Agenda Item H.5
Supplemental Attachment 2 ***(Electronic only)***
April 2023

ESSENTIAL FISH HABITAT APPENDIX

TO THE

COASTAL PELAGIC SPECIES FISHERY MANAGEMENT PLAN

April 2023 DRAFT

Contents

Table of Tables

Table of Figures

1 INTRODUCTION

The 1996 amendments to the Magnuson-Stevens Act (MSA) established new requirements for describing and identifying essential fish habitat (EFH) in Federal fishery management plans (FMPs). The amendments (16 U. S. C. 1801 *et. seq*.) also require consultation between the National Marine Fisheries Service (NMFS) and Federal agencies on activities that may adversely impact EFH for those species managed under FMPs. The amended MSA requires Fishery Management Councils to amend all of their FMPs to describe and identify EFH for the fishery based on guidelines established by NMFS, to minimize to the extent practicable adverse effects on such habitat caused by fishing, and to identify other actions to encourage the conservation and enhancement of EFH. NMFS guidelines on EFH requirements for FMPs were published as a Final Rule in the *Federal Register* on January 17, 2002 (67 FR 2376). These guidelines were used in the description and identification of EFH for the Coastal Pelagic Species (CPS) FMP.

The MSA defines "essential fish habitat" as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." To clarify this definition, the following interpretations are made: "waters" include aquatic areas and their associated physical, chemical, and biological properties that are used by fish (here and thereafter defined as any fish or invertebrate), and may include areas historically used by fish where appropriate; "substrate" includes sediment, hard bottom, structures underlying the waters, and associated biological communities; "necessary" means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers the full life cycle of a species. EFH must be designated for each managed species, but, where appropriate, may be designated for assemblages of species or life stages that have similar habitat needs and requirements.

The CPS FMP includes four finfish (Pacific sardine, Pacific (Chub) mackerel, northern anchovy (northern and central subpopulations), and jack mackerel), one mollusk (market squid), and all species of krill, a crustacean, within the West Coast Exclusive Economic Zone (EEZ) (Table 1.1). CPS finfish are pelagic (in the water column and not associated with substrate) during all life stages, and generally occur above the thermocline in the upper mixed layer. Market squid are demersal during their egg stage, but pelagic during their larval and juvenile stages. Maturing market squid (virgin) are pelagic, but spawning adults are demersal during the last few days of their life. Krill are pelagic at all life stages. For the purposes of EFH, the CPS finfish is treated as a single species assemblage. market squid EFH is defined separately. Krill are treated as a species assemblage due to their similar habitat requirements and insufficient information to designate EFH for each individual species. However, because sufficient information exists to designate EFH at the species level for *Euphausia pacifica* and *Thysanoessa spinifera*, those two species have individual EFH designations. Within assemblages, species have similarities in their life histories and similarities in their habitat requirements. However, among species assemblages, there are some differences in life histories or habitat requirements across life stages. Under the CPS FMP, fishing is prohibited on any krill species (see Amendment 12, PFMC 2006).

Table 1.1. CPS scientific and common names and assemblage under the CPS FMP.

Common Name	**Scientific Name**
Finfish	
Pacific sardine	*Sardinops sagax*
Pacific (chub) mackerel	*Scomber japonicus*
Northern anchovy (central and northern subpopulations)	*Engraulis mordax*
Jack mackerel	*Trachurus symmetricus*
Market squid	*Doryteuthis opalescens*
Krill or Euphausiids (Including all species in West Coast EEZ)	
Euphausia pacifica	
Thysanoessa spinifera	
Other krill (includes all krill species in the West Coast EEZ other than *E. pacifica* and *T. spinifera*)	*Nyctiphanes simplex* *Nematocelis difficilis* *T. gregaria* *E. recurva* *E. gibboides* *E. eximia* *Thysanoessa inspinata* *Stylocheiron affine* *Euphausia hemigibba*

2 EFH FOR THE CPS FISHERY

In determining EFH for CPS, the estuarine and marine habitat necessary to provide sufficient CPS production to support a sustainable fishery and a healthy ecosystem was considered. Using Level 1 information, (i.e., presence/absence distribution data) EFH for CPS is primarily based upon a thermal range bordered within the geographic area where a CPS occurs at any life stage, where the species of CPS has occurred historically during periods of similar environmental conditions, where a CPS has been associated with both pelagic waters and benthic substrates (e.g., market squid), or where environmental conditions do not preclude colonization by the CPS. EFH for CPS is derived from distributional data (presence/absence), oceanographic data (e.g., sea surface temperatures [SST]), relationships between oceanographic variables (e.g., temperature, salinity, chlorophyll a), and other published information. Specific EFH boundaries are based on best available scientific information. Sufficient Level 1 information exists to describe and identify EFH for the CPS finfish assemblage, market squid, and krill (*Euphausiia pacifica*, *Thysanoessa spinifera*, and 'other krill").

The specific description and identification of EFH for each species or assemblage accommodates the fact that the geographic range of all CPS varies widely over time in response to the temperature of the upper mixed layer of the ocean, and to atmospheric/climatic events such as the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and marine heat waves (e.g., Yatsu et al. 2008, Chasco et al. 2020, McClatchie et al. 2018, Muhling 2020, Lilly and Ohman 2021, Santora et al. 2011, van Noord and Dorval, 2017, Zwolinski and Demer 2012).

2.1 Finfish Assemblage: EFH Description and Identification

Juvenile and adult CPS finfish are generally not found at temperatures colder than 10°C or warmer than 26°C and preferred temperatures and minimum spawning temperatures are generally above 12°C. Spawning is most common at 13° to 17°C in US waters (e.g., Ahlstrom 1959, Lo et al. 2009, Lo et al. 2013, Dorval et al. 2014, Dorval et al. 2018), but this temperature range can extend up to 20°C or greater off Mexico (Weber and McClatchie 2012). More detailed information on CPS temperature range of each species is provided in Section 2.1.1 to 2.1.4 of this document. Annual SST experienced by CPS are found in Figure 2.2 and Figure 2.3.

SST and habitat boundaries for CPS finfish vary seasonally, inter-annually, and decadally. During favorable oceanic conditions (e.g., warm regimes), most CPS finfish populations undergo northward migration in summer-fall (as far as British Columbia) for feeding, and southward migration in winter-spring for spawning in the southern California bight (SCB) (e.g., Félix-Uraga et al. 2004, Demer et al. 2012, Stierhoff et al. 2019, Zwolinski et al. 2019). In unusually warm years (e.g., El Niño), CPS finfish such as Pacific sardine and Pacific mackerel may shift their population northward, leading to increased summer abundance off the U.S. Pacific Northwest, British Columbia and Alaska (e.g., McFarlane et al. 2005, Lo et al. 2010, Lo et al. 2011). On a decadal scale, these CPS may shift their populations southward during cold regimes, leading for example to the complete depletion of the Pacific sardine population off British Columbia and the U.S. Pacific Northwest (e.g., 1950s-1970s), or to small residual populations off northern California and Oregon (e.g., 2015-present) (FOCS 2012, Zwolinski et al. 2012, Dorval et al. 2016, Auth et al. 2018, Stierhoff et al. 2019). During favorable oceanic conditions, most CPS finfish populations exhibit peak spawning in the SCB in March-April, although Northern anchovy peak spawning may start as early as February. Across centuries and millennia, hence prior to exploitation, CPS finfish populations have boomed and busted within their preferred habitats, shifting northward or southward, and collapsing or recovering within the U.S. EEZ, depending on prevalent oceanic conditions (e.g., Soutar and Isaacs 1974, Baumgartner et al. 1992, McClatchie et al. 2017, 2018).

During the 1999-2012 period, the position of the 10°C isotherm (a rough estimate of the lower thermal and northern geographic bound for CPS finfish) in winter (January-March) was on average off the coast of Oregon (~ between 42° and 43° N. latitude) (Figure 2.4). During the warmer period of 2013-2020, the 10°C isotherm in winter was further north along the coast, but between 45° and 46° N. latitude offshore (Figure 2.5). The 14°C isotherm (a rough measure of the location of preferred temperatures) during winter was on average off California (~ 32.3° -37° N. latitude) in 1999-2012 but shifted slightly northward off California (~ between 34° and 38° N. latitude) in 2013-2020.

SST and habitat boundaries for CPS finfish extend farther to the north during the summer than during the winter. The position of the 10°C isotherm during summer (July-September) was off Canada during both the 1999-2012 and 2013-2020 periods (Figure 2.6 and Figure 2.7). As described above, sea surface temperatures of 13° to 17°C are generally preferred for spawning in U.S. waters.

Differences between spawning habitat (13° to 17°C) and geographic range (>10°C) are consistent with seasonal migration patterns of Pacific sardine and Pacific mackerel, which tend to move north to feed during summer and south to spawn during winter (e.g., Demer and Zwolinski 2012, Zwolinski 2012). Abundance and biomass are probably both related to the geographic extent of spawning. Pacific mackerel and Pacific sardine in particular may have increased reproductive success during warm decades (i.e., the 1930s, 1980s, 1990s, and 2000s) when spawning peaks are located within the core area in the SCB (e.g., Lo et al. 2009, Lo et al. 2010, Weber and McClatchie 2012, Dorval et al. 2014). In the absence of Pacific sardine, productivity of northern anchovy tends to peak during colder decades (e.g., 1960s, 1970s), although showed high fluctuations (0.5-2 million mt of spawning biomass) throughout the 1960-1990 period (McCall et al. 2016). After a low period of abundance from 2009 to 2011 (McCall et al. 2016), the central subpopulation of northern anchovy (CSNA) has recovered since 2017, showing high abundance off California and peak spawning in the SCB (Dorval et al. 2018, Stierhoff et al. 2019, Kuriyama et al. 2022).

SST (°C) and spatial distribution data in the California Current Ecosystem (CCE) presented in Figure 2.2 through Figure 2.13 were compiled from various National Oceanic and Atmospheric Administration (NOAA) Surveys and Satellite data by B.A. Muhling, University of California, Santa Cruz. Although for the purpose of this document these data were summarized on different time scales, they were derived from the same datasets and analyzed using the same statistical methods that were reviewed and published in Muhling et al. (2020). Further, Muhling et al. (2020)'s data are available to the public on the NOAA website Environmental Research's Division Data Access Program (ERDDAP, https://coastwatch.pfeg.noaa.gov/erddap/index.html).

