Journal of Marine Systems 146 (2015) 121–130

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Diet variability of forage fishes in the Northern California Current System

Andrew D. Hill [a], Elizabeth A. Daly [a], Richard D. Brodeur [b,*]

[a] Hatfield Marine Science Center, Oregon State University, Newport, OR 97365, United States
[b] Northwest Fisheries Science Center, NOAA Fisheries, Newport, OR 97365, United States

ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form 24 July 2014
Accepted 11 August 2014
Available online 17 August 2014

Keywords:
Pelagic nekton
Forage fish diet composition
Juvenile salmon diets
Interannual variability
Seasonal variability
Diet overlap

ABSTRACT

As fisheries management shifts to an ecosystem-based approach, understanding energy pathways and trophic relationships in the Northern California Current (NCC) will become increasingly important for predictive modeling and understanding ecosystem response to changing ocean conditions. In the NCC, pelagic forage fishes are a critical link between seasonal and interannual variation in primary production and upper trophic groups. We compared diets among dominant forage fish (sardines, anchovies, herring, and smelts) in the NCC collected in May and June of 2011 and June 2012, and found high diet variability between and within species on seasonal and annual time scales, and also on decadal scales when compared to results of past studies conducted in the early 2000s. Copepoda were a large proportion by weight of several forage fish diets in 2011 and 2012, which differed from a preponderance of Euphausiidae found in previous studies, even though all years exhibited cool ocean conditions. We also examined diet overlap among these species and with co-occurring subyearling Chinook salmon and found that surf smelt diets overlapped more with subyearling Chinook diets than any other forage fish. Herring and sardine diets overlapped the most with each other in our interdecadal comparisons and some prey items were common to all forage fish diets. Forage fish that show plasticity in diet may be more adapted to ocean conditions of low productivity or anomalous prey fields. These findings highlight the variable and not well-understood connections between ocean conditions and energy pathways within the NCC.

Published by Elsevier B.V.

1. Introduction

Driven by both short-term and long-term abiotic forcing, the Northern California Current (NCC) is characterized by substantial seasonal and interannual variability of primary and secondary production (Checkley and Barth, 2009; Ware and Thomson, 2005). The California Current is one of only four eastern boundary current upwelling ecosystems in the world which collectively yield a high percentage of the annual fisheries catches, mostly in the form of small pelagic forage fishes (Alder et al., 2008; Pikitch et al., 2012), although the NCC catch is substantially lower than the rest of the upwelling regions (Conti and Scardi, 2010). Pelagic forage fishes are a critical link between variable and seasonally abundant primary production and upper trophic groups since a substantial portion of the forage fish biomass is represented by only a few species feeding at or near the secondary consumer level (Cury et al., 2000) and there are few alternative energy pathways to higher trophic levels in upwelling regions (Ruzicka et al., 2012).

Though underlying mechanisms for the high variability in forage fish abundance in the California Current are unclear, bottom-up (upwelling, El Niño Southern Oscillation, Pacific Decadal Oscillation, North Pacific Gyre Oscillation) and top-down forcing (catch rates and predation) are substantial pressures (Bjorkstedt et al., 2011; Brodeur et al., 1987; Chavez et al., 2003; Emmett et al., 2006; Ware and Thomson, 2005). In a recent analysis of global forage fish management, Pikitch et al. (2012) recommend a dramatic reduction of catch rates since conventional management models do not adequately address the variability and pressures on population abundance and fail to recognize the pivotal role that forage fish play in sustaining upper trophic levels. Using ecosystem simulation modeling, Kaplan et al. (2013) found that fishing forage fish down negatively affected numerous higher trophic level consumers (e.g., predatory fishes, birds, marine mammals) in the California Current. As management of marine resources shifts to an ecosystem-based approach (Field and Francis, 2006; Peck et al., 2014; Pikitch et al., 2004) and in light of altering ocean environments relating to climate change, understanding pelagic energy pathways and trophic relationships in the NCC and other upwelling regions will become increasingly important for predictive fisheries modeling (Brodeur et al., 2007a; Miller and Brodeur, 2007; Ruzicka et al., 2007, 2012).

The purpose of this study was to analyze diets of five dominant forage fish in the NCC, namely surf smelt (*Hypomesus pretiosus*), Pacific herring (*Clupea pallasi*), Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), and whitebait smelt (*Allosmerus elongates*), in seasonal and annual comparisons to examine diet composition, divergence, and overlap. We compare our results to studies done a decade earlier (Miller and Brodeur, 2007) to explore connections between interdecadal variations in ocean conditions and diet composition. We also compared the diets of forage fish with co-occurring subyearling

* Corresponding author. Tel.: +1 541 867 0336.
E-mail address: rick.brodeur@noaa.gov (R.D. Brodeur).

http://dx.doi.org/10.1016/j.jmarsys.2014.08.006
0924-7963/Published by Elsevier B.V.

