



## Variation in age and growth of greenstriped rockfish (*Sebastes elongatus*) along the U.S. west coast (Washington to California)

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### ABSTRACT

Greenstriped rockfish, *Sebastes elongatus*, are a common commercial and recreational species often taken as bycatch in commercial fisheries off the U.S. west coast. We evaluated weight–length relationships and size-at-age using von Bertalanffy growth models for greenstriped rockfish sampled along the U.S. west coast from 2003 to 2008. Based on regression analyses, populations were subdivided into two depth strata (55–122 m and 122–450 m) and four geographic regions (48°10'N–48°28'N, 40°26'N–48°10'N, 34°27'N–40°26'N, and 32°30'N–34°27'N) and differences in length, age, and growth examined by gender. Strong evidence of variation in weight–length relationships was found north and south of Cape Mendocino (40°26'N) but little variation was noted for depth or gender. In contrast, variations in von Bertalanffy growth models were highly dimorphic between sexes with consistent patterns across depth and geographic regions. Females grew more slowly and reached larger asymptotic sizes ( $L_{\infty}$ , cm) relative to males in all regions examined. Asymptotic size for both males and females tended to increase at higher latitude and increased depth. However, the smallest asymptotic sizes occurred in the region from Pt. Conception to Cape Mendocino, CA (34°27'N–40°26'N), rather than lower latitudes south of Pt. Conception (32°30'N–34°27'N). Greenstriped rockfish growth coefficients ( $k$ ,  $\text{yr}^{-1}$ ) exhibited a more complex pattern. Higher growth coefficients were associated with regions within the northern California Current System characterized by high productivity.

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### 1. Introduction

Greenstriped rockfish, *Sebastes elongatus* Ayers 1859, are moderately sized (maximum size near 45 cm) scorpaenids ranging from the Gulf of Alaska (near Chirikof Island in the Aleutians, 56°13'N) to central Baja California, Mexico (28°10'N), taken primarily in bottom trawls (commercial and research) from British Columbia to Northern Baja California (Love et al., 2002). Adults inhabit the upper continental slope and outer shelf in the eastern north Pacific, in waters ranging from 12 to 491 m depth, but are more commonly found at depths of 120–200 m off the U.S. west coast (Love et al., 2002; Shaw and Gunderson, 2006). Distribution varies by bottom type, with greenstriped rockfish off Washington, Oregon, and California most abundant in trawlable habitats, such as mud and cobble terrain (Stein et al., 1992; Yoklavich et al., 2000; Jagielo et al., 2003) but also found occasionally over hard, high relief bottom near boulders and rocky reefs (Lamb and Edgell, 1986; Love et al., 1990). Greenstriped rockfish are viviparous and display an ontogenetic

migration, with adults moving into deeper waters as they mature (Love et al., 2002). They exhibit sexual dimorphism with females generally larger than males of the same age. Greenstriped rockfish, like many rockfish species, are long-lived with maximum observed ages greater than 50 years (Munk, 2001; Love et al., 2002).

Despite being frequently taken in recreational and commercial fisheries, greenstriped rockfish are not the object of a long-term directed fishery because of their relatively small size and soft fillets (Love et al., 2002). Nonetheless, landings increased from the 1980s into the 1990s primarily due to bycatch in the trawl fishery but also as a result of recreational catch, hook and line landings, and a growing importance in Asian markets (Love et al., 2002). Discards make up an important component of total fishing mortality throughout much of the range (Hicks et al., 2009). Accurate information on age and growth is needed for effective management and reliable assessment of greenstriped rockfish stocks (Gerritsen and McGrath, 2007; Hicks et al., 2009). Life history parameters, including age and growth structure have been examined in other studies on this species (Shaw and Gunderson, 2006). Wyllie-Echeverria (1987) reported latitudinal trends in life history traits, including a latitudinal cline in maturity. Shaw and Gunderson (2006) demonstrated decreasing mean lengths for both male and female greenstriped

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rockfish from Vancouver, Canada south to Pt. Conception, CA. In an effort to improve management for this species, we evaluated differences in age and growth of greenstriped rockfish throughout the study area, extending from the U.S. Canada border to the U.S. Mexico border. Differences in the weight–length relationship and growth curves were explored as a function of gender, depth distribution, and locality. Following Kimura (1990, 2008) we compared the effects of gender, depth, and geographic location on the von Bertalanffy growth parameter estimates via standard non-linear least squares and associated likelihood methods and utilized the Akaike Information Criterion (AIC) (Akaike, 1973, 1992) to select parsimonious models.