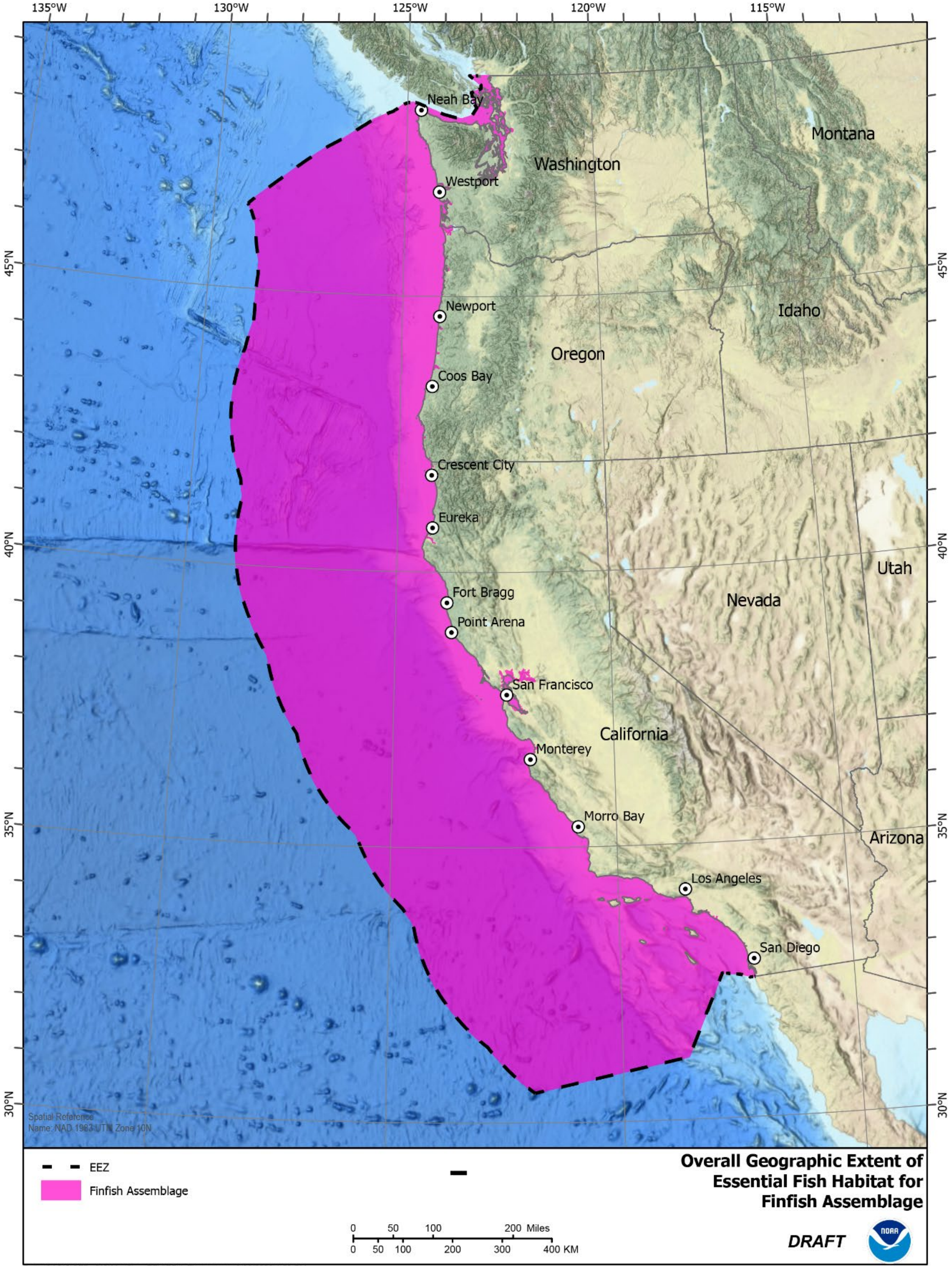
EFH for the CPS finfish assemblage: the east-west geographic boundary of EFH for the finfish assemblage is defined to be all marine and estuarine waters from the shoreline along the coasts of

California, Oregon, and Washington (including Puget Sound) offshore to the limits of the EEZ and above the thermocline where SST range between 10° to 26°C. The northern distributional range of CPS finfish is dynamic and variable due to the seasonal cooling of the sea surface temperature,(see Figure 2.2 and Figure 2.3), hence in some seasons the 10°C isotherm can be north of the U.S.-Canada border. Similarly, the southern distributional range can extend south of the U.S.-Mexico border where sea surface temperatures are consistently below 26° C. Therefore, the southern extent of EFH for CPS finfish is the U.S.-Mexico maritime boundary (Figure 2.1), whereas the northern EFH boundary is the U.S.-Canada border. EFH for CPS finfish is summarized in Table 2.1.

Table 2.1. Summary of distribution and EFH for CPS finfish (northern anchovy, Jack mackerel, Pacific sardine, Pacific mackerel).

Species Common and Scientific Names	**Life stage**	**San Diego-Pt Conception (California)**	**Pt. Conception-Cape Mendocino (California)**	**Cape Mendocino-Puget Sound (California-Oregon-Washington)**	**Benthic Association**
Northern anchovy (*Engraulis mordax*)	Eggs/Larvae/Juveniles	yes	yes	yes	no
	Adults	yes	yes	yes	no
Jack mackerel (*Trachurus symmetricus*	Eggs/Larvae/Juveniles	yes	yes	yes	no
	Adults	yes	yes	yes	no
Pacific sardine (*Sardinops sagax*)	Eggs/Larvae/Juveniles	yes	yes*	yes*	no
	Adults	yes	yes*	yes*	no
Pacific (Chub) mackerel (*Scomber japonicus*	Eggs/Larvae/Juveniles	yes	yes*	yes*	no
	Adults	yes	yes	yes	no

Note: * Indicates that abundance of a life stage is likely to be higher in this region during warm environmental conditions.



Path: C:\GIS\SFD_GIS\Mapfiles_EFH\EFH_Figures.aprx 2/22/2023 1:03 PM

Figure 2.1. Geographic extent of EFH for CPS Finfish.

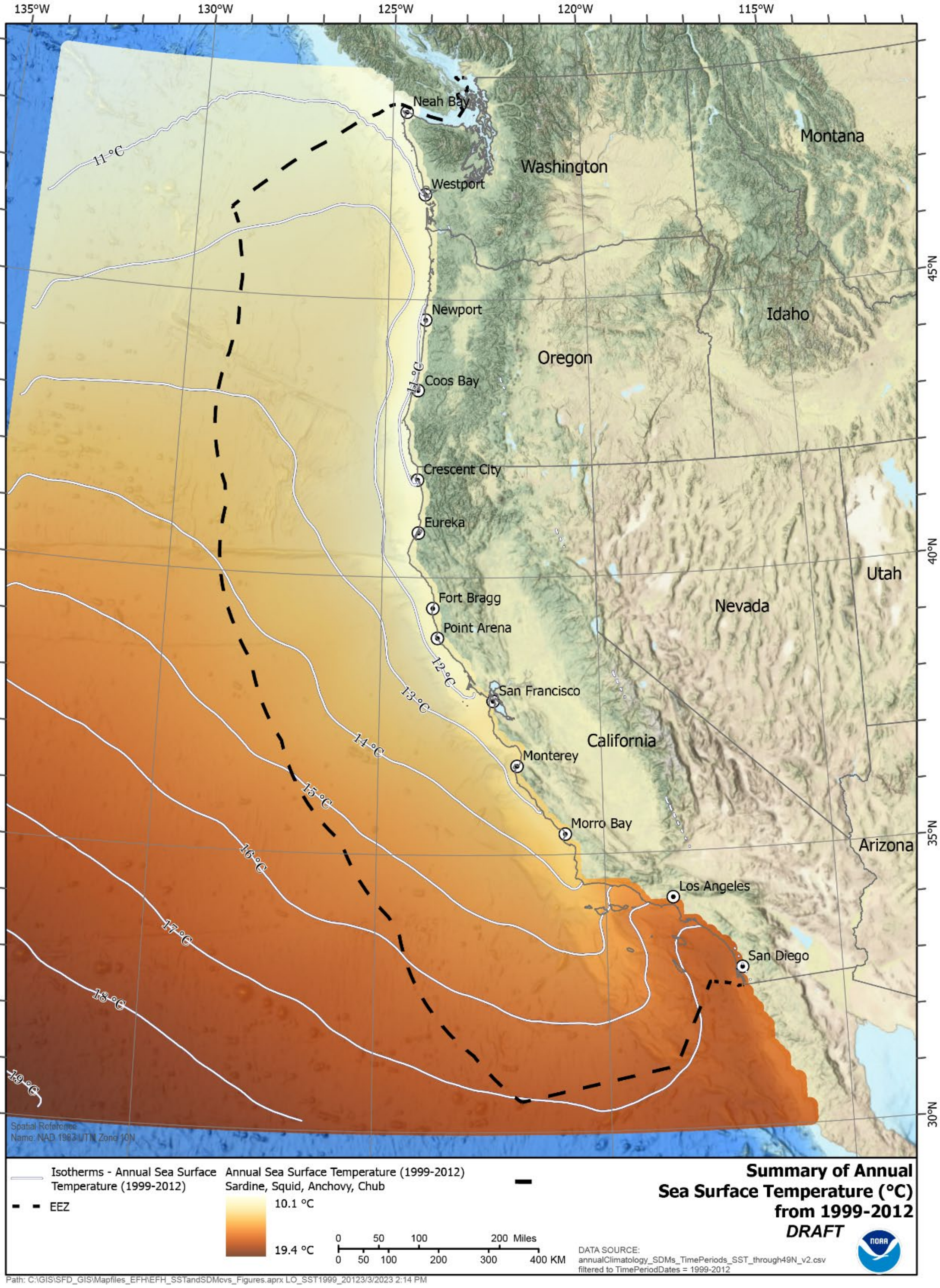


Figure 2.2. Summary of annual sea surface temperature (°C) from 1999-2012, within and eastward of the U.S. EEZ. Data used to build this map was provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

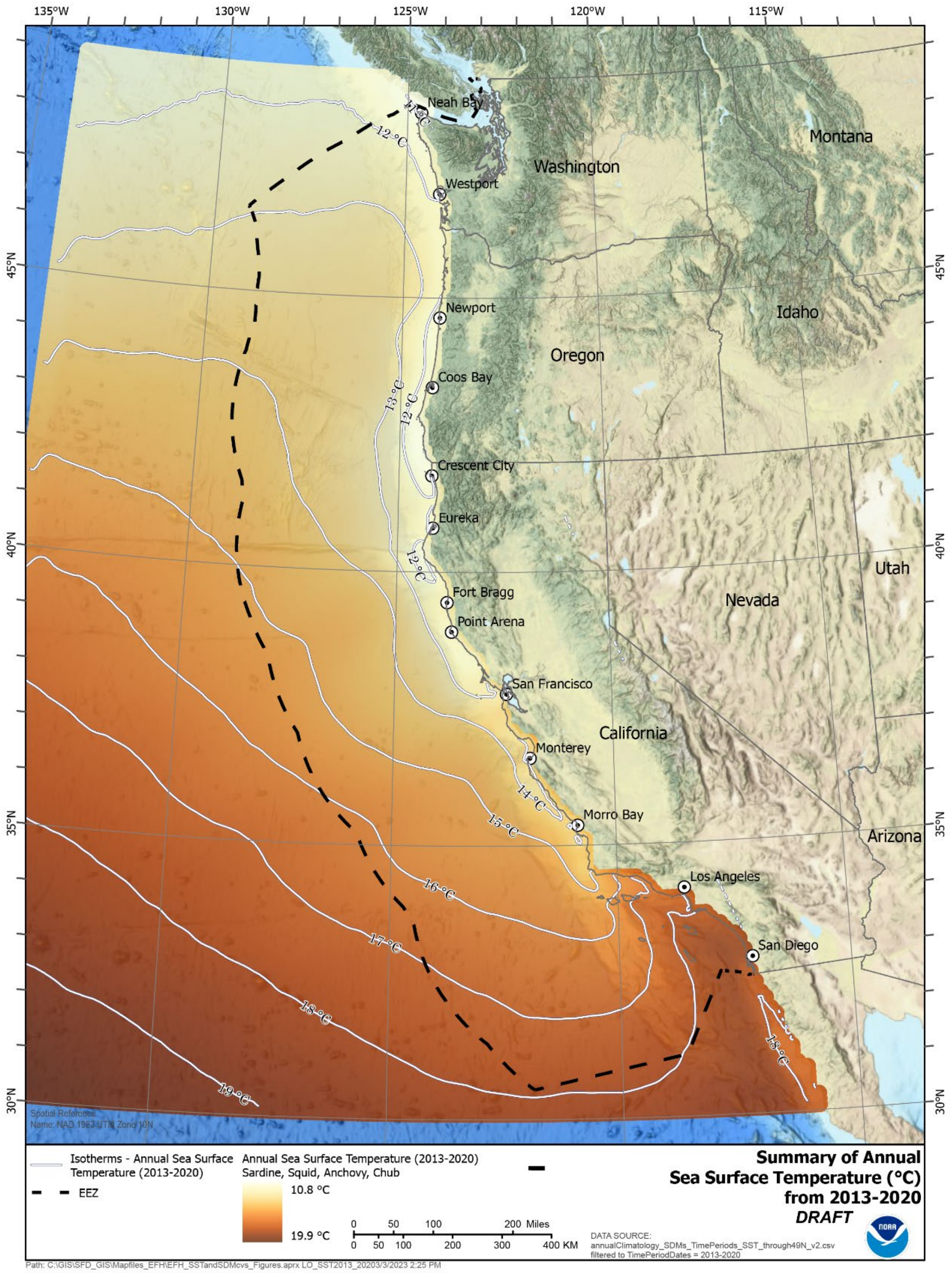


Figure 2.3. Summary of annual sea surface temperature (°C) from 2013-2020, within and eastward of the U.S. EEZ. Data used to build this map was provided by Muhling, using the same source of data in Muhling et al. (2020).

