classintv.rank.df(file=x)
#  result <- classintv.rank.df(
#    ,classnum=3,use0=F,style="quantile"
#  )
# and save the result.
#  write.table(result,file.choose(),sep=",")
#
############# the end of the function
```

```
###########################
# ***A function to create input files for Marxan
#   written by Takehisa Yamakita 2014/1/3 ver.1.0
#
df2input.marxan <- function(
    x,outwd=choose.dir(),targetnum=12,spfnum=10
){
  setwd(outwd) # set directory of marxan analysis
  dir.create("input")
  x <- na.omit(x)# remove the rows containing NA
  nrx <- nrow(x)
  # pu: planning unit
  pu <- data.frame(id=1:nrx,cost=rep(1,nrx),
                                  status=rep(0,nrx))
  # spec: species id and target
  coln <- colnames(x[,−1])
  ncoln <- length(coln)
  spec <- data.frame(id=c(1:ncoln),
                         target=rep(targetnum,ncoln),
                         spf=rep(spfnum,ncoln))
  # pu vs pr
  require(reshape)
  puvspr0 <- melt(x,id.vars=1, , variable_name = "species")
  puvspr <- data.frame(species=as.numeric(puvspr0
 $species),
                          pu=puvspr0$id,amount=(puvspr0
 $value))
  puvspr <- puvspr[order(puvspr[,2],puvspr[,1]),]
  # save input files in input folder of marxan
  write.table(pu,"input/pu.dat",sep=",",row.names=F)
  write.table(spec,"input/spec.dat",sep=",",row.names=F)
  write.table(puvspr,"input/puvspr.dat",sep=",",row.names=F)
  write.csv(coln,"input/colname_id.csv")
}
## *Usage examples
# x<-data.frame(id=1:5,sp1=runif(5),sp2=rnorm(5),
 sp3=rlnorm(5),
#           sp4=rexp(5,1),sp5=0:4,sp6=c(1:4,NA),sp7=rep
 (0,5) )
# df2input.marxan(x,outwd=choose.dir(),targetnum=12,
 spfnum=10)
# dir("input/")
############# the end of the function
###########################
# *Analysis of test data and figures in this paper
# create the data frame of different distribution pattern
set.seed(2)
x <- data.frame(id=1:100,cr1=runif(100),cr2=rnorm(100)
    ,cr3=rnorm(100,sd=10),cr4=rlnorm(100),cr5=rexp(100,1)
    ,cr6=c(0:98,NA),cr7=c(rnorm(90),abs(rnorm(10)*100)))
x <- na.omit(x)
# Figure: distribution of original values
x11(width=250, height=50);par(mfrow=c(1,7))
for(i in 2:8){
    hist(x[,i],main=colnames(x)[i],xlab="",ylab="")
}
# histogram of the transformed values
library(car)
xtrans <- x
for(i in 2:8){
     xtrans[,i] <- bcPower(
       x[,i]+abs(min(x[,i])) +0.001,
       powerTransform(x[,i] +abs(min(x[,i]))+0.001)
 $roundlam
     )
}
xtrans <- scale(xtrans)
par(mfrow=c(1,7))
for(i in 2:8){
  hist(xtrans[,i],main=paste("trans_",colnames(x)[i],sep=""))
}
# Figure: Quantile histogram
x[,-1] <- classintv.rank.df(file=x[,-1])
par(mfrow=c(1,7))
for(i in 2:8){
  hist(x[,i],main=colnames(x)[i],xlab="",ylab="")
}
# Integration of the seven criteria
nrx <- nrow(x)
result.df <- data.frame(
  id=1:nrx, mean=rep(NA, nrx), geomean=rep(NA, nrx),
  max=rep(NA,nrx), pcasum=rep(NA,nrx),
  marxan= rep(NA,nrx)
)# create buffer
result.df[,2] <- apply(x[,2:8],1,mean) #mean
result.df[,3] <- apply(
  x[,2:8],1, function(x){prod(x)^(1/length(x))}
)# geometric mean
result.df[,4] <- apply(x[,2:8],1,max) #max
pca <- princomp(x[,2:8])
biplot(pca) #show the result of PCA
result.df[,5] <- apply(pca$scores[,1:3],1,sum)#sum of axis
# create input file of marxan
df2input.marxan(x[,1:8],targetnum=60)
# input files will be saved in chosen working directory
# (please include id column in the first column)
dir("input/")
# **run the marxan at the outside of R**
# read the “out_ssoln.txt” from output folder of the marxan
res.marxan <- read.csv(file.choose())#
res.marxan <- res.marxan[order(res.marxan[,1]),]
result.df[,6] <- res.marxan[,2]
# reclassify
result.df2 <- result.df
result.df2 <- classintv.rank.df(file= result.df,,classnum=5)
# result of “max” cannot be classified
# make figures
x11(width=200, height=50)
par(mfrow=c(1,5)) #before classify
for(i in 2:6){
    hist(result.df [,i],main=colnames(result.df)[i])
}
par(mfrow=c(1,5)) #after classify
for(i in 2:6){
    hist(result.df2 [,i],main=colnames(result.df2)[i])
}
#
# the end of the analysis of the test data
##############
#====================== end of file
```

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