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Long-term ecosystem change in the western North Pacific inferred from commercial fisheries and top predator diet

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ABSTRACT

Assessment of the current status of marine ecosystems is necessary for the sustainable utilization of ecosystem services through fisheries and other human activities under changing environmental conditions. Understanding of historical changes in marine ecosystems can help us to assess their current status. In this study, we analyzed Japanese commercial fishery catch data and scientific survey data of the diet of northern fur seal (*Callorhinus ursinus*, NFS) to investigate potential long-term ecosystem changes in the western North Pacific Ocean off northeastern Japan over the past 60 years. Total commercial catches experienced peaks around 1960 and during the 1980s, decreasing to low levels around 1970 and after 1990. Catches were substantively impacted by the Tohoku earthquake and tsunami in 2011. Species composition of the commercial catch changed over time, resulting in changes in the mean trophic level (MTL) of the catches. Trends in observed commercial catches were affected by many factors, including species population fluctuations potentially related to large-scale environmental shifts, migration and distribution patterns of species related to local oceanography, changes in fishing technology, and the introduction of fishery management frameworks. The composition of NFS diet also changed over time: although overall changes were small, MTL derived from NFS stomach contents declined from the early 1970s to the late 1980s. This fall in the MTL of the diet of NFS is suggestive of a shift in pelagic fish fauna from a “mackerel-dominant regime” to a “sardine-dominant regime”. Inconsistencies between changes in species composition and MTLs of the commercial catch and NFS diet resulted from differences in commercial fishing targeting and NFS foraging behavior strategies. Although commercial catch is a valuable source of information for investigating historical changes in fisheries, biological resources, and ecosystems, catch data should be interpreted carefully and other relevant information available should also be considered.

1. Introduction

Recently, fisheries have attracted global attention because of their impacts on marine living resources and ecosystems (Hilborn et al., 2005; Murawski et al., 2007; Myers and Worm, 2003; Pauly et al., 2002; Worm et al., 2009). Global capture fisheries production remains to be stable, however catch trends by country, fishing area or species have varied significantly through time (FAO, 2014). To sustainably utilize fishery resources and maintain marine ecosystem function and biodiversity, it is necessary to make sound assessments of the impacts of commercial fisheries and other anthropogenic activities on marine ecosystems under shifting environmental conditions (Botsford et al., 1997; FAO, 2003). Historical data provide valuable baseline information for evaluating the current condition of ecosystems in light of past status (Lotze and Worm, 2009; Pauly, 1995; Tian et al., 2014). Catch data accumulated by commercial fisheries can offer some insights into the status of fishery resources and the impact of fisheries activities on the broader marine environment, although views differ on the effectiveness of catch data in assessing the health of fish stocks (Hilborn and Branch, 2013; Hilborn and Hilborn, 2012; Myers and Worm, 2003; Pauly, 2013).

A comparison study carried out on fish communities and trophic structure of the Tsushima, Kuroshio, and Oyashio currents ecosystems around Japan aimed at identifying variability associated with climate regime shifts (Tian et al., 2014). This study demonstrated the efficacy of historical data in understanding drivers of marine ecosystems variability. Commercial catch data are affected by many factors including management regulation and socioeconomics (Maunder et al., 2006; Murawski et al., 2007; Polacheck, 2006). With this in mind, the use of fishery-independent data, such as those collected by scientific surveys (Branch et al., 2010) or studies on marine top

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predators (Bowen, 1997; Piatt et al., 2007) may considerably improve the interpretation of historical changes in marine ecosystems and impacts on fisheries based on catch data alone.

Northern fur seals (*Callorhinus ursinus*, NFS) are the most abundant in all otariid species and are widely distributed in the subarctic waters of the North Pacific Ocean (Jefferson et al., 2008). The waters adjacent to the Tohoku region in northeastern Japan provide a major wintering and foraging area for NFS; approximately 100,000 seals, mostly adult females and juveniles, migrate to this area from winter to early spring (Gentry, 1997). The main prey species of NFS in this region consists of small schooling pelagic fishes (e.g. Japanese sardine, *Sardinops melanostictus*, and chub mackerel, *Scomber japonicus*), mesopelagic micronektonic fishes (myctophids), small schooling mesopelagic squid (e.g., sparkling enope squid, *Watasenia scintillans*), and oceanic squids (e.g., boreal clubhook squid, *Onychoteuthis borealijaponica*) (Mori et al., 2001; Yonezaki et al., 2003, 2008). Scientific efforts aimed at monitoring the reproductive condition and feeding ecology of NFS were conducted by National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Japan (NRIFSF) under the auspices of the North Pacific Fur Seal Commission (NPFSC) from the 1960s to the 1980s (NPFSC, 1962, 1969, 1971, 1975, 1980, 1984), and follow-up surveys were conducted by NRIFSF in the 1990s (Yonezaki et al., 2003). These survey data comprise the Miho Collection, a long-term scientific archive of data that provides valuable information on the ecology of NFS (Yonezaki et al., 2008; Yonezaki and Kiyota, 2014). These data also have the potential to provide information on marine ecosystem variability, particularly because NFS is regarded to be an opportunistic predator on fish and squid that are most available in their foraging habitat (Kajimura, 1984). The NFS diet data from this collection can be considered as complementary to fishery catch data in providing insights into ecosystem variability, because it includes species that are not recorded by commercial catch statistics (e.g., mesopelagic micronekton) and the data are largely independent of factors influencing fisheries catches such as socio-economics and management.