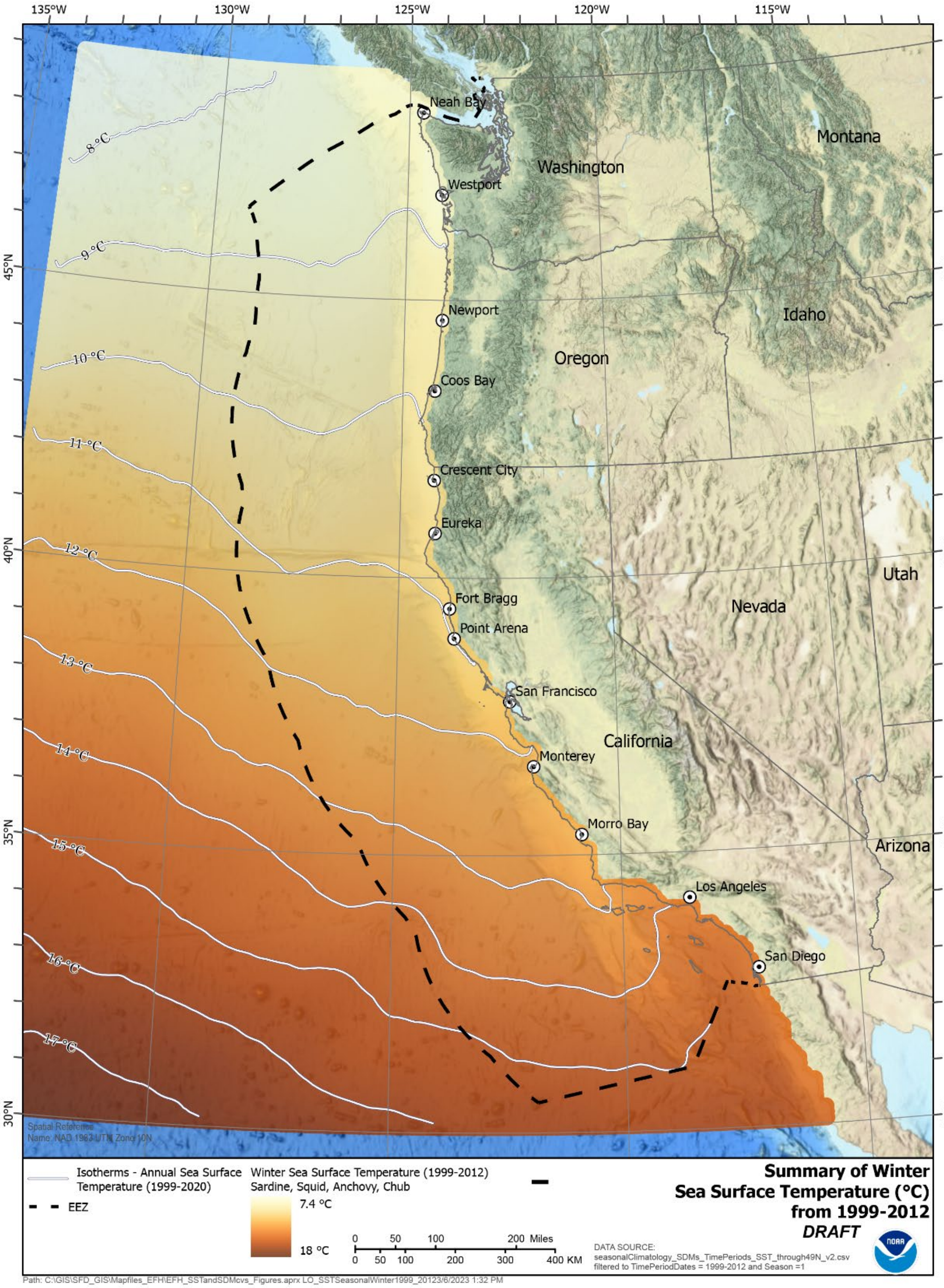


Figure 2.4. Spatial distribution of sea surface temperature (°C) in winter (January-March) during the 1999-2012 period, within and eastward of the U.S. EEZ. Data used to build this map was provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

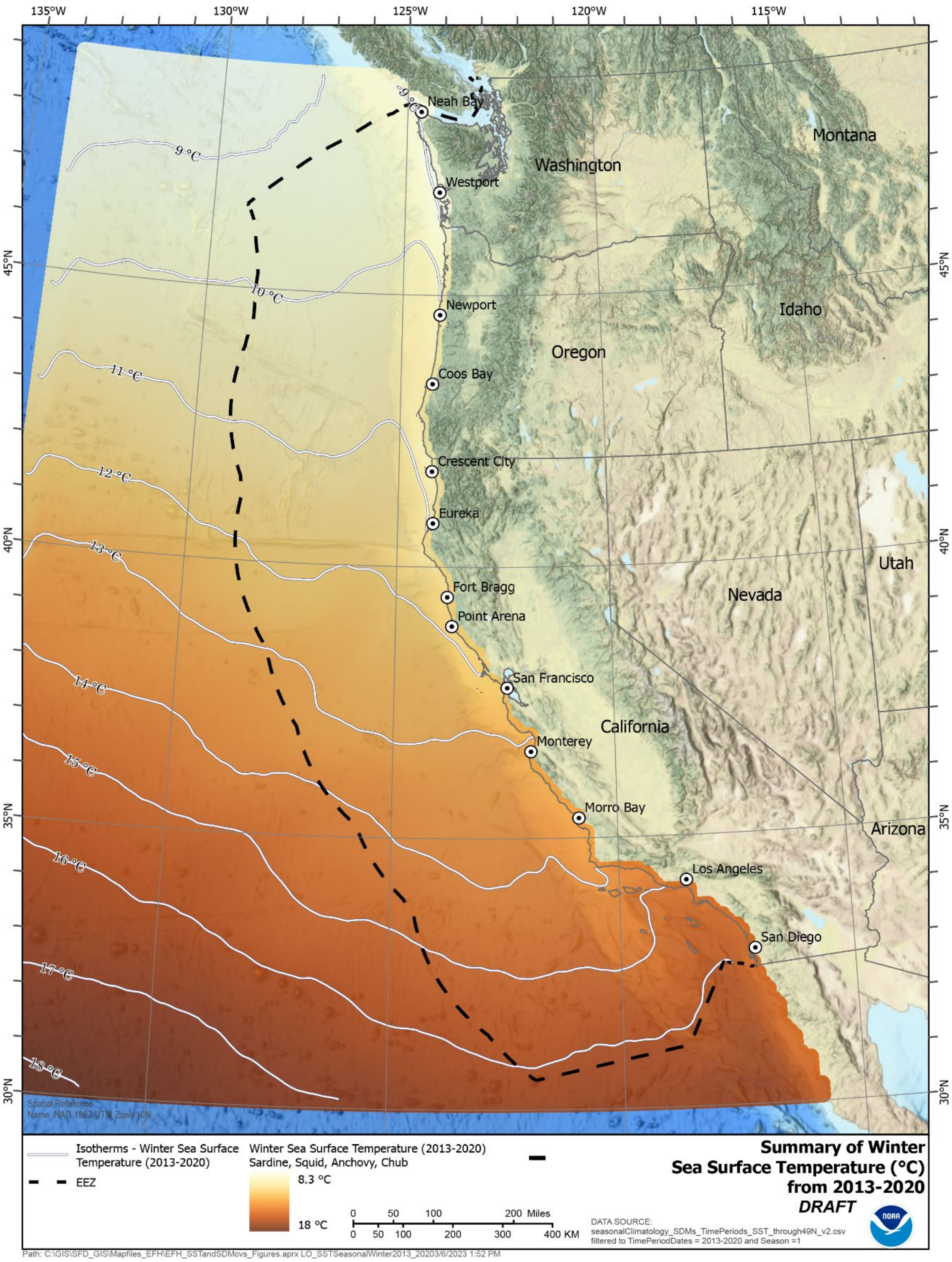


Figure 2.5. Spatial distribution of sea surface temperature (°C) in winter (January-March) during the 2013-2020 period, within and eastward of the U.S. EEZ. Data used to build this map was provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

