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Application of association analysis for identifing indicator taxa of vulnerable marine ecosystems in the Emperor Seamounts area, North Pacific Ocean

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ABSTRACT

Reflecting the growing interest in ecosystem-based fishery management, deep sea bottom fisheries are being called upon to minimize adverse impacts on vulnerable marine ecosystems (VMEs), communities of marine organisms susceptible to anthropogenic disturbance. Many fishery management organizations have introduced indicator-based management measures for VME conservation, such as encounter protocols, in which VME indicator species and bycatch weight thresholds are assigned. If the bycatch amount of the indicator species in a fishing operation exceeds the predetermined threshold, the fishing vessel halts the fishing operation and moves a certain distance away from the encounter point. However, the representativeness of VME indicator taxa has not been evaluated quantitatively. In this study, we analyzed the co-occurrence of benthic animals collected by scientific bottom tow-net surveys in the Emperor Seamounts area, North Pacific Ocean, to characterize benthic communities in the area and to examine the ability of six candidate indicator taxa (gorgonians, Alcyonacea excluding gorgonians, Antipatharia, Scleractinia, Stylasterina, and Porifera) to represent the local benthic communities. Cluster analysis revealed four clusters of benthic communities, each of which includes both sessile and mobile benthos: (1) gorgonians-Scleractinia community with many mobile benthic taxa and Pisces; (2) Porifera-Stylasterina community with Polychaeta and Bivalvia; (3) Antipatharia-Alcyonacea (excluding gorgonians) community with Cephalopoda; and (4) Zoanthidea-Pennatulacea community with Crinoidae and Holothuroidea. The first cluster included the largest number of taxa and showed strong tendencies of co-occurrence, possibly reflecting the habitat-providing function of gorgonians and Scleractinia as well as the common environmental preferences of filter feeders, which constitute major components of the cluster. We used association analysis to identify VME indicator species in the study area. Association analysis reveals relationships between items in the form of association rules, where the occurrence of an "antecedent" {**A**} implies the co-occurrence of a "consequent" {**B**}; {**A**} and {**B**} contain items, in this case, taxa. Association analysis applied to the co-occurrence data extracted many effective association rules that include gorgonians or Scleractinia as the consequent and many benthic taxa as antecedents. These results demonstrate that gorgonians and Scleractinia are effective VME indicators in the study area because they co-occur with many other benthic animals and represent VME characteristics such as functional significance as habitat and structural complexity as well as fragility and slow recovery from physical damage.

1. Introduction

Assessing and managing the impacts of deep sea fisheries on vulnerable marine ecosystems (VMEs) are urgent tasks for fisheries management organizations in order to meet the United Nations' global requirement for ecosystem-based fishery management (United Nations General Assembly, 2007, 2010). VMEs are communities of marine organisms susceptible to anthropogenic

Abbreviations: NPFC, North Pacific Fisheries Commission; RFMOs, regional fishery management organizations; VMEs, vulnerable marine ecosystems.

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disturbance that show characteristics such as uniqueness or rarity, fragility, and structural complexity; have functional significance as habitat and life-history traits of the component species make recovery difficult (Fisheries and Agriculture Organization of the United Nations [FAO], 2009). Reports from Alaska and Florida in the United States, the northern Atlantic Ocean, and many other areas have shown that some species of cold-water corals or sponges build complex structures and produce unique demersal communities in the same way as do shallow-water coral reefs (Freiwald et al., 2004). The frameworks of cold-water corals provide habitats or spawning and nursery grounds for fishes and many other animal species and thereby support diverse ecosystems (Baillon et al., 2012; Roberts et al., 2006). Due to their slow growth, long life spans, and slow recovery from physical damage, as well as their structure-forming property, cold-water corals are considered to be important components of VMEs.

Many regional fishery management organizations (RFMOs) for bottom fisheries have introduced indicator-based management measures for VME conservation. VME encounter protocols are management measures in which VME indicator taxa are assigned and bycatch of the indicator taxa greater than the predetermined thresholds would temporarily halt the fishing operation and move the fishing vessel a certain distance away from the encounter point (North East Atlantic Fisheries Commission [NEAFC], 2015; Northwest Atlantic Fisheries Organization [NAFO], 2009, 2017; North Pacific Fisheries Commission [NPFC], 2016; Penney et al., 2009). These management measures should be developed on a case-by-case basis and take into account the characteristics of local fauna and fisheries (FAO, 2009).

The Emperor Seamount chain spans from 30°N to 55°N and from 168°E to 178°E, extending from the northwestern Hawaiian Islands to the Aleutian Trench in the western North Pacific (Fig. 1). Seamounts to the south of 45°N support commercial fisheries targeting bottom fishes such as splendid alfonsino (*Beryx splendens*) and North Pacific armorhead (*Pentaceros wheeleri*, Kiyota et al., 2016). Commercial bottom fisheries in the Emperor Seamounts area are managed by the NPFC, and scientific surveys on bottom habitats have been conducted to establish science-based management measures. Four orders of corals ("Gorgonacea", Alcyonacea, Antipatharia, and Scleractinia) are tentatively assigned as VME indicator taxa in the NPFC convention text. However, the effectiveness of these four taxa as VME indicators has not yet been verified quantitatively.

