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Variability in trophic positions of four commercially important groundfish species in the Gulf of Alaska

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ABSTRACT

We examined trends in nitrogen stable isotope data as a proxy for trophic position (mean trophic level, TL) of commercial and survey catches as an ecosystem-based indicator of sustainability of four groundfish species in the Gulf of Alaska. From 2000 to 2004, walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), arrowtooth flounder (*Atheresthes stomias*), and Pacific halibut (*Hippoglossus stenolepis*) were collected from the waters surrounding Kodiak Island, Alaska. Several analyses of covariance (ANCOVA) models were tested to detect variations in mean TL among years with fish length as a covariate. Best-fit models were selected using the Akaiki Information Criterion to estimate trends in mean TL of commercial catch using length-frequency data from onboard fishery observers for each target species. Then, linear regression models were used to estimate mean TL of commercial catch over 1990–2009 and the mean TL of population biomass over 1984–2007 based on length-frequency data and biomass estimates from trawl surveys conducted by National Marine Fisheries Service and from historical catch data. The TL of catch for each species except walleye pollock remained stable over the time frame of the study. Walleye pollock TLs became increasingly variable after 1999. Similar trends in mean TL were observed for the survey biomass of walleye pollock. Additionally, there was an observed decrease of the occurrence of higher TL Pacific halibut over time. While the decline had no impact on overall TL estimates during 1990–2009, a continued decline may affect mean TL in the future. Overall, length seems to be the most important factor in estimating a species' TL. Therefore, including relationships between length of catch and TL estimates could lead to an early detection of TL declines that may be associated with unsustainable fishing mortality.

1. Introduction

Since the 1990s, fisheries managers have been advised to broaden awareness beyond a single-species focus by taking an ecosystem approach to fisheries, also termed ecosystem-based fisheries management (EBFM; US National Research Council, 1998). The broader set of considerations in EBFM include system sustainability (or productivity), maintenance of biodiversity, and protection of habitat (Sinclair et al., 2002; Zhang et al., 2009). This more holistic approach has led to the development of a host of ecosystem indicators as metrics to evaluate whether EBFM objectives are being achieved (FAO, 2003; Livingston et al., 2005). Some of these ecosystem indicators involve considerations of trophic position or trophic level (TL). Following the practice in the marine fisheries literature, here we use TL and trophic position interchangeably.

The mean TL of fisheries landings has been advanced as a particularly important indicator in exploited marine ecosystems (Pauly et al., 1998, 2001); trends in this index have been adopted as indicators of sustainability and/or biodiversity (Gislason et al., 2000; Livingston et al., 2005; Zhang et al., 2009, 2011). Using mass-balance models and United Nations Food and Agriculture Organization (FAO) data, Pauly et al. (1998) documented a worldwide average decrease of 0.1–0.3 TL per decade in commercial catches over 1950–1994. The proposed mechanism, "fishing down" marine food webs, is a process that commences with depletion of high TL predators, followed by the sequential depletion of successively lower TL fisheries (Pauly et al., 1998), resulting in a decline in mean TL of the catch and simplification of the food web (Pauly et al., 2002). An alternative mechanism, "fishing through" marine

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food webs, also leads to declines in mean TL of commercial catches, but through addition of lower TL fisheries while maintaining higher TL fisheries (Essington et al., 2006). Declines in mean TL have mostly been observed in the North Atlantic Ocean (Pauly et al., 1998, 2001). In the North Pacific Ocean (western and eastern regions combined), the mean TL of commercial landings also declined between the 1970s and 1990s (Pauly et al., 1998); however, in the northeast Pacific Ocean (i.e., Gulf of Alaska (GOA), Bering Sea, and Aleutian Islands), this index remained stable over a similar time period (Livingston, 2005).

This use of mean TL of the catch as an ecosystem indicator of unsustainable fisheries and biodiversity degradation has been controversial (Gislason et al., 2000). There are concerns about the interpretation of catch-based estimates of mean TL, as results often diverge from trends in mean TL estimated from fishery-independent surveys (Branch et al., 2010). This divergence may arise from factors such as changes in fishery economics (e.g., price, market demand), fishery management, fishing technology (e.g., gear changes) and other factors (Branch et al., 2010). Moreover, studies using catch- and assessment-based estimates of mean TL typically utilize a single fixed estimate of TL for each species. Apparent trends in mean TL of global landings are sensitive to changes in species-specific TL estimates; for instance, an updated estimate for the most heavily exploited marine fish species in the world, Peruvian anchoveta (*Engraulis ringens*), from TL of 2.2 to 2.7 had a particularly marked effect on perceived trends in global mean TL (Branch et al., 2010). Divergent results from such analyses using fixed values of species-specific TLs emphasize the importance of considering temporal variability in species' trophic position.