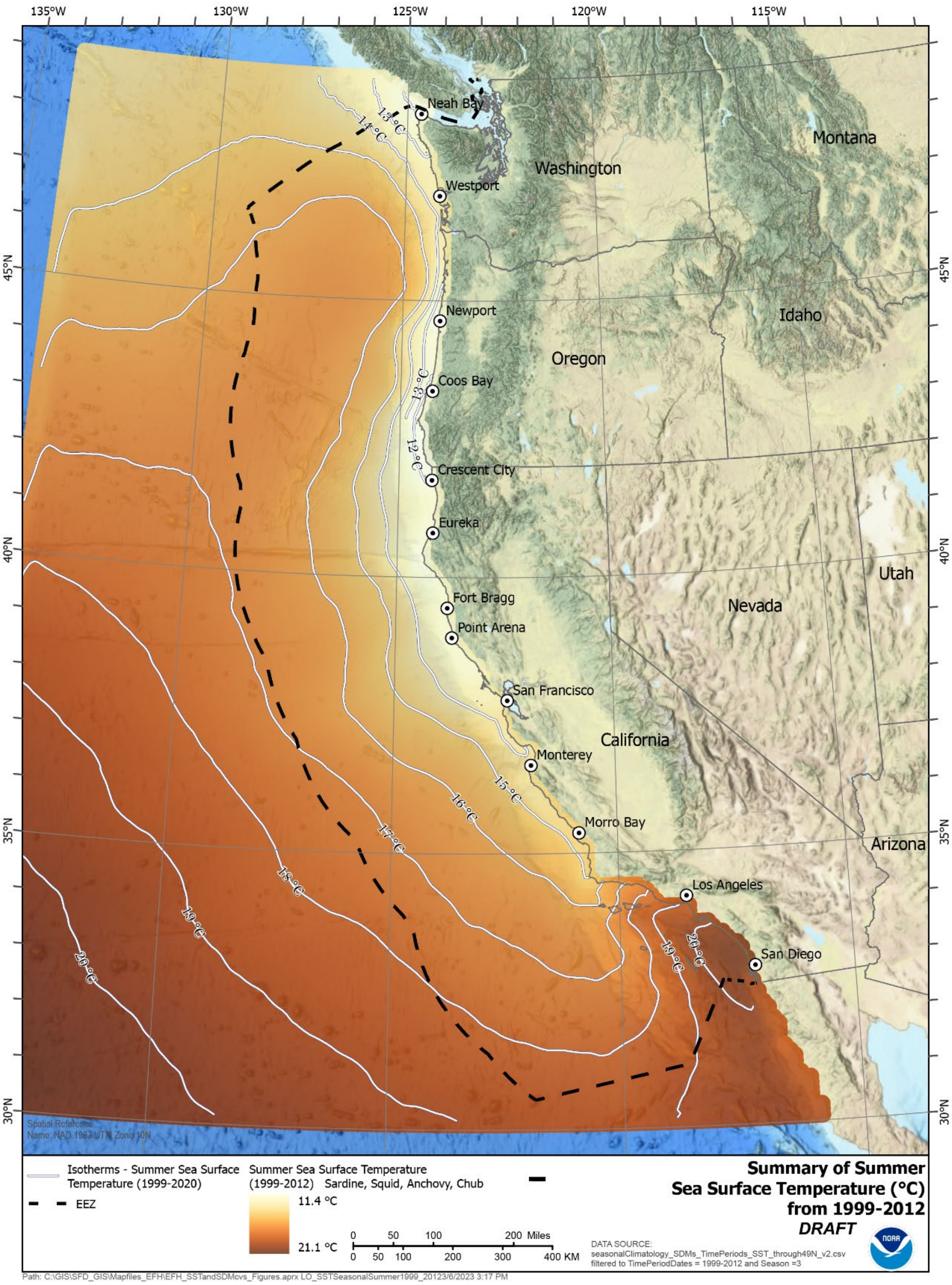


Figure 2.6. Spatial distribution of sea surface temperature (°C) in summer (July-September) during the 1999-2012 period, within and eastward of the U.S. EEZ. Data used to build this map was provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

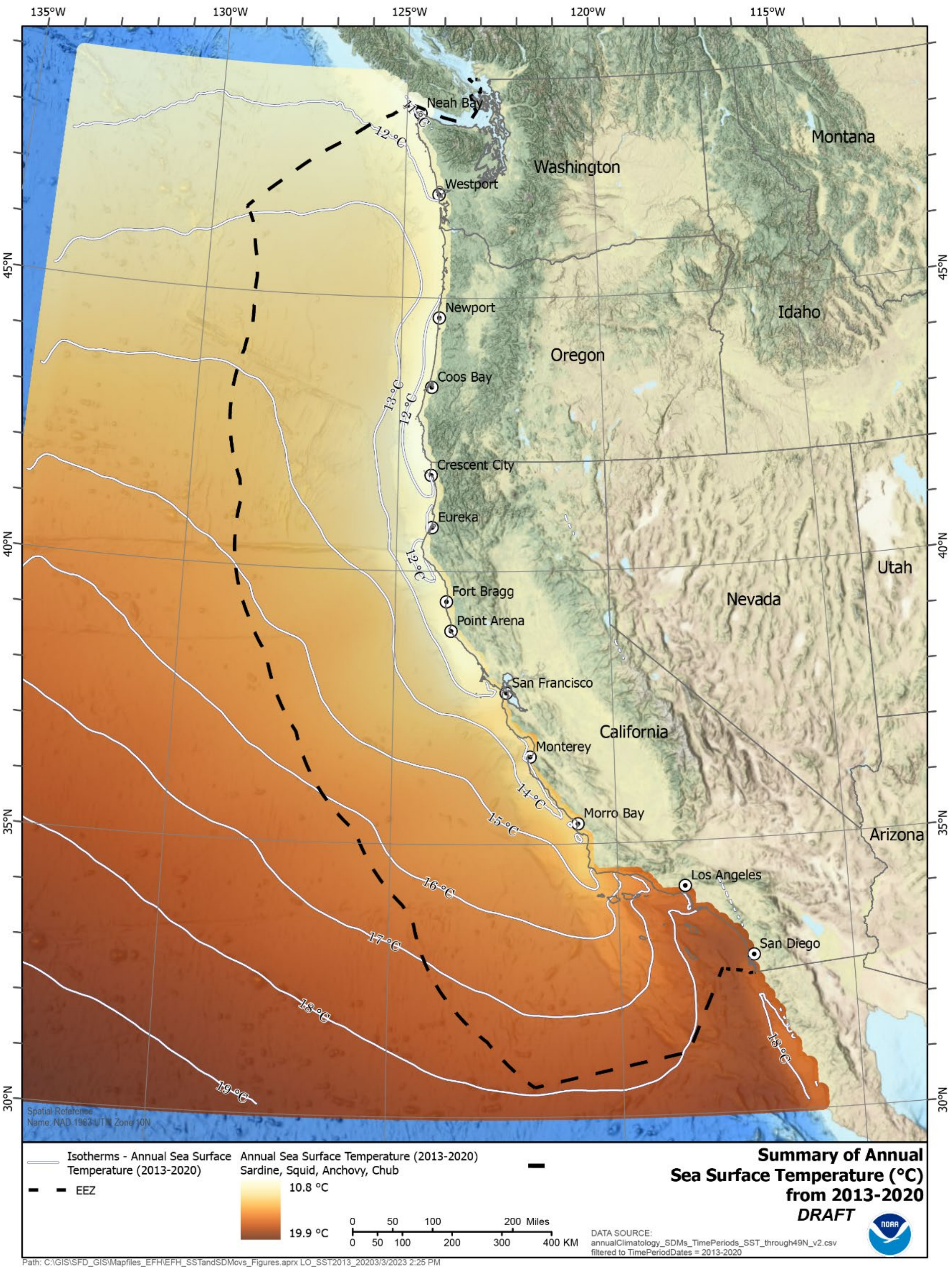


Figure 2.7. Spatial distribution of sea surface temperature (°C) in summer (July-September) during the 2013-2020 period, within and eastward of the U.S. EEZ. Data used to build this map was provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

2.1.1 NORTHERN ANCHOVY

2.1.1.1 Distribution and Habitat

Northern anchovy (*Engraulis mordax*) is a small planktivorous fish that is distributed in the northeastern Pacific Ocean from the Queen Charlotte Islands (British Columbia) to Magdalena Bay, Baja California and the Gulf of California (Mexico). Recent phylogenetic analysis confirmed the evolutionary relatedness of *E. mordax* to other fishes of the family Engraulidae within the order Clupeiformes, but also indicated non-monophyly for the herring family, Clupeidae (Lewis and Lema, 2019). Northern anchovy are divided into three subpopulations, namely the northern subpopulation of northern anchovy (NSNA), the central subpopulation of northern anchovy (CSNA), and the southern subpopulation of northern anchovy (SSNA) (Fielder 1986, PFMC 2019). The NSNA may range from British Columbia to Cape Mendocino, whereas the SSNA is entirely within Mexican waters. The CSNA, which supports significant commercial fisheries in the U.S. and Mexico, ranges from approximately San Francisco, California, to Punta Baja, Baja California. The bulk of the CSNA is located in the SCB, a 20,000-square-nautical-mile area bounded by Point Conception, California, in the north and Point Descanso, Mexico, (about 40 miles south of the U.S.-Mexico border) in the south.

Off California, northern anchovy are typically found in waters that range from 12°C to 21.5°C (Thompson et al. 2019). Laboratory-reared northern anchovy can be induced to mature their gonads and to spawn at about 15° and 17°C (Leong 1971) and they may produce larvae that hatched and developed normally in temperature ranging from 11.5° to 27°C (Brewer 1976). However, laboratory defined lethal temperatures occur at 7°C and 29°C (Brewer 1976)**.** There is a great deal of regional variation in age composition and size (Kuriyama et al. 2022, Schwartzkopf et al. 2022), with older and larger northern anchovy found farther offshore and to the north (Parrish et al. 1985). These patterns are accentuated during warm years such as El Niño and when abundance is high (Methot 1989). Tagging experiments have shown that northern anchovy moved from southern California to central California in summer and from central to southern California in the spring (Haugen et al. 1969). Spawning stock biomass is typically higher in southern California than in northern California during the spring season (e.g., Picquelle and Hewitt 1983, Hewitt 1985, Dorval et al. 2018), whereas total stock biomass tends to be higher off northern California during summer and fall (Mais 1974, Stierhoff et al. 2020, Kuriyama et al. 2022). In the Oregon to Vancouver Island region, the NSNA must overwinter in upper mixed layer temperatures as low as 8°C to 9°C.

Off California, eggs and larvae are found near the surface, and they are generally most abundant at depths of less than 50 meters (Ahlstrom 1959). In the 1940s and 1950s, most anchovy eggs were collected in water temperatures from 13° to 17°C, and larvae were most abundant in temperatures of 12 to 18°C (Ahlstrom 1959). Throughout the 1980s, anchovy eggs were most abundant at about 14ºC (e.g., Lluch-Belda et al. 1991), but their overall distribution ranges between 11°and 17°C in the SCB (Picquelle and Hewitt 1983, Hewitt 1985). Recently, Dorval et al. (2018) reported spawning of CSNA from 11° to 17°C (mean = 14.4°C), with high density areas of eggs located mostly between the 13 and 14°C isotherms. Therefore, current spring spawning habitat of the CSNA generally occurs at the same temperature range and locations as observed in the 1980s in the SCB. However, during unusual years (e.g., El Niño years), eggs and larvae may be found as much as 150 km offshore, from within the SCB, due to habitat extension and advection (Fielder et al. 1986). Although some studies have found that the geographic range of northern anchovy may be influenced by climatic events, causing potential mixing between subpopulations and shift in their distributional range (Weber and McClatchie 2010, Sydemann et al. 2020, Weber et al. 2021), Muhling et al. (2020) found that northern anchovy largely maintained their historical spatiotemporal distribution during marine heat waves. Remotely sensed oceanographic data have also been modeled to predict the seasonal location of the spawning stock along the U.S. Pacific coast, providing new ecological indicators such as thermal fronts, chlorophyll a (Reiss et al. 2008, Reese et al. 2011), and dynamic height (Asch 2013, Asch and Checkley 2013) for defining preferred-spawning habitats or predicting fine scale spawning patterns. Reiss et al. (2008) estimated that the spawning habitat of the central population averaged between 1,000 and 200,000 km^2 for the period of 1998-2005. Asch and Checkley (2013) found that the greatest probability of encountering Northern anchovy eggs occurred at dynamic heights of 79-83 centimeters (cm). Time series data (AD 1000-1500) reconstructed from sediment fish scales in the Santa Barbara Basin also revealed that high anchovy biomass was associated with increased upwelling diatoms and cool/negative PDO events (Skrivanek and Hendy, 2015).

