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Shifts in condition and distribution of eastern North Pacific flatfish along the U.S. west coast (2003–2010)

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ABSTRACT

Flatfish condition indices and distribution were examined along the U.S. west coast (55–1280 m) in relation to environmental variability and biomass using data from ten frequently occurring species collected in annual groundfish surveys from 2003 to 2010. The study was conducted during a period characterized by a cooling trend in the northern California Current system and by declining biomass for flatfish in general. Annual condition indices for six species (arrowtooth flounder, Dover sole, English sole, Pacific sanddab, petrale sole, and rex sole) were significantly related either to large-scale climatic indices (Pacific Decadal Oscillation, Multivariate El Niño–Southern Oscillation Index, North Pacific Gyre Oscillation) and/or annual biomass levels. Condition was most closely related to environmental effects rather than either biomass alone or both variables, with condition typically higher during cool climatic conditions. A similar analysis revealed that changes in distribution (measured as variation in annual catch-weighted mean latitude, longitude, depth and temperature) tended to be best described by models incorporating environmental effects and biomass rather than either variable alone. Linear trends in the center of distribution along a southeast–northwest axis were significant for seven species (arrowtooth flounder, deepsea sole, Dover sole, flathead sole, Pacific sanddab, petrale sole, and slender sole) with a tendency for flatfish to be displaced towards the southeast as environmental conditions shifted from warm to cooler conditions and biomass declined. A spatial distribution analysis indicated that for the majority of species (80%) the greatest magnitude of displacement (km) occurred when the centers of biomass were compared between environmental phases (average annual displacement 34 km) rather than changing biomass levels (average displacement 24 km). Taken together both approaches revealed that environmental changes and variation in biomass play significant roles in flatfish distribution.

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1. Introduction

The California Current System (CCS) is a major coastal upwelling system that extends along the coasts of Washington, Oregon and northern California (Bestelmeyer et al., 2011). The ocean circulation in this region is characterized as an eastern boundary current which supports highly productive fisheries (Pauly and Christensen, 1995). The main ocean circulation is driven by seasonal winds creating upwelling conditions during the summer months and downwelling conditions during the winter months (Huyer, 1983). This seasonal circulation is under the influence of inter-connected, atmospheric and oceanographic processes, the El Niño–Southern Oscillation (represented by the Multivariate El Niño–Southern Oscillation Index, MEI), the strength and position of the Aleutian low atmospheric pressure system (represented by the Pacific Decadal Oscillation index, PDO), and the relative strength of the gyre circulation in the North Pacific (represented by the North Pacific Gyre Oscillation index, NPGO) (Mantua et al., 1997; Alexander et al., 2002; Di Lorenzo et al., 2008; Wolter and Timlin, 2011). Changes associated with the PDO, MEI, and NPGO have been linked to dramatic and long-term change in the population trends for biota of the North Pacific, including phytoplankton, zooplankton, and groundfish (McGowan et al., 1998; Hare and Mantua, 2000; Peterson et al., 2006; Menge et al., 2009).

The northern CCS underwent a distinct shift around 2006, with both the PDO and MEI shifting from "warm" to "cool" phases; relatively warm years of 2003–2006 were followed by four relatively cool years (2007–2010) (Bjorkstedt et al., 2011). During this period, the PDO and MEI displayed a high level of coherence

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(Bjorkstedt et al., 2011). At about the same time, the NPGO shifted from a "negative" to a "positive" phase signaling a change in environmental conditions. During the warm PDO and MEI, and the negative NPGO phase, the northeastern Pacific Ocean warms and productivity of waters off the U.S. west coast declines; during the alternate phases, the opposite pattern occurs (Schwing et al., 2009). Within the CCS, this recent cooling trend follows a long-term increase in sea surface temperature of roughly 1 °C from 1955 to 1999 (Bjorkstedt et al., 2011; Di Lorenzo et al., 2005).

Previous studies have documented shifts in fish distribution in relation to climate change and fluctuating population size at various locations including, along the U.S. northeast continental shelf (Nye et al., 2009), the Bering Sea (Mueter and Litzow, 2008), North Sea (Perry et al., 2005), and Bay of Biscay (Hermant et al., 2010). These changes were manifest as shifts in the mean center of biomass, expanding or contracting ranges, or changes in depth (Perry et al. 2005; Dulvy et al., 2008; Nye et al., 2009). Hermant et al. (2010) noted that warming associated with climate change had a major impact on interannual variability of flatfish abundance in the Bay of Biscay. In the Bering Sea, five of eight flatfish species examined exhibited a significant shift in distribution (CPUE-weighted mean latitude) in response to recent climate warming (Mueter and Litzow, 2008). Although most prior studies examined changes associated with warming conditions, Drinkwater (2005) related successive north and south movement of fish in the North Atlantic to alternating warming and cooling events.

