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Integrating community structure and stable isotope analysis to assess a heavily exploited coastal marine ecosystem off Central Vietnam

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A B S T R A C T

We examined the community and trophic structure of the heavily exploited benthic-demersal community off Phan Thiết Bay, Central Vietnam. Using cluster analysis and non-metric multidimensional scaling (NMS) of catch data from a trawl survey, we examined the nekton community structure pertaining to bottom substrate type and depth. For dominant fish and invertebrate taxa we applied stable isotope analysis, using $\delta^{15}N$ to examine trophic level (TL) and size-specific ontogenetic shifts, and $\delta^{13}C$ as a measure of contribution by benthic secondary production. Based on trawl data small fishes and cephalopods were the numerically and biomass-dominant taxa. Community structure analysis showed many of the sample sites shared the same species composition, but that there was significant heterogeneity related to substrate types of sand and gravelly muddy sand. Results from $\delta^{15}N$ showed 70% of the species were between TL 3.3 and 3.8, with no species indicating true piscivory (TL 4); highest TL was from the squid *Loligo japonica* (TL 3.8). Size-specific $\delta^{15}N$-based trophic shift was expressed in taxa when the proportional size range (ΔL_{max}) obtained for analysis was at least 40% of the largest reported size for the species (L_{max}). From $\delta^{13}C$, nekton expressed between 35 and 77% dependence on benthic secondary production. Evidence of over-exploitation from our study included the relatively low TL's of dominant taxa, small size distribution of specimens collected, and the dominance of taxa with very high growth rates such as cephalopods (juvenile *Octopus* sp. and cuttlefish) and small fishes. The effectiveness of stable isotopes as an indicator of over-exploitation is discussed.

1. Introduction

About 65% of Vietnam's fisheries production is derived from its coastal waters <50 m depth, with intensive fishing over the last 30 yrs resulting in precipitous declines in fisheries catch-per-unit-effort (CPUE, van Zwieten et al., 2002; Pomeroy et al., 2009). The coastal region of Vietnam is also experiencing massive growth in both industry and tourism, increasing demand for fisheries products while increasing the potential for coastal eutrophication. Vulnerabilities of Vietnam's coastal ecosystems to over-exploitation and habitat degradation underscore the importance of implementing a more adaptive management approach, one which applies multiple indicators of ecosystem health and functioning (Raakjaer et al., 2007), and not based solely on fisheries-based census data.

The fisheries of Vietnam have been reviewed in a number of studies involving over-exploitation and management (van Zwieten et al., 2002; Raakjaer et al., 2007; Pomeroy et al., 2009), and establishment of marine protected areas (Dung, 2009; Svensson et al., 2009). Yet, almost no ecological information is available on exploited fish or invertebrate species, information of which is essential for ecosystem-based management of Vietnam's waters (Raakjaer et al., 2007) and a more functional perspective on the flow of energy through the exploited ecosystem. Over-exploitation can be reflected in a lowering of average trophic level (Pauly et al., 1998), biomass size spectra (Jennings et al., 2001), a shift to smaller more productive species (Myers, 1993; Jennings et al., 2001), shifts in benthic production (Jennings et al., 2001; Hiddink et al., 2008) and potential shifts through trophic cascades (Frank et al., 2005). How these are measured can be accomplished in-part from fisheries catch data; however the addition of other analytical methods such as stable isotope analysis of carbon and nitrogen, which can measure source production and trophic structure, show particular promise.

Stable isotopes of carbon and nitrogen have been shown as time-averaged measures of relative trophic position and source production of an organism (Peterson and Fry, 1987) and therefore a measure of food web trophic structure (Vander Zanden and Rasmussen, 1999), degree of benthic–pelagic coupling (Takai et al., 2002; Mincks et al., 2008; Votier et al., 2010), ontogenetic shifts

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(Galván et al., 2010), and as a precursor measure of eutrophication (Cole et al., 2004; Miller et al., 2010). Stable isotopes are measured as a ratio of the heavy to light form relative to a standard using the following equation: $\delta X = [(R_{sample}/R_{standard}) - 1] \times 10^3$, where X is the isotope value in parts per mil (‰) and R is the ratio of the heavy to the light isotope of the sample (R_{sample}) to an analytical standard ($R_{standard}$). Standards are calibrated to atmospheric N_2 for nitrogen and Vienna Pee Dee Belemnite for carbon (Peterson and Fry, 1987). For nitrogen, the heavier (^{15}N) isotope is retained at a higher rate over the lighter isotope (^{14}N), and this difference is expressed as an approximate enrichment of 3.4‰ in δ^{15}N of an organism relative to its diet (Post, 2002). This allows for δ^{15}N to be used as an effective measure of relative trophic position of an organism. Differences in δ^{15}N can also occur at the base of the food web (phytoplankton) and be reflected in higher trophic levels, where the source of nitrogen to primary producers may occur more from N-fixing cyanobacteria (low δ^{15}N) or are from recycled nitrate (O'Reilly and Hecky, 2002). Extremely elevated levels can indicate some degree of eutrophication and denitrification, which may occur naturally or from anthropogenic loading. Carbon stable isotopes (δ^{13}C) are applied more as a relative measure of source production, because the differences in δ^{13}C occur more between the different sources of carbon fixation at the level of primary production (Fry, 2006). For aquatic systems differences in δ^{13}C occur more between nearshore (more enriched in ^{13}C) and offshore waters (Miller et al., 2008), and with depth (Bosley et al., 2004). Measures of δ^{15}N and δ^{13}C therefore provide a respective measure of TL and spatial properties of the coastal community, such as from benthic–pelagic coupling or between nearshore and offshore systems. Using stable isotope analysis in concert with community structure data, such as catch surveys with quantitative assessment of biomass can also provide greater insight as to the potential relative strengths of trophic links in terms of nearshore-offshore systems and also the basic functioning of the ecosystem.