All northern anchovy life stages are found in the surface waters of the EEZ, but there is temporal and spatial variation in their distribution. Methot (1981) found that nearshore habitat areas (<90 meters) between Pt. Conception, California and Pt. Banda, Baja California represented 23 percent of the available habitat for CSNA juveniles. Densities of northern anchovy juveniles in nearshore areas were about ten times higher than in other habitat areas. Methot (1981) concluded that nearshore habitats supported at least 70 percent of the juvenile anchovy population (Methot 1981). Ralston et al. (2015) showed that from 1990 to 2012, northern anchovy were mostly distributed in waters less than 200 m of depth, with highest abundances occurring closer to the shorelines off California. Information on northern anchovy habitat use is summarized in Table 2.2, whereas its spatial distributions within and seaward of the U.S. EEZ during the 1999-2012 and 2013-2020 periods are presented in Figure 2.8 and Figure 2.9.

Table 2.2. Summary of habitat information for northern anchovy within the U.S. EEZ.

Life Stage	**Diet**	**Season**	**Location**	**Water Column**	**Oceanographic Features**
Eggs and larvae	Yolk sac and planktivorous	Year-round, peaks from Feb. to April	Surface waters of the EEZ	Near surface, < 50m	11^{o}C - 17^{o}C
Juveniles and Adults	Phytoplankton, zooplankton	Year-round	Surface waters of the EEZ	Near surface, < 200 m	12^{o} C - 22^{o}C

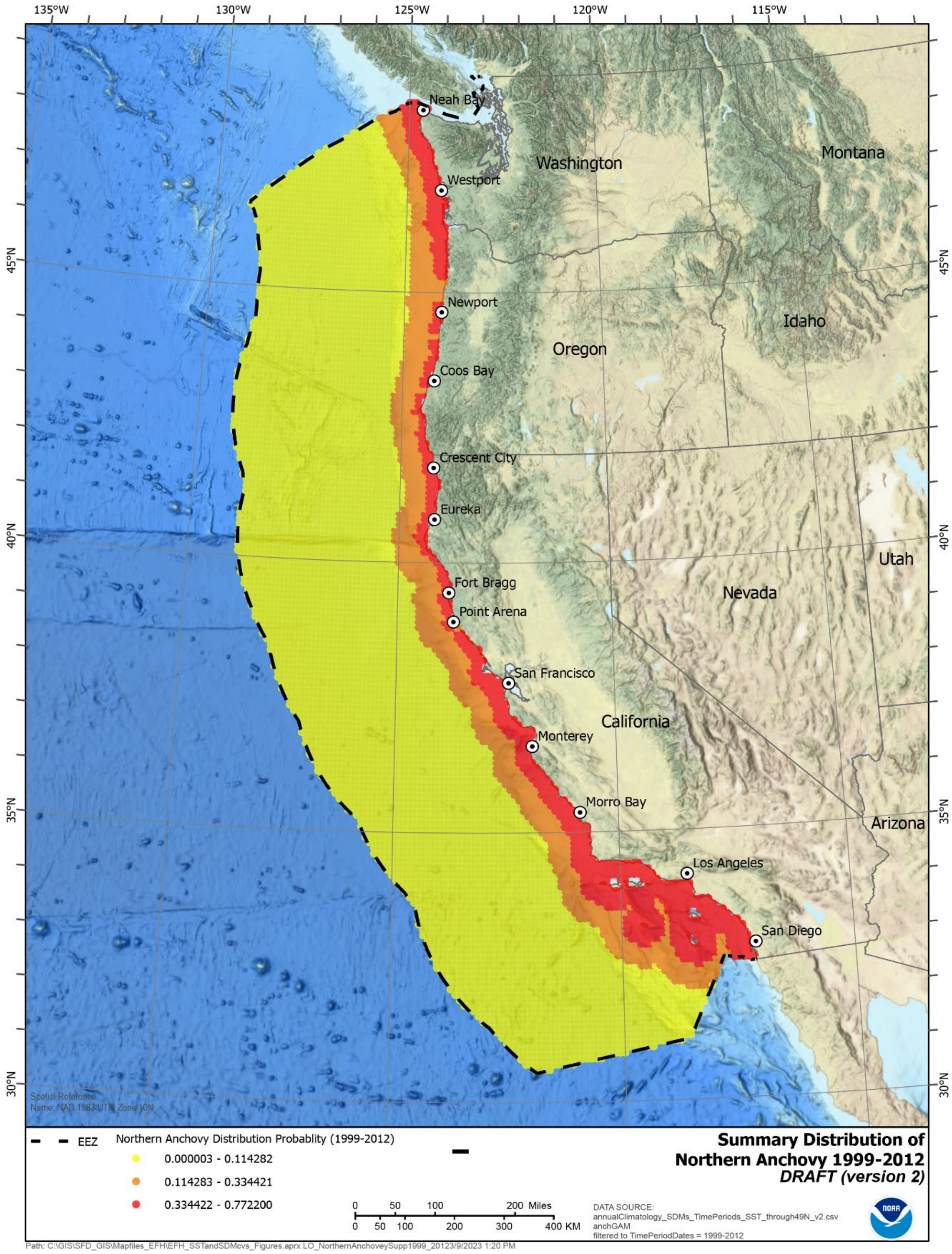


Figure 2.8. Summary distribution of northern anchovy within and seaward of the U.S. EEZ during the 1999-2012 period. Probability distribution was computed using generalized additive mixed models (GAMM) and provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

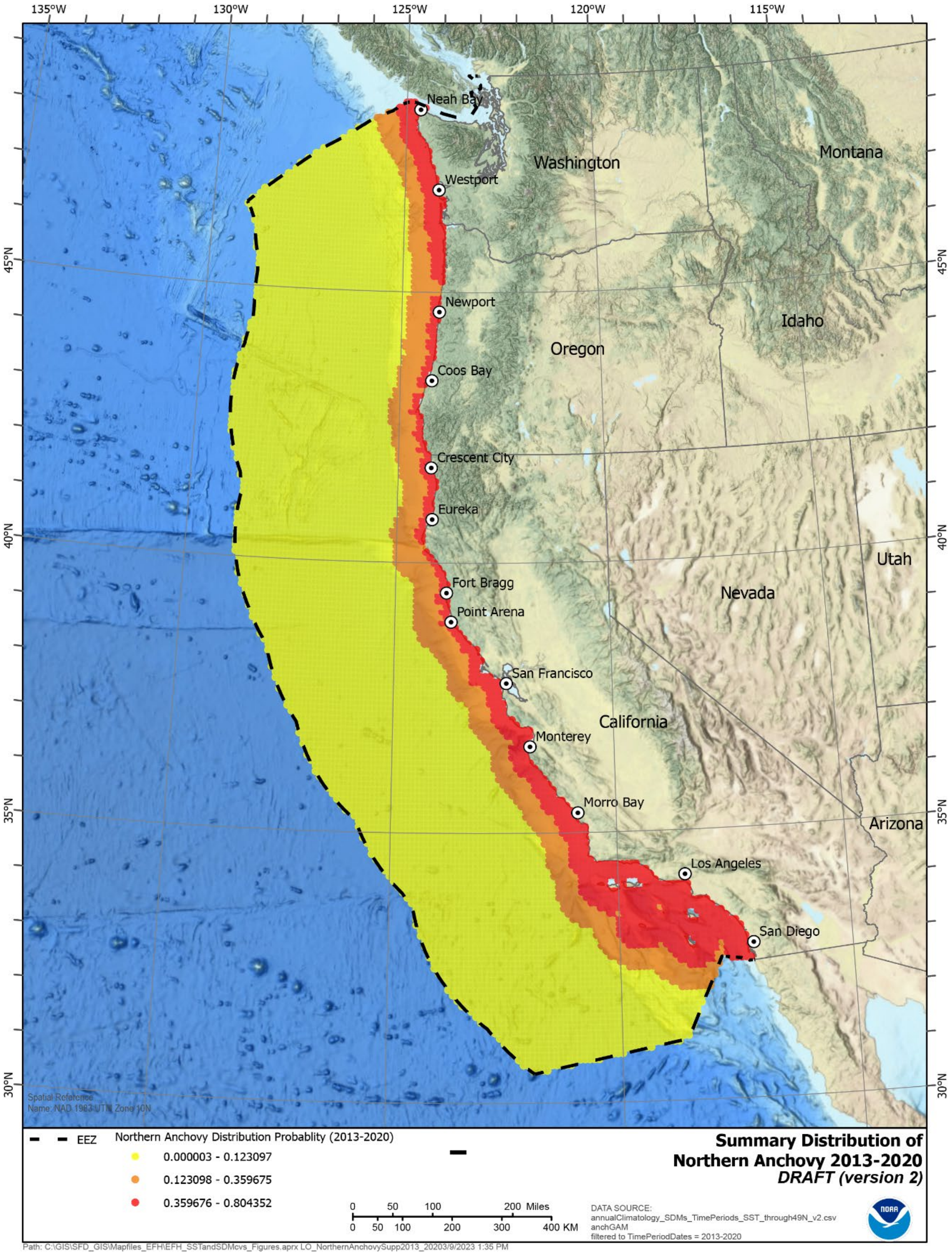


Figure 2.9. Summary distribution of northern anchovy within and seaward of U.S. EEZ during the 2013-2020 period. Probability distribution was computed using GAMM models and provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

2.1.1.2 Life History

Northern anchovy are small, short-lived fish typically found in schools near the surface. Northern anchovy age may range from 0 to 7 years-old, but the dominant age classes in the populations typically are from 0 to 4 years-old. Recent aging research conducted by Schwartzkopf et al. (2022) found that the maximum age and size of northern anchovy collected from the CSNA were 6 years-old and 164 mm standard length (SL), respectively. From 2015 to 2021 age-0 and age-1 accounted for 65 percent of samples collected from Southwest Fisheries Science Center (SWFSC) trawl surveys, whereas age 4+ made up only 8 percent of these samples. In the fishery, age-1 and age-2 were dominant, accounting for 68 percent of the samples, whereas fishery samples comprised only 2 percent of age-4+ individual fish.

Northern anchovy grow fast and like most CPS, they complete most of their growth within the first two years of their life. However, there is also clinal variation in the age structure and growth dynamics among the three subpopulations of northern anchovy. Litz et al. (2008) estimated maximum length to be 250 mm SL for the NSNA, whereas Clark and Phillips (1952) found that CSNA individual fish exhibited a maximum length of 184 mm (SL). Parrish et al. (1985) and Mais (1974) reported that the maximum length collected from the southern subpopulation off Mexico was ~125 mm (SL). Off central California, older fish tend to occur in greater numbers than in the SCB (Mallicoate and Parrish 1981). In addition, Parrish et al. (1985) reported that fish ages ranged from 1 to 7 years-old in the CSNA, whereas SSNA comprised younger fish ranging from 1 to 5 years-old. Adult fish collected from the SSNA tend to have a slower growth rate than those collected from the CSNA. For juveniles, growth was also faster for the CSNA compared to the SSNA. Parrish et al. (1985) also reported that individual fish caught in offshore areas of the SCB had faster growth rates than those caught in inshore waters.

Various factors may regulate northern anchovy somatic growth, including food quantity and quality, ocean temperature, upwelling intensity and timing, and early life history mortality rates. Takahashi et al. (2012) found that delayed upwelling contributed to reduced growth rates due to low food availability. Canales et al. (2016) reported that a shift of diets toward smaller zooplankton resulted in slower growth of *Engraulis* spp. Nearshore eutrophic habitats, where large zooplankton are abundant, have been also identified as areas with the highest potential for adult Northern anchovy growth (Rykaczewski 2019). Food availability and varying metabolic rates from temperature changes also directly impact growth rates of larval and juvenile northern anchovy (Butler 1989).