Trophic position may vary in relation to changes in size and community composition. At the population level, size-selective fishing and entry of a large year class into the exploited stock lead to a shift toward smaller body sizes, while propagation of a strong year class to older ages or reductions in fishing mortality result in a shift to larger individuals. Such changes in size composition may alter mean TL, as trophic position increases with size for most fish species (see Jennings et al., 2002a for opposite trend) likely attributed to an increase in gape size, burst swimming speed, capture efficiency, energetic requirements, and visual acuity (Scharf et al., 2000; Jennings et al., 2002b; Sherwood and Rose, 2005). At the ecosystem level, an example of a change in community composition resulting in a change in mean TL occurred following a climate shift to a warm regime in the late 1970s in the GOA. The ecosystem shifted from a community dominated by lower TL pelagic forage fish and benthic invertebrates (e.g., crab and shrimp) to one dominated by higher TL piscivorous gadoids and flatfish (Anderson and Piatt, 1999; Litzow, 2006). This shift in community structure led to an increase in the overall TL of the commercial catch from the 1970s through the early 1990s (Urban and Vining, 2008).

Mean TL of catch is often evaluated using mass-balance models, such as Ecopath, which combines diet data from gut content analysis (GCA), production, and biomass estimates (Pauly et al., 1998, 2000). These models typically assign a single trophic position to each species or species group; at most, these models assign a separate trophic position for adults and juveniles of the same species, respectively. Gut content analysis provides good resolution for trophic linkages between identifiable organisms, but it only reflects recent predation and often overlooks gelatinous and detrital matter and ignores specimens with empty stomachs. In contrast, stable isotope analysis (SIA) utilizes the principle of a consistent enrichment of δ^{15}N from prey to consumer (Minagawa and Wada, 1984; Post, 2002). Moreover, SIA incorporates only prey items assimilated by consumers, thus more accurately representing the transfer of energy between trophic levels. While both methods have their own caveats and assumptions, SIA is attractive because it integrates prey selection over a longer time scale, depending on the biological turnover rate of the tissue (Hesslein et al., 1993; Miller, 2000); thus, it may provide more accurate information about the mean trophic position of a consumer than GCA. In addition, SIA allows for easier assessment of relationships between TL and body size for a given species.

In a previous study using SIA, we assessed seasonal, interannual, and ontogenetic variations in the trophic roles of walleye pollock (*Gadus chalcogrammus*, hereafter pollock), Pacific cod (*G. macrocephalus*, hereafter cod), arrowtooth flounder (*Atheresthes stomias*; hereafter ATF), and Pacific halibut (*Hippoglossus stenolepis*; hereafter halibut) (Marsh et al., 2012). These four groundfish species have dominated the demersal fish biomass in the GOA since the early 1980s (Mueter and Norcross, 2002) and comprise about 75% of the total groundfish catch (NPFMC, 2009). For each species, trophic position, as indicated by nitrogen stable isotope signature (δ^{15}N), increased with total length. Both trophic position and relative contribution of benthic versus pelagic diet, indicated by lipid-normalized carbon stable isotope signature (δ^{13}C′), varied interannually, coinciding with a more pelagic diet in summer and a more benthic diet in fall. Such findings on temporal and ontogenetic variability in trophic position enable an evaluation of some of the methods and assumptions in the application of mean TL of the catch as an ecosystem indicator.

Two goals motivated our study of pollock, cod, ATF and halibut in the GOA. First, we were interested to compare patterns in mean TL of the catch based on Ecopath-derived estimates using fixed values of trophic position for each species from GCA with those derived from SIA (δ^{15}N) with annually estimated trophic positions. If use of mean TL of the catch depends heavily on method (Ecopath vs. SIA) or an assumption of fixed species trophic position despite evidence of annual variability, then the utility of mean TL as an ecosystem indicator would be degraded. Second, although no groundfish species in the GOA are currently subject to overfishing (NOAA, 2014), development of a high-resolution baseline on trophic position of these species at the commercial catch or stock abundance scale may provide a useful basis against which to judge future effects of fishing or climate regime shifts. As these four groundfish are highly connected within the GOA food web, a significant decline in the abundance of one or more of these species could potentially signal another major restructuring of the marine ecosystem (Gaichas and Francis, 2008), which could have substantial impacts on fishing-dependent communities. To accomplish these goals, our specific objectives were to: (1) estimate mean annual TL and TL range of the commercial catch for the four species; (2) estimate mean annual TL and TL range of population biomass estimates for each of the four species; and (3) compare TL estimates based on SIA with published Ecopath-derived TL estimates.

2. Methods

2.1. Data collection and processing

Fish samples were obtained during field collections of the Gulf Apex Predator-Prey Project (GAP; http://seagrant.uaf.edu/map/gap/) at the University of Alaska Fairbanks (UAF). Fish were collected from midwater and bottom trawls in the waters surrounding Kodiak Island in the central GOA from 2000 to 2004 in NMFS reporting area 630 (Fig. 1). Details on trawl gear and tow specifications were described by Marsh et al. (2012). All samples were identified to species and measured (wet weight to the nearest 0.1 g and total length to the nearest 1.0 mm). Stomachs were excised and removed from larger fish. The remaining fish tissue was ground up using a meat grinder, frozen at −30 °C, freeze-dried, and ground into a powder (see Marsh et al., 2012 for details). A total of 229