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Abundance, distribution, and feeding patterns of juvenile coho salmon (*Oncorhynchus kisutch*) in the Juan de Fuca Eddy

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ABSTRACT

The Juan de Fuca Eddy is a seasonal, counter-clockwise gyre off the mouth of the Strait of Juan de Fuca between Washington, USA and British Columbia, Canada that may provide favorable feeding habitat for juvenile coho salmon (*Oncorhynchus kisutch*) during their early marine existence. In late September 2002, physical and biological sampling was conducted along two transects of the eddy region. Surface rope trawling was conducted to capture juvenile salmon and other nekton, along with bongo and neuston net tows to examine potential mesozooplanktonic salmon prey. Presence of the Juan de Fuca Eddy was confirmed with vertical water profiles. In addition, nutrient and chlorophyll *a* concentrations collected from 3-m depth were within the range observed in previous studies within the eddy region. In the mesozooplankton community, euphausiids, chaetognaths, and decapod megalopae were common. In the diet of juvenile coho salmon, euphausiids and decapod megalopae were dominant by percent number, and larval and juvenile fish were dominant by percent weight. Feeding intensity (percent body weight) based on stomach contents was variable, but not significantly different among stations. To compare the Juan de Fuca Eddy region with an upwelling area, we sampled along a transect off La Push (LP), Washington, USA which is south of the eddy. The eddy region was found to be less productive than the LP transect. Nutrients were lower, chlorophyll *a* concentrations were higher, and zooplankton abundance was generally higher along the LP transect than in the eddy region. In addition, more juvenile coho salmon were captured from the LP transect than the eddy region. Prey items in stomachs of salmon from the LP transect were heterogeneous compared to those from the eddy region. Feeding intensity along the LP transect was slightly lower and more variable than in the eddy region, and differences in feeding intensity among LP stations were significant. In addition, feeding intensities among stations nested within regions were significantly different.

1. Introduction

The Juan de Fuca Eddy is a semi-permanent counter-clockwise gyre that forms after the spring transition, when winds shift from southerly to northwesterly, freshwater outflow from the Strait of Juan de Fuca is strong, and the California Current southward flow increases (Freeland and Denman, 1982; Thomson and Ware, 1988; Freeland, 1992; Hickey and Banas, 2003). The topography of deep, narrow Spur and Juan de Fuca submarine canyons plays a role in current movements, upwelling, and subsequent formation of the eddy (Freeland and Denman, 1982; Mackas and Sefton, 1982; Freeland and McIntosh, 1989; Freeland, 1992; Mackas, 1992). Water that is upwelled into Juan de Fuca Eddy from the California Undercurrent is dense and cold, has low oxygen, and is rich in nutrients that stimulate primary productivity (Denman et al., 1981; Freeland and Denman, 1982; Crawford and Dewey, 1989; Freeland, 1992; Mackas and Galbraith, 1992). The eddy persists until the fall transition, which is characterized by a change in direction of winds and currents causing the eddy to subside and dissipate (Thomson and Ware, 1988; Thomson et al., 1989; Hickey and Banas, 2003).

Previous studies indicate that the eddy is highly productive through its physical processes. Nutrient supplies for phytoplankton biomass (chlorophyll *a*) were theorized to come from advection of the California Undercurrent up the Juan de Fuca Canyon onto the continental shelf as well as those upwelled from bottom waters

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over the shelf (Denman et al., 1981). Nutrient influx from the Strait of Juan de Fuca is also suspected (MacFadyen et al., 2008). Stefánsson and Richards (1963) noted that nutrients in surface water outside the Strait of Juan de Fuca were possibly entrained and upwelled from deeper nutrient-rich water in addition to nutrient influx from the strait.

Biological studies that focus on the Juan de Fuca Eddy or identify it as a subregion in a broader sampling area are limited. The population of the pennate diatom *Pseudo-nitzschia*, which produces domoic acid, may be enhanced by nutrients in the eddy (Trainer et al., 2002). Phytoplankton biomass and chlorophyll *a* concentrations were higher at a station inside the eddy than at two stations outside of the eddy, and domoic acid was highest within the euphotic zone in the eddy (Marchetti et al., 2004). Phytoplankton and zooplankton distribution patterns in the eddy and nearby were related to summer circulation patterns in the region (Mackas and Sefton, 1982). Within this region, the zooplankton population was divided into three unique communities, one of which is in the eddy (Mackas, 1992; Mackas et al., 2001). Off southwestern Vancouver Island, seabird densities were usually high adjacent to or in the area of the eddy, where optimal conditions and euphausiid prey for seabirds were located (Burger, 2003). However, the utilization of the Juan de Fuca Eddy by marine nekton has not been examined to date.

It has been suggested that the highest marine mortality rate of Pacific salmon (*Oncorhynchus* spp.) occurs soon after juveniles enter the ocean and are adapting to marine conditions (Parker, 1968; Pearcy, 1992; Werthheimer and Thrower, 2007). Since the ability of salmon to adjust their feeding behavior and adapt to new food sources and habitats is a critical factor to marine survival, it is important to identify areas that may provide favorable feeding habitats for juvenile salmon. The Juan de Fuca Eddy may provide such a habitat through its high productivity and play an important energetic role for juvenile salmonids in that they may use eddies to conserve energy while maintaining position (Freeland, 1988).