Natural mortality (M) has been estimated to range from 0.6 to 0.8 year^{-1}, which means that 45 percent to 55 percent of the total CSNA would die each year of natural causes if no fishing occurred. Estimates within this range of M values have been directly used in past stock assessment of the CSNA (e.g., Jacobson et al. 1995) or used to establish priors for estimating M (Kuriyama et al. 2022) from assessment models. Predation from marine mammals, fishes and birds is an important factor that determines these high natural mortality rates (see Section 2.1.2.3 below).

Northern anchovy of the CSNA have a protracted spawning season, but spawning increases in late winter and early spring and peaks from February to April (Picquelle and Hewitt 1984, Hewitt 1985, Dorval et al. 2018). Preferred spawning temperature is 14ºC and eggs are most abundant at temperatures between 11ºC to 17ºC. Northern anchovy are multiple batch spawners and have indeterminate fecundity (Hunter and Macewicz 1980; Hunter and Leong 1981). On average, individual females spawn every 6-10 days and up to 20 times per year (Hunter and Goldberg 1980, Hunter and Macewicz 1980, Parrish et al. 1986). Batch fecundity, spawning frequency, and spawning season duration in Northern anchovy increase with female size (both length and weight) and age such that larger older females contribute disproportionately more to total annual egg production relative to first-time spawners (Hunter and Macewicz 1985; Parrish et al. 1986). For example, one year-old females have a shorter spawning season and an earlier spawning peak than older females (Hunter and Macewicz 1985, Parrish et al. 1986). Moreover, fourth year spawning females reproduce more times per year than first time females, 23.4 vs. 5.3, respectively (Parrish et al. 1986), and batch fecundity is an exponential function of gonad-free female body mass (Hunter and Macewicz 1980).

Northern anchovy eggs are typically ovoid and translucent and require two to four days to hatch, depending on water temperatures. Both the eggs and larvae are found near the surface. The northern range of egg distribution off California is typically associated with the 14.5°C isotherm (Lasker et al. 1981; Picquelle and Hewitt 1983; Hewitt 1985) and in 2017 high density areas of eggs were located mostly between the 13-14°C isotherms in the SCB (Dorval et al. 2018).

Histological analysis conducted on gonad samples collected in 2017 and 2021 showed that Northern anchovy started maturing at age 0, and their length at 50 percent maturity ranged from 97 mm-102 mm SL on average (Dorval et al. 2018, Schwartzkopf et al. 2022). The fraction of 1 year-olds that is sexually mature in a given year depends on water temperature and has been observed to range from 47 percent to 100 percent (Methot 1989). Schwartzkopf et al. (2022) found that 87 percent of females were mature at age 0, 97 percent were mature at age 1, and all females were mature by age 2 in spring 2017. For spring 2021, 37 percent were mature at age 0, 83 percent were mature at age 1, 93 percent were mature at age 2, 98 percent were mature at age 3, and all females were mature by age 4. Schwartzkopf et al. (2022) found that the smallest mature female CSNA of 89 mm was an age 0, and all females were estimated to be mature by 2 years of age (120 mm SL) based on a von Bertalanffy growth model.

2.1.1.3 Relevant Trophic Information

Northern anchovy are subject to natural predation throughout all life stages. Eggs and larvae fall prey to an assortment of invertebrate and vertebrate planktivores. As juveniles, northern anchovy are vulnerable to a wide variety of predators, including many recreationally and commercially important species of fish. As adults, northern anchovy are preyed upon by endangered salmon stocks (e.g., Chinook and coho salmon), endangered birds (e.g., California brown pelican *Pelecanus occidentalis californicus* and the California least tern *Sterna albifrons brownie),* numerous fishes (some of which have recreational and commercial value), mammals, and birds. Links between brown pelican breeding success and northern anchovy abundance have been documented (e.g., Anderson et al. 1980, 1982). Recent research has particularly focused on determining the trophic interactions of Northern anchovy within the CCE food web, and on quantifying the impact of its abundance on population sizes and the temporal variability in the habitat range of top marine predators. Thus, various indices have been developed to assess the value of northern anchovy in the diets of marine predators and to elucidate the most important factors that control foraging habitats of fish such as salmons, Pacific albacore, and thresher sharks (Glaser et al. 2011; Dale et al. 2017; Adams et al. 2017; Litz et al. 2017, Preti et al. 2012, Thayer et al. 2014, Nickels et al. *In review*); birds such as cormorants, terns, murres, and shearwaters (Elliott et al. 2015, 2016; Sydemann et al. 2015; Peterson et al. 2018; Phillips et al. 2016; Webb and Harvey, 2015; Zamon et al. 2014); and marine mammals such as California sea lions and harbor seals (Lance et al. 2012, Riemer et al. 2011; Robinson et al. 2018). Seabirds, such as murres and shearwaters eat primarily planktivorous fish such as northern anchovy (Zamon et al. 2014). Northern anchovy is also a major dietary component of certain colonies of California least terns, and thus their importance for this endangered species may vary in space and time (see Appendix 2 in Lewiston and Deutschman 2014). Elegant tern, Heermann's gull, and brown pelican feed on pre-recruits of Pacific sardine and northern anchovy, and their population sizes are sensitive to variations in the abundance of these forage fish (Velarde et al. 2015, Kaplan et al. 2019). Between 2008 and 2012, diets of Brandt's cormorant decreased in the consumption of northern anchovy, as these seabirds switched their feeding to rockfish (Elliott et al. 2015). Phillips et al. (2017) found that the distribution of common murres, sooty shearwater, and juvenile salmon was associated with forage fish (including northern anchovy), and these birds and fish species were more abundant in the Columbia River plume waters than in adjacent marine waters. Pacific sardine and northern anchovy occur frequently in the diet of sea lions (Orr et al. 2011). In the 1900s, sea lion diets were dominated by these two forage fish, but both species were less prominent in recent years (Robinson et al. 2018). Pacific sardine and northern anchovy were also the two most important prey of thresher sharks during the 1998-2014 period, but not in recent years (Pretti et al. 2012, 2018). In some years, northern anchovy may make half of the diet of subyearling Chinook salmon (Dale et al. 2017), and this species grows faster and reaches larger size in periods when ocean conditions increase the availability of Northern anchovy (Litz et al. 2017). The spatial distribution of northern anchovy and its predator Pacific hake are highly correlated with cool-water mesopelagic ichthyoplankton. Further, Nickels et al. (*In Review*) found that Pacific albacore specialized in feeding on northern anchovy in areas characterized by "Low Biologically Effective Upwelling Transport index." Furthermore, Glaser et al. (2011) estimated that Pacific albacore may consume from less than 1 percent to over 17 percent of northern anchovy pre-recruitment biomass annually (Glaser et al. 2011). These interactions of anchovy with its prey and predators highlight the importance of this species in the CCE, leading Kaplan et al. (2020) to predict that a depletion of 40 percent of forage fish (including northern anchovy) in this ecosystem can impact the abundance of 20-50 percent of other functional groups by greater than 20 percent.

2.1.2 JACK MACKEREL

2.1.2.1 Distribution and Habitat

Jack mackerel are a pelagic schooling species that ranges widely throughout the northeastern Pacific, from the Pacific coast to an offshore limit approximated by a line running from Cabo San Lucas, Baja California Sur (including the Gulf of California), to the eastern Aleutian Islands, Alaska (Morley et al. 2012, Jorgensen et al. 2016). Much of the range lies outside the 200-mile U.S. EEZ (MacCall and Stauffer 1983, Konchina et al. 2011). Data collected on Jack mackerel from 2007 to 2020 have been used to map the quality of its habitat along the U.S. West Coast (Morley et al. 2012). Morley et al. (2012) found that jack mackerel had moved into regions with larger areas of continental shelf habitats, with the latitudinal centroid of this species distribution shifting poleward about 20.6 km per decade. Based on these data, the thermal habitat of jack mackerel is projected to shift by more than 1300 km northward by the end of this century in 2081–2100, as this species expands into Alaska and the eastern Bering Sea under climate change (Morley et al. 2012).

Off California, jack mackerel prefer spawning in temperatures ranging from 13.5° to 15.6°C and in waters of < 33.1 salinity (Asch and Checkley 2013). However, eggs have also been collected in higher salinities from 33.28 to 33.56 (McClatchie et al. 2012). Abundance of jack mackerel larvae is typically centered between 80 to 240 miles offshore (Ahlstrom and Ball 1954). Eggs and larvae are most abundant in waters of less than 50 m of depth but can be distributed up to 120 m (Ahlstrom 1959). Larvae occur in higher abundance at temperatures between 14° and 15.9°C (Ahlstrom 1959). Dynamic height has been identified as a potential physical parameter that can be used to identify jack mackerel spawning habitats. Asch and Checkley (2013) found that the greatest probability of occurrence of Jack mackerel eggs was located at dynamic height of 84–89 cm, and this parameter remained statistically significant in model runs of spawning habitat after considering the effects of other variables such as temperature, salinity, chlorophyll, zooplankton volume, geostrophic currents, and eddies.

Small jack mackerel (10 cm to 30 cm FL and up to six years of age) are most abundant in the SCB, where they are often found near the mainland coast and islands and over shallow rocky banks (Nebenzahl 1997). Older, larger fish (50 cm to 60 cm FL and 16 years to 30 years) range from Cabo San Lucas, Baja California Sur, to the Gulf of Alaska, where they are generally found offshore in deep water and along the coastline to the north of Point Conception. Large fish rarely appear in southern inshore waters (Nebenzahl 1997). Fish of intermediate lengths (30 cm to 50 cm Total Length; nine years to 20 years of age) were found in considerable numbers during the spring of 1991 around the 200-mile limit of the U.S. EEZ off southern California; fish of five years to nine years of age were the most numerous and fish ten years to 20 years old were common (Nebenzahl 1997).

Jack mackerel sampled between 1978 and 1984 by trawl surveys off Oregon and Washington ranged from 30 cm to 62 cm and from four to 36 years old. More than half of the fish sampled were greater than 20 years old and fish greater than 30 years old were common (Nebenzahl 1997). Jack mackerel collected by the SWFSC trawl Surveys during the 2004-2022 period from British Columbia to San Diego measured from 25-60 cm fork length (FL), and in the past two decades observed length distribution have changed little across years in U.S. coastal waters (E. Dorval, pers. comm.). In recent years, the abundance of jack mackerel has increased in U.S. waters, showing, for example, the greatest proportion in CPS catch and trawl clusters between Westport, WA, and Fort Bragg, CA in 2016 (Stierhoff et al. 2021). As with other CPS finfish, older and larger fish are most common further north and offshore. Jack mackerel differ from the other CPS in that they are quite long lived and more commonly found offshore. Jack mackerel older than 30 years are common in the northern portion of their range (Nebenzahl 1997). Spawning occurs farther offshore than for other CPS (Jacobson et al. 1997).

Jack mackerel off southern California move inshore and offshore as well as north and south. They are more available on offshore banks in late spring, summer and early fall than during the remainder of the year. In southern California waters, jack mackerel schools are often found over rocky banks, artificial reefs, and shallow rocky coastal areas. In California's Santa Barbara

Channel, jack mackerel are also associated with offshore petroleum platforms (> 14 km from shore) where they occur seasonally (Martin and Lowe 2010). They remain near the bottom or under kelp canopies during daylight and venture into deeper surrounding areas at night. Young juvenile fish sometimes form small schools beneath floating kelp and debris in the open sea. Information on jack mackerel habitat use within the U.S. EEZ is summarized in Table 2.3.

