



## Delineating the boundary and structure of higher trophic level assemblages in the western North Pacific Ocean



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### ABSTRACT

Understanding the community structure of oceanic higher trophic level (HTL) organisms (e.g., sharks, tunas, salmon, and squids) is fundamental to management of marine resources in a way that ensures their sustainable use and maintains marine ecosystem functionality and biodiversity. We analyzed the spatial structure of HTL assemblages in the western North Pacific Ocean using driftnet survey data collected at latitudes of 35–46 °N along transect lines at 144 °E, 155 °E, and 175.5 °E longitude in July and August 2011. We proposed a new dissimilarity metric segmentation procedure (Dissimilarity Segmentation) based on the differences of mean Bray-Curtis dissimilarity indices between two individual driftnet hauls within the same subarea or among different subareas. Dissimilarity Segmentation allowed us to divide the western North Pacific Ocean into three subareas: a northern subarea (> 41 °N including 41 °N on the 175.5 °E transect), a transition subarea (37–41 °N), and a southern subarea (< 37 °N). The HTL biomass in the northern subarea was high, and the species diversity was low; dominant and common species accounted for most of the biomass. The HTL assemblage in the southern subarea was composed of many species that were uncommon or rare; the biomass was lower, and the species diversity was higher than in the northern subarea. In the transition subarea, neon flying squid accounted for most of the biomass, and although the biomass was intermediate, species diversity was highest among the three subareas. Canonical correspondence analysis with oceanic environmental variables, principally chlorophyll *a*, sea surface salinity, and sea surface height, as the explanatory variables accounted for 43.6% of the variance of the HTL pelagic species composition. This result suggests that the HTL pelagic community in the western North Pacific is influenced largely by productivity and oceanic physical structure. These results suggest that an analytical approach based on Dissimilarity Segmentation combined with medium- to long-term survey datasets could facilitate the investigation of spatial-temporal variations in the spatial structure of HTL pelagic communities and the environmental causes thereof.

### 1. Introduction

In recent years, there has been an increasing social and ecological demand for fishery management that includes among its goals the sustainable use of marine biological resources and the maintenance of marine ecosystem functionality and biodiversity (e.g. Botsford et al., 1997; Garcia et al., 2003). This demand has arisen from concern that irreversible changes of ecosystems may occur due to, inter alia, overfishing, the bycatch of non-target species, and, in the cases of

vulnerable marine ecosystems, perturbations (e.g. Collie et al., 1997, 2000; Jennings and Kaiser, 1998; Scheffer et al., 2005). Fishery management needs to take into consideration aspects of marine ecosystems other than fish, including the (1) heterogeneity of biological communities, especially key components such as apex predators and structure-forming species, and (2) key characteristics that help maintain the stability of the community (e.g. population connectivity, interaction webs, and biogeochemical interactions). To understand the role of heterogeneity and of the key processes that help to stabilize

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marine ecosystems, it would be useful to divide marine ecosystems into subareas that are relatively easy to study and analyze on the basis of species distributions, ecological traits, and habitat characteristics.

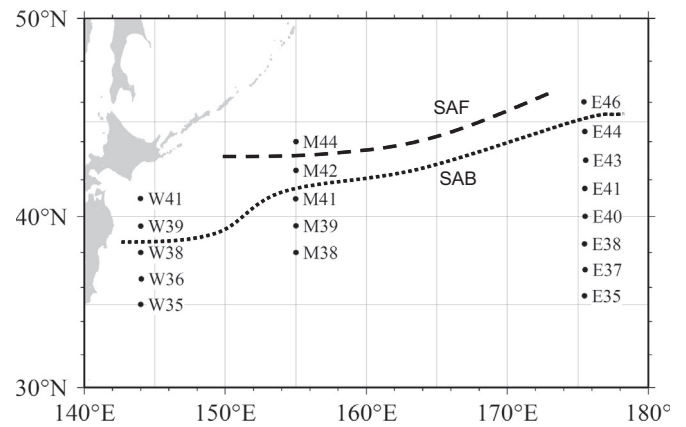
Although spatial division and classification of ecosystem components (i.e. community structure) have classically been conducted with cluster algorithms, the choice of clustering method is critical because the dendrograms that result from cluster analysis depend on the cluster algorithms (Legendre and Legendre, 2012). It is therefore important to fully understand the properties of clustering methods to correctly interpret ecological structures (Legendre and Legendre, 2012). When two or more clustering models seem appropriate to an analytical objective, one should apply them all to the data, compare the results, and interpret the differences among models in the light of the known properties of the clustering models (Legendre and Legendre, 2012). In comparing the dendrograms that result from clustering analysis, it is necessary to rely mainly on visual appraisal of the differences between the dendrograms, because there is no numeric metric of the relevancy of clustering results.