In other areas in the vicinity of the Juan de Fuca Eddy, previous studies of juvenile coho salmon (*Oncorhynchus kisutch*) distribution and feeding patterns in the ocean have focused on the La Pérouse, Swiftsure, and Amphitrite banks on the continental shelf off Vancouver Island (Olsen et al., 1988; Morris and Healey, 1990), the Washington and Oregon coasts (Miller et al., 1983; Emmett et al., 1986; Pearcy and Fisher, 1988; Brodeur, 1989; Brodeur and Pearcy, 1990), and a broader area of the northeast Pacific Ocean (Hartt and Dell, 1986; Brodeur et al., 2007; Fisher et al., 2007). During summer, coho salmon are one of the dominant pelagic fishes along southwestern Vancouver Island (Hay et al., 1992; Ware and McFarlane, 1995; Robinson, 2000) and are common off the Washington coast (Pearcy and Fisher, 1988; Brodeur et al., 2005; Fisher et al., 2007). None of these studies focused specifically on the Juan de Fuca Eddy as a subregion within the larger sampling area. Therefore, we conducted an exploratory study of the distribution and abundance of juvenile coho salmon and potential planktonic prey and associated environmental parameters in the Juan de Fuca Eddy region in September 2002. The objectives of this study were to determine whether: (1) the Juan de Fuca Eddy represents favorable habitat in terms of productivity and availability of planktonic prey consumed by juvenile coho salmon and (2) juvenile coho salmon ingest different prey within vs. outside the eddy. Addressing these two objectives will provide insight into the potential that productive ocean waters such as the Juan de Fuca Eddy serve as a recruitment area for juvenile coho salmon. In addition, briefly comparing the eddy with an upwelling area off the Washington coast will lead to a better understanding into how two productive areas can differ.

2. Methods

2.1. Study area

The study area was located over Spur and Juan de Fuca submarine canyons off Cape Flattery, Washington, USA and southwestern Vancouver Island, British Columbia, Canada. The Juan de Fuca Eddy is normally centered over the terminus of Spur Canyon (Freeland and Denman, 1982; Mackas and Sefton, 1982; Crawford, 1988; Crawford and Thomson, 1991). Because the Canada–USA international boundary bisects the eddy (MacFadyen et al., 2005), sampling was limited to the USA waters. In September 2002, we sampled two transects approximately perpendicular to each other and bisecting the eddy region with the goal of sampling the eddy center and perimeter. The SW–NE transect had seven stations (Fig. 1). Station E01 was sampled on 20 September and stations E02–E07 were sampled on 21 September. The NW–SE transect had six stations, E08–E13, and was sampled on 22 September. Station E14 was not located on either transect and was sampled on 22 September. To compare the eddy environment with stations over the continental shelf where upwelling is the norm, the La Push (LP) transect, which was sampled on 26 September, was chosen. All samples were collected between 0700 and 2100.

2.2. Water properties

A Sea Bird SBE 19*plus* profiler was deployed to 100-m depth at each station to collect vertical profiles of conductivity, temperature, and depth (CTD). Quality control of CTD data entailed several steps: (1) alignment of temperature and conductivity, (2) correction for ship heaves, and (3) correction for salinity spikes. Processed CTD data were averaged into 1-m depth intervals for analysis.

Duplicate samples for in vitro chlorophyll *a* concentrations were collected from 3-m depth with a 2-l Niskin water sampler from a single cast. The purpose of taking duplicates was to maintain the precision of chlorophyll *a* measurements from collection to processing (Arar and Collins, 1997). Samples were immediately filtered

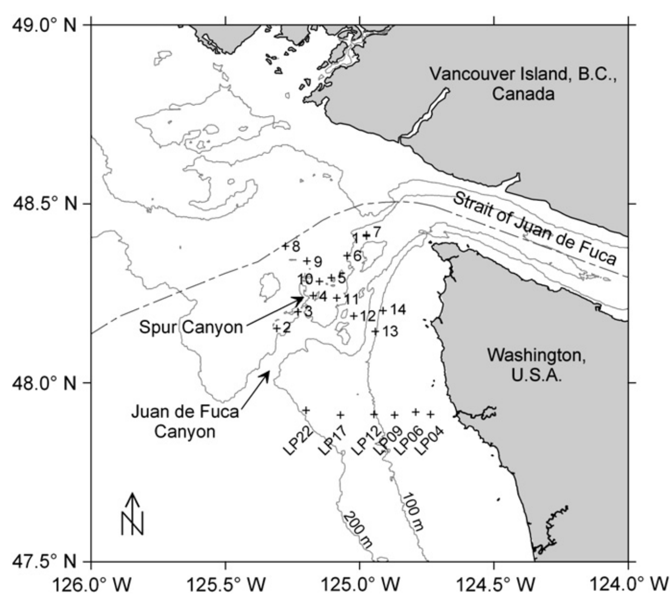

Fig. 1. Study area of Juan de Fuca Eddy, 20–22 September 2002 and La Push transect, 26 September 2002. Eddy stations are denoted by plus signs and numbers. For simplicity in this figure, the eddy stations are labeled by numbers only, whereas they are denoted by "E" and 2-digit numbers elsewhere in this paper. La Push stations are denoted by plus signs, "LP", and 2 digits. Dashed line is the Canada–USA international boundary.