Table 2.3. Summary of habitat information for jack mackerel within the U.S. EEZ.

Life Stage	**Diet**	**Season**	**Location**	**Water Column**	**Oceanographic Features**
Eggs and larvae	Yolk sac; larvae consume copepods	Feb. to Oct. with peak from March to July	Pelagic, schooling	Pelagic	14°C – 16°C < 35 (Salinity)
Juveniles	N/A	Year-round	Sometimes in small schools under floating kelp and debris	Pelagic	10°C to 26°C
Adults	Zooplankton (copepods, pteropods and euphausiids), juvenile squid, and Northern anchovy and other teleosts	Year-round	Inshore and offshore; sometimes over rocky bottoms	Pelagic	10°C to 26°C

2.1.2.2 Life History

Jack mackerel grow to about 60 cm and live 35 years or longer (Nebenzahl 1997). Estimates of natural mortality are uncertain, but the natural mortality rate (M) averaged over the lifespan of a typical fish is probably less than 0.20 to 0.25 year^{-1}. This means that about 18 percent to 22 percent of the total stock would die each year of natural causes if no fishing occurred.

Small jack mackerel taken off southern California and northern Baja California eat large zooplankton (copepods, pteropods, and euphausiids), juvenile squid, and northern anchovy. Larvae feed almost entirely on copepods. In the Pacific Northwest, adult jack mackerel have been found to feed on Pacific sardine (Emmett et al. 2005).

Jack mackerel are batch spawners, and 50 percent or more of all females reach sexual maturity during their first year of life. Older jack mackerel, in samples taken about 200 miles offshore from Southern California, spawned about every five days, although 8 percent of the females were found to spawn at 1 to 3 days intervals (Macewicz and Hunter (1993). The average female may spawn as many as 36 times per year (Macewicz and Hunter 1993).

The spawning season for jack mackerel off California extends from February to October, with peak activity from March to July (MacCall and Prager 1988). Young spawners off southern California begin spawning later in the year than older spawners. From 1980-2018, spring larval abundance in the California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey was highest in 1996, 2005, 2014, and 2015; whereas abundance was lowest in 1990, 1991, 2009, 2011 and 2012 (Gallo et al. 2019). Although in lower densities, the SWFSC Acoustic Trawl Method (ATM) survey has collected jack mackerel eggs from British Columbia (offshore of Vancouver Island) up to Point Conception during summer surveys (e.g., Stierhoff et al. 2020). Little is known of the maturity cycle of large fish offshore, but peak spawning appears to occur later in more northerly waters.

2.1.2.3 Relevant Trophic Information

As an ichthyoplankton predator, jack mackerel seem to prefer feeding shoreward of fronts (McClatchie et al. 2013). The diet composition of jack mackerel may vary among cool and warm years. For example, Brodeur et al. (2019) found that teleosts were an important proportion (58 percent) of jack mackerel diet only in 2016 during the 2000-2016 period. Large predators like tunas and billfish eat jack mackerel, but except as young-of-the-year and yearlings, jack mackerel are probably a minor forage source for smaller predators. Older jack mackerel probably do not contribute significantly to food supplies of marine birds, because they are too large to be eaten by most bird species and school inaccessibly deep. Little information is available on predation of jack mackerel by marine mammals. Jack mackerel are not often eaten by California sea lions, *Zalophus californianus*, or northern fur seals, *Callorhinus ursinus*. As a prey, this species contributes little (i.e., compared to other CPS) to the maintenance of top marine predators (Sturdevant et al. 2012, Martin et al. 2010, Preti et al. 2012, Robinson et al. 2018), and therefore its abundance was assessed to have little impact on the CCE as a prey item (Kaplan et al. 2013).

2.1.3 PACIFIC SARDINE

2.1.3.1 Distribution and Habitat

Pacific sardine are small pelagic schooling fish that inhabit coastal subtropical and temperate waters. The genus *Sardinops* is found in eastern boundary currents of the Atlantic and Pacific, and in western boundary currents of the Indo-Pacific oceans. Recent phylogenetic analysis indicates the existence of two sardine species in the Pacific Ocean, *S. sagax* and *S. melanostictus* (Japanese sardine) (Tang and Chen 2021). Pacific sardine off the West Coast of North America has been assumed to form three subpopulations or stocks, namely northern population (cold stock from northern Baja California to Alaska), southern population (temperate stock off Baja California), and a Gulf of California population or warm stock. Electrophoretic/genetic studies (Hedgecock et al. 1989) showed, however, no genetic variation among Pacific sardine from central and southern California, the Pacific coast of Baja California or the Gulf of California (Hedgecock et al. 1989). Several other methods (e.g., morphometrics, otolith chemistry, parasite genetics, parasites as biological tags, physical tags) have been applied to study Pacific sardine stock structure, but with mixed results. None of these methods have been able to clearly delineate these stocks, but they have shown various levels of mixing between fish groups along the U.S. Pacific coast. Because the lack of adequate sampling coverage affected most of these studies, the integration of these methods may be needed to resolve Pacific sardine stock structure over their spatial and temporal frame of occurrence (Baldwin et al. 2012).

Pacific sardine have at times been the most abundant fish species in the California Current (Barnes et al. 1992). When abundance is high and environmental conditions are favorable, Pacific sardine are distributed from the tip of Baja California (23° N. latitude) to southeastern Alaska, and throughout the Gulf of Mexico. Historically, when abundance was low, as during the late 1960s,1970s,1980s, Pacific sardine were generally not found north of Point Conception and may be more abundant in waters off southern and central Baja California. However, in recent years small residual populations have been found north of Cape Mendocino (Auth et al. 2018, Dorval et al. 2018, Stierhoff et al. 2020). Dramatic changes in distribution, depending on environmental conditions and abundance (which are tightly linked) occur in Pacific sardine populations around the world (e.g., Lluch-Belda et al. 1989, Zwolinski and Demer 2017, Yatsu and Kawabata 2017, Politikos 2018). During the 1950s to 1970s, a period of reduced stock size and unfavorable cold SST, Pacific sardine apparently abandoned the northern portion of its range. In the 1990s and 2000s, the combination of increased stock size and warmer sea surface temperatures caused Pacific sardine to reoccupy grounds off northern California, Oregon, Washington, and British Columbia (e.g., McFarlane et al. 2005). Abandonment and recolonization of the higher latitude portion of their range has been associated with changes in abundance of Pacific sardine populations around the world (Parrish et al. 1989, Qui 2015, Yatsu and Kawabata, 2017)

Based on fishery-dependent and oceanographic data, recent studies have used the distribution of temperature-at-catch to develop conceptual models on the thermal range of each Pacific sardine subpopulation (Felix-Uraga et al. 2004, 2005; Demer et al., 2012, Garcia-Morales et al. 2012). In general, these studies hypothesize that Pacific sardine subpopulations exhibit temporal asynchrony influenced by seasonal variability in SST within the CCE, with: 1) the northern subpopulation (cold stock) occurring in temperature ranging from 13° to 17°C; 2) the southern subpopulation (temperate stock) from 17° to 22°C; and 3) the Gulf of California subpopulation (warm stock) from 22° to 27°C. Notably, laboratory-reared Pacific sardine from the northern subpopulation grow well in temperature ranging from 13-21°C (Dorval et al. 2011), and they exhibit a physiological ideal temperature of 9°-19°C for 15°C acclimated individuals, and 11°C-21°C for 17°C acclimated individuals (Pribyl et al. 2016). In general, Pacific sardine subpopulations tend to move northward in summer-fall, with the northern subpopulation occupying habitats up to British Columbia, Canada, and the southern subpopulation occupying habitats up to Monterey, California (Felix-Uraga et al. 2004, 2005; Demer et al., 2012, Garcia-Morales et al. 2012). Additionally, tagging studies (Clark and Janssen 1945) indicated that the older and larger fish moved farther north. Neither the existence of three subpopulations nor differences in thermal ranges of such subpopulations have ever been fully validated and thus their dynamics and habitat use remain working hypotheses.

Pacific sardine are pelagic at all life history stages. They occur in estuaries but are most common in the nearshore and offshore domains along the coast. Seasonal migrations of Pacific sardine have been mostly inferred from surveys and/or catch data collected from Mexico to Canada (e.g., Félix-Uraga 2004, Lo et al. 2011, Demer et al. 2012, Stierhoff et al. 2021). Older and larger adults may move from spawning grounds in southern California and northern Baja California to feeding grounds off the Pacific northwest and Canada (e.g., McFarlane and Beamish 2001, McFarlane et al. 2005, McDaniel et al. 2016). Juveniles and young adults are typically more abundant in nearshore waters off California than in more northern regions (e.g., Javor and Vetter 2011). In most years, juveniles are not abundant off the Pacific Northwest, likely due to poor spawning success; however, they may occur in high densities in years of successful spawning (Emmet et al.

2005). During warm years such as El Ninos, adult Pacific sardine have been collected as far north as southeastern Alaska and have spawned in the Pacific Northwest (Schultz et al. 1932, Wing et al. 2000, Auth et al. 2018). McDaniel et al. (2016) showed that Pacific sardine exhibited a pattern of increasing age-at-length with seasonal northward migrations and offshore movement for spawning. They hypothesized that migratory behaviors were related to age-based ontogenetic changes associated with maturation of Pacific sardine.

Pacific sardine eggs and larvae occur nearly everywhere adults are found and occupy mostly the upper mixed layer. Larvae are most abundant in depths of 0-23 m but can be distributed up to 96m (Ahlstrom 1959). The depth range of eggs was estimated by Ahlstrom (1959) to vary from 0 to about 120 m. Off California, eggs and yolk-sac larvae were most abundant between 12.02°C and 15°C during the 1994-2016 period (e.g., Lo et al. 2009, 2013, Dorval et al. 2014, 2016). When abundance is high, eggs and larvae are mostly concentrated in the Daily Egg Production Method (DEPM) Standard Area (from San Diego to San Francisco, CalCOFI line 95 to 60) and can be distributed 50 km to 150 km offshore of the area north of Point Conception with lesser quantities found in the region offshore of the Channel Islands. During low abundance in the 1960-1980s, the adult spawning stock was mostly located off southern California and Ensenada, but since 2015 the spawning stock has been located north of Cape Mendocino (Dorval et al. 2016, Auth et al. 2018). As a result, the temporal distributions of larvae have changed with much earlier occurrence of this life stage in the Northern CCE. Patterns in the nearshore and offshore distribution of Pacific sardine eggs and larvae and their association with major oceanographic features, such as El Niño events and the PDO are better understood in recent studies (e.g., Balcerak et al. 2012, Song et al. 2012, Zwolinski and Demer 2012, Brodeur 2019). Beyond temperature, data collected remotely (via satellite) on chlorophyll, salinity, eddy kinetic energy, and dynamic heights have been used to predict the seasonal location of the spawning stock along the U.S. Pacific coast and to define new ecological indicators of spawning of this species. New models have combined satellite and survey data, allowing the prediction of seasonal habitats of Pacific sardine (e.g., Reiss et al. 2008, Weber and McClatchie 2010, Zwolinski et al. 2011, Asch and Checkley 2013), and potential shift in its habitat due to climate change (Muhling et al. 2020). Nieto et al. (2014) found that Pacific sardine recruitment success was inversely correlated with distance from predicted habitat centroids, indicating that offshore transport had a negative effect on Pacific sardine recruitment, despite expanding favorable spawning habitat offshore. Further, Ash et al. (2013) found dynamic height controlled the distribution of Pacific sardine spawning habitats, and that temperature, salinity, and chlorophyll-a accounted for 80-95 percent of the dynamic height effects. Finally, information on Pacific sardine habitat use is summarized in Table 2.4; whereas its spatial distributions within and seaward of the U.S. EEZ during the 1999-2012 and 2013-2020 periods are presented in Figure 2.10 and Figure 2.11.