In this study, we assessed the representativeness of the candidate VME indicator taxa, while focusing on the functional significance as habitat and structural complexity among the VME characteristics. We also consider Porifera and Stylasterina as candidate VME indicator taxa, because they are specified as VME indicators in many other RFMOs (Commission for the Conservation of Antarctic Marine Living Resources [CCAMLR], 2009; NAFO, 2017; NEAFC, 2015; Penney et al., 2009). We first analyzed biological samples collected by scientific bottom tow-net surveys to assess the co-occurrence tendencies of benthic taxa and the characteristics of benthic communities in the area. We then applied association analysis to extract association rules that reveal co-occurrence tendencies of each candidate VME indicator taxon with other animals.

2. Materials and methods

2.1. Benthos sampling and identification

We collected benthic samples during scientific surveys conducted on R/V *Kaiyo-maru* (93 m, 2942 GT) of the Fisheries Agency of Japan at 170 locations in the Emperor Seamounts area from 2009 to 2014. The seamounts surveyed were Northern Koko (36.5–37.0°N, 171.5°E), Koko (34.5–35.0°N, 171.0–172.0°E), Yuryaku (32.5°N, 172.0°E), Kammu (32.0°N, 172.0–173.0°E), Colahan (31.0°N, 175.0–176.0°E), and C—H (30.5°N, 177.5–178.0°E; Figs. 1 and 2).

A beam trawl for sea urchin (net mouth width, 1.5 m; mesh size of the inner net, 5 × 5 mm) and large (mouth width, 1.0 m; mesh, 5 × 5 mm) or small (mouth width, 0.5 m; mesh, 5 × 5 mm) dredges were used for sampling benthos. During sampling, vessel speed was set at approximately 1 knot (max 1.5 knots); the towing duration was set at 5–10 min for the sea-urchin beam trawl or 2–10 min for the dredges after the first contact of the sampling gear with the sea floor. A beam trawl was employed mainly on the flat tops of seamounts and swept 393 m^2 of sea floor per haul, on average. Large and small dredges were used as supplements on sloped and rough bottomed areas (Fig. 2). They swept 213 m^2 and 110 m^2 of sea floor per haul, on average, respectively. The benthic samples were analyzed on board and preserved in 70% ethanol.

Cold-water corals were identified to the lowest possible taxon, and other benthic animals were identified to higher taxa such as family, order, or phylum according to the procedure described by Miyamoto et al. (unpublished).[1] In this study, we adopted the former classification system of Cnidaria and treat gorgonians (Alcyonacea with solid axis; i.e., Scleraxonia, Holaxonia, and Calcaxonia) separately from other Alcyonacea (soft corals; hereafter "Alcyonacea excluding gorgonians"), because gorgonians have a different growth form than other Alcyonacea and these two groups are treated as separate VME indicators in NPFC and many other RFMOs. The benthic animals sampled were aggregated into 21 taxa: Porifera (sponges), Stylasterina (hydrocorals), Pennatulacea (sea pens), gorgonians (sea fans), Alcyonacea excluding gorgonians (soft corals), Antipatharia (black corals), Scleractinia (stony corals), Actiniaria (sea anemones), Corallimorpharia, Zoanthidea, Gastropoda, Bivalvia, Cephalopoda, Polychaeta, Crustacea, Crinoidea (sea lilies), Asteroidea (sea stars), Ophiuroidea (brittle and basket stars), Echinoidea (sea urchins), Holothuroidea (sea cucumbers), and Pisces (fishes).

2.2. Analysis of co-occurrence and association

We examined the occurrences of the 21 taxa in each sampling haul and compiled the presence/absence data for each haul. Based on the haul-by-haul presence/absence data, co-occurrence relationships among the benthic taxa were analyzed. In this study, we defined a pair of taxa as co-occurring if both taxa were present in a sampling haul.

We calculated the Jaccard index (Real, 1999) between a pair of taxa from the occurrence frequencies of the two taxa in all hauls. The Jaccard index, J(A, B), can be expressed as follows:

$$\mathrm{J}(\mathbf{A},\ \mathbf{B}) = \frac{n(\mathbf{A} \cap \mathbf{B})}{n(\mathrm{A} \cup \mathrm{B})} \quad (1)$$

where $n(\mathrm{A} \cap \mathrm{B})$ gives the number of hauls in which both Taxon A and Taxon B occurred, and $n(\mathrm{A} \cup \mathrm{B})$ gives the number of hauls in which Taxon A or Taxon B or both occurred. The Jaccard index takes a value from 0 to 1, with higher values indicating a stronger co-occurrence tendency between the two taxa. Cluster analysis was applied to examine the co-occurrence relationship among the 21 taxa by using the Jaccard distance (= 1–Jaccard index) as a distance metric and Ward's hierarchical agglomerative method (Pierre and Louis, 2012).

[1] Miyamoto, M., Kiyota, M., Hayashibara, T., Nonaka, M., Imahara, Y., Tachikawa, H., Unpublished results. Faunal composition of cold-water corals and other deep-sea benthos in the Emperor Seamounts area, North Pacific Ocean. Galaxea.