## 2. Methods

### 2.1. Survey design and methods

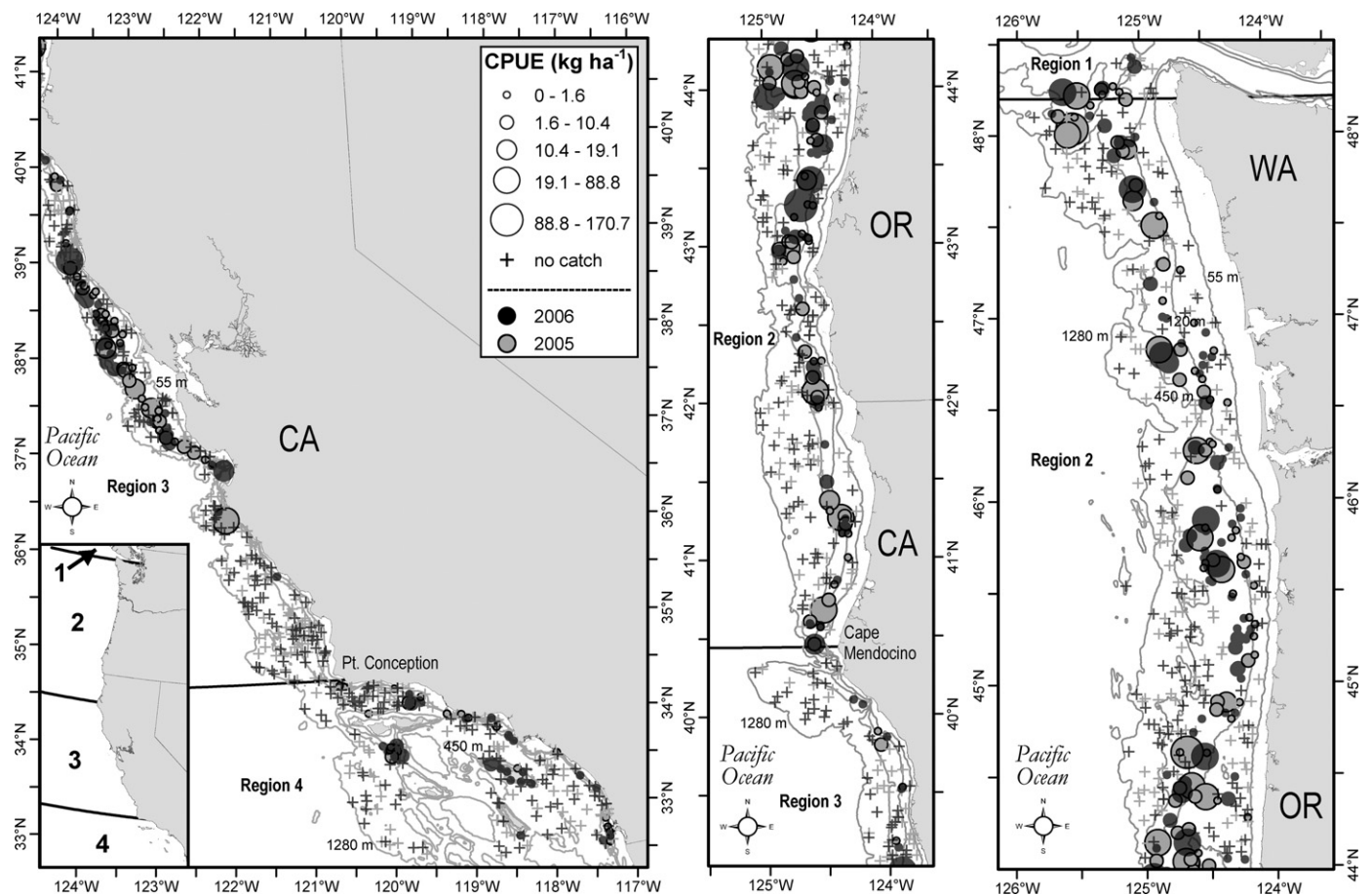
Greenstriped rockfish were sampled from 2003 to 2008 during the annual Northwest Fisheries Science Center's (NWFSC) fishery-independent bottom trawl survey of groundfish resources off the U.S. west coast (Keller et al., 2008). Surveys occurred late-May through October from the U.S.–Canada border (lat. 48°28'N) to the U.S.–Mexico border (lat. 32°30'N) at depths of 55–1280 m. The entire geographic extent of the survey was covered twice each year using a stratified (by geographic location and depth) random sampling design with an average of 750 sites sampled each year. Vessels were equipped with customized Aberdeen-style trawls with a 3.8 cm mesh (stretched measure) liner in the codend, a

25.9 m headrope, and a 31.7 m foot rope. Samples were collected by trawling within randomly selected cells for a target fishing time of 15 min at a target speed of 1.13 m s<sup>-1</sup> (2.2 knots). All fishing operations were conducted in strict compliance with national and regional protocols detailed in Stauffer (2004).

### 2.2. Biological sampling

All fish and invertebrates collected were identified to species (or the lowest possible taxa), weighed, and enumerated. Based on tree-regression analyses (SAS, 1999), greenstriped rockfish were subdivided into two depth strata: shallow (55–122 m) and deep (122.1–450 m) and four geographic strata: region 1 (48°10'N–48°28'N), region 2 (40°26'N–48°10'N), region 3 (34°27'N–40°26'N), and region 4 (32°30'N–34°27'N) with geographic boundaries occurring in northern Washington near Cape Alava (48°10'N), Cape Mendocino, CA (40°26'N), and Point Conception, CA (34°27'N) (Fig. 1).

Sex was determined for a subsample of greenstriped rockfish randomly selected from the catch at each location; when gender could not be determined greenstriped rockfish were categorized as unsexed. Fork length (cm) and individual weight (kg) were recorded and otoliths were extracted for age determination. Ages were determined by the break and burn method (Chilton and Beamish, 1982), a generally accepted method for aging Pacific rockfish (MacLellan, 1997). Love et al. (1990) validated annular deposition of opaque and translucent zones for greenstriped rockfish using marginal increment analysis. For this analysis,



**Fig. 1.** Extent of the Northwest Fisheries Science Center's (NWFSC) west coast groundfish bottom trawl survey showing greenstriped rockfish distribution and relative abundance (catch per unit effort, kg ha<sup>-1</sup>) from the 2005 and 2006 surveys. Biogeographic breakpoints at Cape Alava, WA (48°10'N), Cape Mendocino, CA (40°26'N), and Pt. Conception, CA (34°27'N) separate the study area into 4 regions.

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