The Pacific Ocean adjacent to northeastern Japan is one of the most productive fishing grounds in the world. This is largely because of the mixing of two ocean currents, the warm Kuroshio Current and the cold Oyashio Current (Favorite et al., 1976; Fig. 1). Various coastal and offshore fisheries operate in these waters targeting pelagic and demersal fishes, and shellfishes (Kitagawa et al., 2008; Okutani, 2005). The commercial catches have been compiled by the Miyagi Prefecture since 1952.

In this study, we assess commercial fishery catches and diet data compiled from scientific surveys of NFS to investigate the potential for the long-term ecosystem changes in the western North Pacific Ocean off northeastern Japan over approximately 60 years. The purposes of this study were to (i) examine changes in commercial catches across each of the fisheries operating in the region, (ii) explore temporal variability in the diet of NFS, and (iii) investigate historical variability in the mean trophic level (MTL) of commercial catches and NFS diet as an indicator of potential fishing down of the food web (Pauly et al., 1998).

2. Material and methods

2.1. Commercial fisheries and marine environment data

We digitized commercial fishery catches (in tonnes) from an area adjacent to northeastern Japan (Fig. 1) from data compiled by the prefectural government of Miyagi across the period 1952–2011 and reported by fishing companies registered in the Miyagi prefecture. We also compiled fisheries effort (fishing days) data across the period 1957–2006, with the exception of the trap net fishery. Since 2006, catch data of the surrounding net fishery were not available. Catch data for Japanese sardines were available for the periods 1957–1985 and 2007–2011; catches of Japanese sardine, Pacific round herring (*Etrumeus teres*), and Japanese anchovy (*Engraulis japonicus*) were aggregated and reported as sardines during the period 1986–2006. Data derived from fisheries that were likely to operate in offshore, distant waters (e.g., skipjack pole-and-line, distant waters squid jigging, former distant-water trawl fisheries in the East China Sea, Yellow, and Bering Seas and former high seas squid and salmon driftnet fisheries) were excluded from analyses. We calculated total catches for each year identifying the major species caught by each fishery in each year.

2.2. Northern fur seal dietary data

Dietary data from NFSs caught in the study area (Fig. 1) between January and April across the period 1953–1988 were extracted from the Miho Collection. These data were derived from 7104 adult female and juvenile NFSs. Collection of samples from NFS focused on areas of high densities of individuals which primarily occurred on the shelf edge and continental slope regions of the study area. Prey species were identified based on the external morphology of undigested and partly digested diet derived from stomach contents and the percent wet weight (PWW) for each species calculated. The PWW of prey species in the stomachs of NFS were pooled across all samples in a given year. Because there were biases in the annual capture locations of NFS (for details, see Yonezaki et al. (2008)), PWW values for each species were then pooled across the 1950s, 1960s, 1970s, and 1980s to produce a total PWW for each decade.

The NFS samples in the Miho Collection could detect the long-term changes that were ovaries, therefore we analyzed the ovary samples for trophic levels of NFS using stable isotope technique. Usually, samples examined by stable isotope analysis for the characterization of diets and trophic levels of marine mammals are derived from muscle, liver, skin and blood (Newsome et al., 2010). Isotopic composition turnover rates vary among tissues according to protein metabolic rate, and are relatively rapid, occurring across scales of a week to a month (Newsome et al., 2010). Tissues such as blood and liver with have high rates of biochemical turnover provide dietary information assimilated from recent feeding bouts, while tissues with slower turnovers such as muscle and hair provide information from feeding bouts across extended periods of time (Tieszen et al., 1983; Kurle and Worthy, 2002). In NFS, liver tissue has high protein turnover, with an average protein half-life of ~1.9–6.7 days while, adipose tissue has a slower turnover, with an average protein half-life of ~12.5–83.3 days (Kurle and Worthy, 2002). Ovary tissues are considered to have a lower metabolic turnover than muscle tissue, and it would therefore be expected that the turnover of these tissues in NFS would be expected to occur over a few months. For the purposes of this study, it was assumed that δ^{15}N vales in the ovaries of NFS females might reflect the diet of individuals in the year of capture.

Ovary samples from adult females NFS ($n=444$) collected during 1969–1997 (1969: $n=60$; 1970: $n=61$; 1971: $n=72$; 1972: $n=58$; 1980: $n=65$; 1987: $n=54$; 1988: $n=58$; 1997: $n=16$) were analyzed for stable isotope ratio of nitrogen (^{14}N/^{15}N). Approximately 5 g of tissue was removed from ovaries, stored in 10% formaldehyde, rinsed with distilled water, dried at 60 °C overnight and ground into a fine powder without lipid removal treatment. Stable isotope of δ^{15}N were determined from each sample using a mass spectrometer (MAT252, Finnigan MAT) coupled online, via a Finnigan ConFlo II interface, with an elemental analyzer (EA 1110, Thermo-Quest). Isotope values were calculated as ‰ deviation from the standard according to the formula,

$$\delta^{15}N_{NFS} = (R_{sample}/R_{standard} - 1)1000 \quad (1)$$

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