In this study, we tested a numeric metric based on dissimilarity indices to divide community structure within the framework of clustering procedures and to compare clustering results. The components of the ecosystem this study focused on were higher trophic level (HTL) pelagic organisms, such as sharks, tuna, salmon, and squid, which have tended to become the main targets of high seas fisheries (e.g. Stevens et al., 2000; Maguire et al., 2006; Polovina et al., 2009). Furthermore, HTL organisms have been deemed to be ecological indicators that reflect ecosystem structure, its condition (e.g. biodiversity and ecosystem service), and its response to environmental change. These indicators are expected to serve an important role in ecosystem conservation (e.g. Hunt and McKinnell, 2006, Sergio et al., 2008). HTL pelagic organisms are widely distributed over the open ocean and migrate according to the life history and ecological traits of each species (e.g. Pacific pomfret: Pearcy et al., 1993). We used driftnet survey data to investigate how HTL species composition varies spatially across the western North Pacific. We characterized the spatial segmentation of community composition based on the proposed dissimilarity metric and existing clustering methods. Because the driftnet is a passive fishery, it is a suitable fishing gear for marine ecosystem monitoring. Because the distribution of these HTL species is influenced by spatial-temporal variations of the oceanic environment, to assess the reasonableness of the spatial segmentation of community composition, we also examined how environmental factors influenced the spatial patterns of the HTL pelagic community structure.

## 2. Methods

### 2.1. Data

The driftnet survey was conducted by the research vessel Kaiunmaru (Aomori prefecture, Japan) from 23 June to 31 July 2011. Eighteen monitoring locations were arranged on three transect lines along 144 °E, 155 °E, and 175.5 °E at latitudes of 35–46 °N (Fig. 1). At each monitoring location, a research driftnet composed of 50 net panels was deployed in the evening and submerged in the water overnight. Each net panel was 50 m in horizontal length and 6 m in vertical height. The major part of each driftnet was a nylon monofilament gillnet consisting of 18 net panels with a stretched mesh size of 115 mm. To conduct non-size-selective collection of pelagic organisms, 32 nylon monofilament net panels with multiple mesh sizes (stretched mesh sizes: 37, 48, 55, 63, 72, 82, 93, 106, 121, 138, and 157 mm) were also used as research driftnets. Each mesh size was incorporated into three net panels, except for the 37-mm mesh size (two panels). The main purpose of the driftnet survey was to describe the distribution and abundance of species that are commercially important for the Japanese high-seas pelagic fishery, such as neon flying squid (*Ommastrephes bartramii*).



**Fig. 1.** Map showing the sampling locations of the driftnet surveys along the three transect lines (black circles). Alphanumeric labels beside the black circles are the name of the driftnet survey hauls on the three survey transect lines; E: eastern transect at 175.5 °E, M: middle transect at 155 °E, and W: western transect at 144 °E. For example, “E41” indicates a driftnet haul at 41 °N from the survey transect at 175 °E. Dashed line indicates the Subarctic Front (SAF) identified by the water temperature ( $< 4$  °C) measured at a depth of 100 m with CTD during the driftnet survey cruise. Dotted line indicates the Subarctic Boundary (SAB) identified by the salinity ( $< 34\text{‰}$ ) measured at depth of 100 m and 200 m with CTD during the driftnet survey cruise.

The driftnet caught 3539 organisms belonging to 60 species in the epipelagic. These species included not only epipelagic species, but also some mesopelagic species that migrated upwards during the night. When mesopelagic species migrate up into the epipelagic for nocturnal feeding, they are both competitors for the prey of small pelagic commercial fishes and prey for larger animals such as salmon, tuna, squid, and marine mammals (Sassa et al., 2002). Hereafter, we treat the organisms collected by the driftnet survey at night as “pelagic species” that interact with each other in the epipelagic during the night. The major components of the driftnet samples were Pacific pomfret (*Brama japonica*:  $n=835$ ), neon flying squid ( $n=710$ ), Pacific saury (*Cololabis saira*:  $n=515$ ), boreal clubhook squid (*Onychoteuthis borealijaponica*:  $n=389$ ), amberjacks (*Seriola* spp.:  $n=136$ ), and coastal flying fish (*Cypselurus pinnatibarbatulus japonicus*:  $n=136$ ). Large Pacific pomfret (standard length  $\geq 25$  cm) and large neon flying squid (mantle length  $\geq 30$  cm) were treated as “species” distinct from small individuals of these species (Supplement 1). Pacific pomfrets also have two body size modes corresponding to the difference of their spatial distributions; the larger fish migrate farther to the north during the summer (Pearcy et al., 1993). Each mode is associated with a distinct diet composition in the transition zone of the central North Pacific. This association may result from a trophic niche shift as body size increases (Watanabe et al., 2003). The body size frequency distribution of neon flying squid had two distinct modes corresponding to the winter-spring cohort (small) and the autumn cohort (large). The composition of the diet of these two size groups differs in the summer in the transition zone of the central North Pacific (Watanabe et al., 2004).

Environmental factors, which previous studies have reported to influence the biomass and distribution of marine organisms, were obtained during the driftnet survey cruises at each monitoring location. These factors included sea surface temperature (SST: e.g. Lehodey et al., 2003; Mugo et al., 2010), salinity (SSS: e.g. Castillo et al., 1996; Murase et al., 2009), oxygen concentration (SSO: e.g. Bertrand et al., 2004), zooplankton abundance (e.g. Ward et al., 2006), and chlorophyll  $a$  (e.g. Ward et al., 2006). SST, SSS, and SSO were equated to the values measured at a depth of 10 m with a CTD probe (SBE 09plus CTD, Sea-Bird Electronics, Inc., Bellevue, Washington, USA). This depth corresponded to the depth fished by the research driftnet. Oceanographic fronts (lines in Fig. 1), namely the Subarctic Front (SAF) and the Subarctic Boundary (SAB), were identified by the water temperature at a depth of 100 m ( $< 4$  °C for the SAF) and the salinity at a depth of

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