Chinook salmon (*Oncorhynchus tshawytscha*) for 2011 to examine the potential for diet overlap and competition. Subyearling Chinook salmon are approximately the same size and often occupy similar horizontal and vertical habitats in coastal waters as forage fish, albeit at much lower abundances (Brodeur et al., 2005; Emmett et al., 2006; Litz et al., 2013).

We hypothesized that there will be a high level of diet variability between forage fish within seasons and years, and that the diet composition of different pelagic forage fish will diverge in times of reduced prey availability to minimize predator competition. Conversely, in times of increased primary production and higher prey abundance such as seen in the summer months during some years, diets will converge as predators capitalize on these superabundant prey resources (Brodeur and Pearcy, 1992). Monitoring the trophic responses of pelagic forage fish may identify trends in energy pathways inherently related to a changing ocean environment.

2. Methods

2.1. Sampling area

The NCC is the northern region of the California Current ecosystem, which extends approximately from 41°N to 49° N along the continental shelf and shelf break between northern California and northern Washington (Fig. 1). This region provides seasonally productive feeding

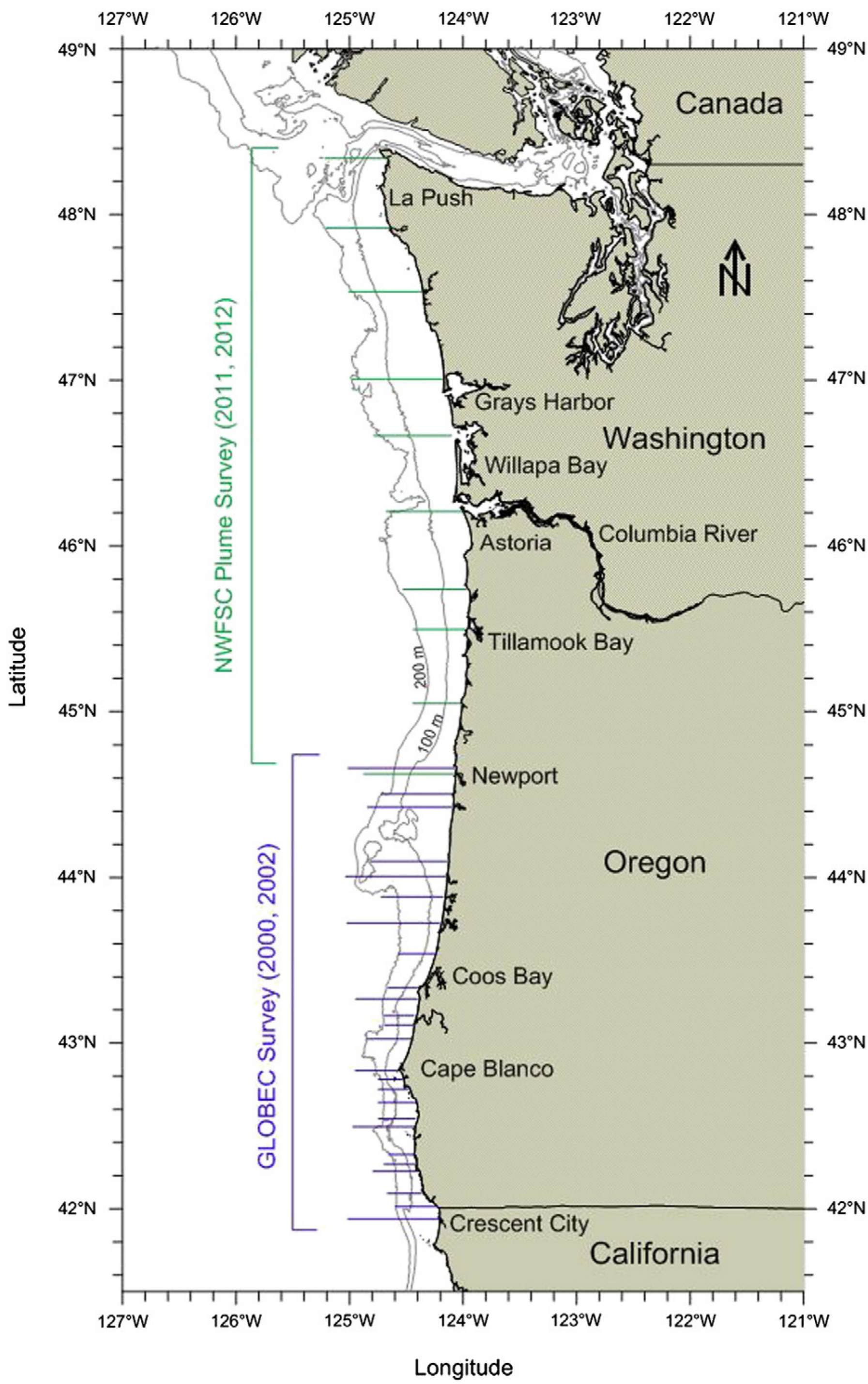

Fig. 1. Location of sampling effort along the shown transects for BPA plume (2011, 2012) and GLOBEC (2000, 2002) sampling.