Here we investigated the influence of recent environmental trends and biomass levels on short-term (2003–2010) changes in condition and distribution of ten abundant flatfish species within the CCS from U.S.–Canada to U.S.–Mexico. We utilized three large-scale indices of climate variability (MEI, PDO, and NPGO) and annual, species-specific, coast-wide biomass indices to elucidate ways in which both density-independent and density-dependent sources of variability affect dynamics of eastern North Pacific flatfish species. Several of the flatfish species examined are economically important with negative biomass trends during recent years (Keller et al., 2012), but none of these species are currently considered overfished (NMFS, 2009). Although similar studies have occurred elsewhere for commercially important demersal fish species, our study presents novel findings for multiple flatfish species within the CCS.

2. Methods

2.1. Survey design and methods

Annual bottom trawl surveys of groundfish resources were conducted off the U.S. west coast using standardized procedures from 2003 to 2010 (Bradburn et al., 2011). Surveys occurred from the area off Cape Flattery, Washington (Lat. 48°10′N) to the U.S.–Mexico border (Lat. 32°30′N) at depths of 55–1280 m (Fig. 1). The entire geographic extent of the survey was covered twice each year using chartered, west-coast commercial fishing vessels (20 to 28-m length). Each year sampling extended from mid-May through late July for the first period and mid-August through late

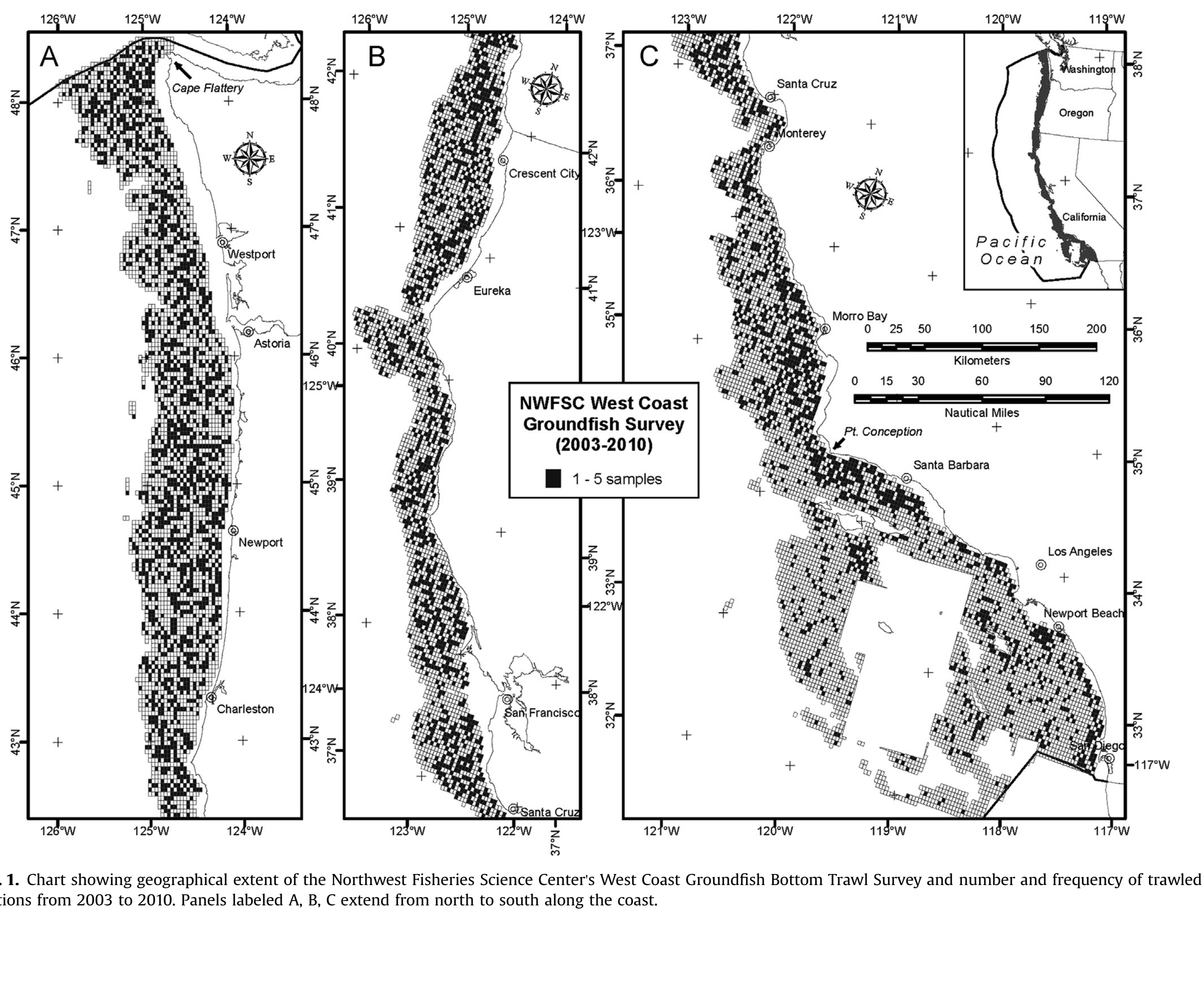

Fig. 1. Chart showing geographical extent of the Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey and number and frequency of trawled stations from 2003 to 2010. Panels labeled A, B, C extend from north to south along the coast.