One of three major coastal zones of Vietnam, the central region between 10 and 15°N exhibits strong summer upwelling during the southwest monsoon months between May and August (Kuo et al., 2004), contributing nutrients and much of the primary and higher trophic level production to the region (An and Thu, 2007). Phan Thiết Bay (Bình Thuận Province) is just south of the central upwelling cell and is considered a major fisheries region of Vietnam, consisting of local bottom draggers, gill netting, and hook-and-line fishers. The shelf region is typical of most of Vietnam's coastline with depths of <50 m as far as 50 km offshore, and a relatively flat relief with bottom substrates of sand, mud, and cobble. As a result, the coastal waters are easily fished by use of trawl or push nets that often have small mesh sizes that indiscriminately take almost all sizes of macro-organisms (Pomeroy et al., 2009).

Over-exploitation in marine ecosystems can favor smaller, faster growing species (Blanchard et al., 2004) but also reduced size within a species (Beverton and Holt, 1957), and a lower trophic level of exploitable biomass (Pauly et al., 1998). In this study, by use of a limited trawl survey we examined the community and trophic structure of exploited benthic-demersal fishes and invertebrates off Phan Thiết Bay, Vietnam. We used catch data and size measures of the most abundant taxa and trophic level assignments from δ^{15}N to test the hypothesis that: (1) the exploited biomass off Phan Thiết Bay is dominated by smaller nekton with relatively high growth rates, and (2) that TL of the nekton community would be relatively low (TL < 3.5). We also applied δ^{13}C to determine the degree to which benthic and pelagic production are contributing to the production of dominant target species. Results from this study provide the first assessment of Vietnam's coastal fisheries by integration of stable isotope analysis with fisheries catch data.

2. Methods

2.1. Field sampling

A total of nine benthic-demersal hauls were performed between 20 and 25 August, 2010 for quantifying the demersal nekton taxa off Phan Thiết Bay (Fig. 1 and Table 1), and to obtain samples for stable isotope analysis. The time of this study was chosen to capture community characteristics and isotopic-based trophic dynamics of the summer monsoon upwelling season, which typically occurs between May and August (Kuo et al., 2004). Benthic-demersal hauls were done using a benthic otter trawl consistent with regular fishing gear by local fishers, with a maximum mouth opening of 17 m wide by 15 m in height, and a net length of 30 m. Mesh size at the mouth was 6 cm, tapering down to 1 cm toward the cod end. The trawl was towed at approximately 3 knots with duration of hauls varying due to gear saturation, in which hauls were discontinued when haul speed was notably reduced. Of the nine hauls, eight were used for quantifying species catches and measurements of fishes, and four were used for stable isotope analysis (Fig. 1). Upon retrieval of the net, the catch was randomly dispersed into 40 L containers, with the total number of containers consisting of the total catch. One container was randomly selected as a subsample, with all major nekton taxa identified, enumerated, and up to 30 individuals of each taxa randomly selected and measured in mm (±0.1) for length as total length for fishes, dorsal mantle length (DML) for cephalopods, shell diameter for gastropods and shell height for bivalve scallops (Pectinidae). Total catch, including species counts and weights for each haul were estimated by using the 40 L subsample and multiplying by the total number of 40 L containers consisting of the haul catch. Weight of each 40 L subsample was also used to estimate the total biomass of catch for each haul using the same method. The total biomass of individual taxa from each haul was estimated by taking the size distribution of the individuals subsampled and using the length-weight relationship from FishBase (Froese and Pauly, 2010) to obtain an estimate of the 40 L subsample biomass, then multiplying by the total number of 40 L containers consisting of the total haul. The logistics of counting and measuring every species was problematic due to the very high diversity (>100 species of fish) and in many instances the cryptogenic taxonomy of some groups. We therefore focused on 18 dominant fish and invertebrate taxa which together consisted of over 50% of the collective total of net hauls by biomass and number. From each haul, nekton community data was then used for community structure analysis.

2.2. Community structure analysis

Community structure analyses were performed using PC-ORD v4.25 (McCune and Mefford, 1999) in which an initial matrix was established based on the catch per unit effort (CPUE) of individual nekton from 8 hauls (rows) and 64 taxa (columns). The CPUE was calculated for each haul as the number of individuals within each taxa divided by the area (m^2) covered by the haul. Agglomerative hierarchical cluster analysis (AHCA) using Sørensen (Brae Curtis) distance and flexible beta ($\beta = -0.25$) linkage function was applied to arrange hauls into nekton community-based cluster groups. Prior to the AHCA the matrix was transformed using general relativization to allow for cluster groupings based more on species associations and to avoid clustering based on high and low-abundant species (McCune and Mefford, 1999). Optimum number of cluster groups from AHCA were based on a combination of several criteria: (1) biological meaning; (2) significance and effect size (A) of groups using a multi-response permutation procedure (MRPP, Sørensen distance), from both above and below the optimum dendrogram cutoff level; and (3) the number of significant