Table 2.4. Summary of habitat information for Pacific sardine, within the U.S. EEZ.

Life Stage	Diet	Season	Location	Water Column	Oceanographic Features
Eggs and larvae	Yolk sac and planktivorous	Year-round, with peak in March-April	Pelagic, 50-150 km offshore	Upper 50 m	Eggs: 13°C - 16°C Larvae: 14°C - 16°C
Juveniles	Planktivorous	Year-round	Pelagic	Above thermocline	10°C - 22°C
Adults	Phytoplankton and zooplankton	Year-round	Pelagic, sometimes in estuaries	Above thermocline	10°C - 22°C

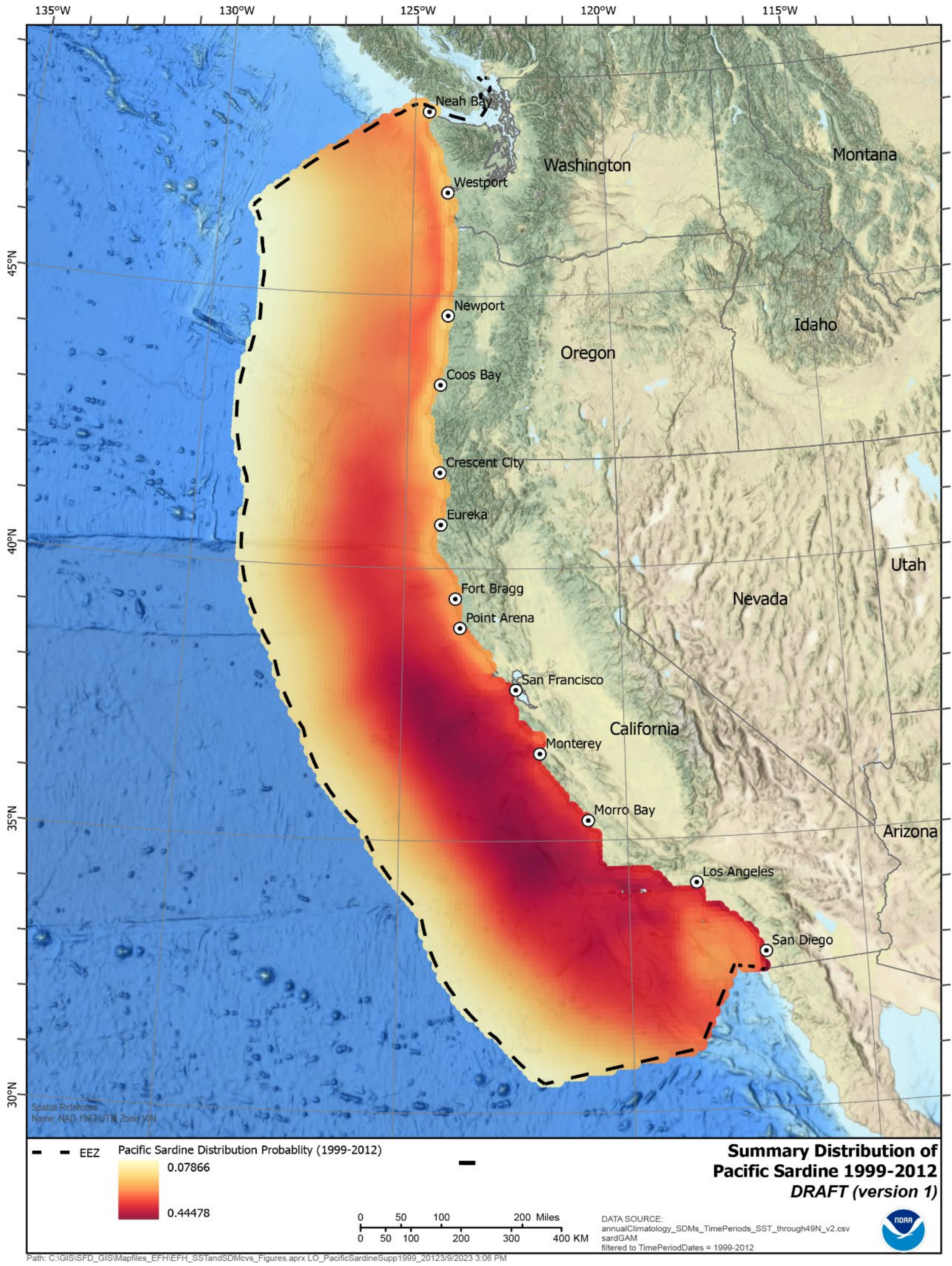


Figure 2.10. Summary distribution of Pacific sardine within and seaward of the U.S. EEZ during the 1999-2012 period. Probability distribution was computed using GAMM models and provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

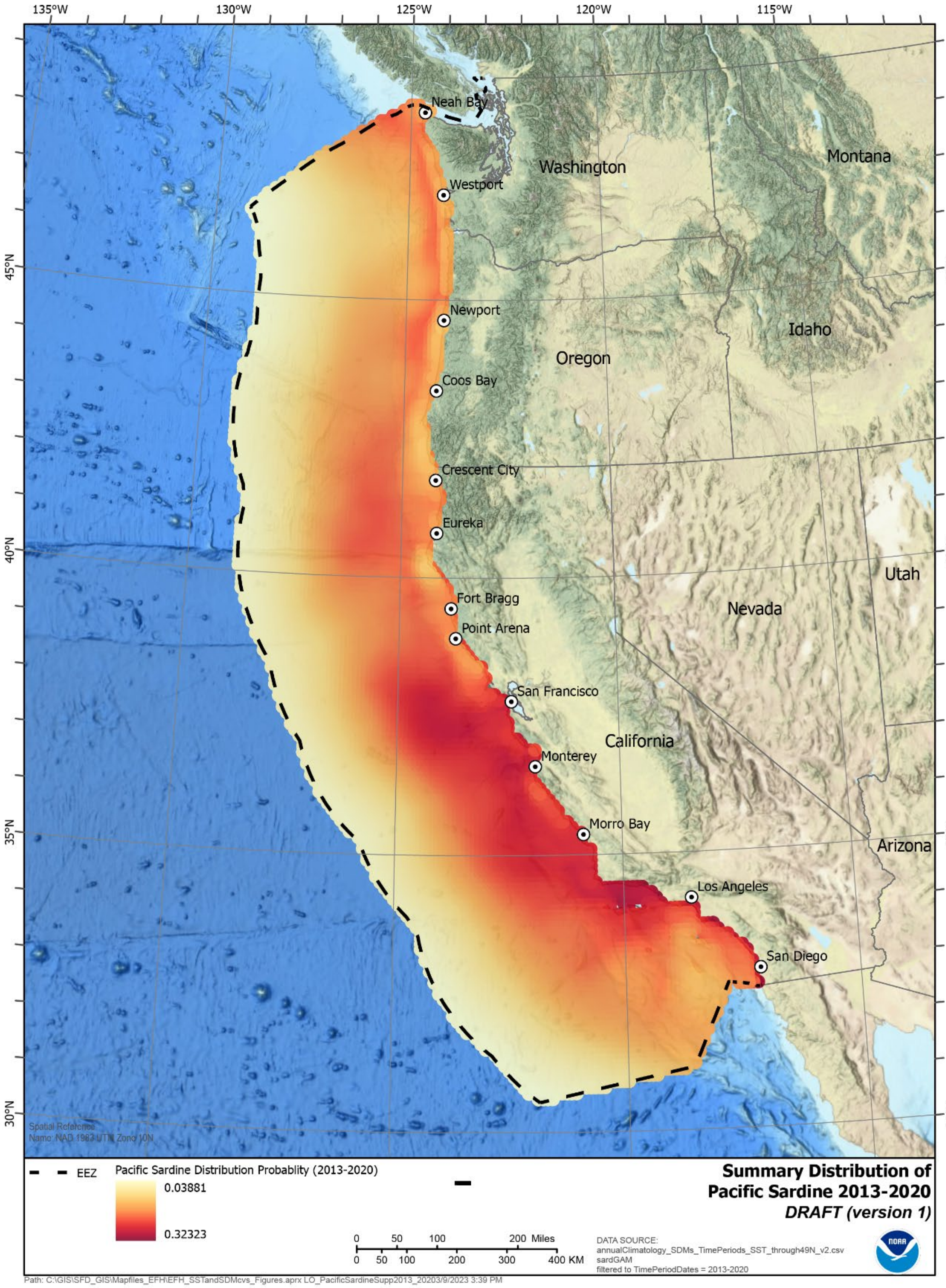


Figure 2.11. Summary distribution of Pacific sardine within and seaward of the U.S. EEZ during the 2013-2020 period. Probability distribution was computed using GAMM models and provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

2.1.3.2 Life History

Pacific sardine may reach 41 cm, but are seldom longer than 30 cm. They mature early, reaching their age-at-50 percent maturity at 0.56 years and their length-at-50 percent maturity at ~ 150.92 mm SL (Dorval et al. 2015). They may live as long as 13 years, but individuals in historical and current California commercial catches are usually younger, ranging from 0 to 8 years-old (e.g., Kuriyama et al. 2020). Fish collected off British Columbia from 1999 to 2005 exhibited a range in ages from 2 to 10 years-old (McFarlane et al. 2022). Further, Enciso et al. (2022) found that Pacific sardine samples collected from Mexican catches in the southern CCE during the 2005-2014 period comprised ages that varied from 0 to 6 years old. Therefore, there is a clinal variation in the distribution of size and age along the eastern Pacific coast, with larger and older fish occurring in the Pacific Northwest and off British Columbia (e.g., McFarlane et al. 2005, McDaniel et al. 2016).

Pacific sardine length is highly variable within each age class, and individual fish may reach their maximum size by the third year of their life (Dorval et al. 2015). Further, Dorval et al. (2015) found there was differential growth rate between Pacific sardine cohorts, and cohort growth rate significantly declined with increasing biomass. Lindegren and Checkley (2013) also found that the strength of Pacific sardine cohorts was directly correlated to mean SST measured in their spawning habitat off California. The abundance of these cohorts highly fluctuated from year to year, influencing population movement, growth and biomass. In warm or cold years, Pacific sardine biomass may also interact with temperature to regulate recruitment success (e.g., Jacobson & McClatchie, 2013). Jacobson & McClatchie (2013) argued that density dependence effects induced by stock biomass might be more important than temperature effects on Pacific sardine recruitment.

Pacific sardine are oviparous multiple-batch spawners with annual fecundity that is indeterminate and highly age or size dependent (Butler et al. 1993, Macewicz et al. 1996). Macewicz (1996) found that the average female Pacific sardine spawned about once every 15 days off California and Baja California during April-May. Butler et al. (1993) estimated that 2 years-old Pacific sardine spawned on average six times per year, whereas the oldest Pacific sardine spawned 40 times per year. Length-at-50 percent maturity of Pacific sardine is highly variable from year to year. For example, in 1994, 50 percent of female Pacific sardine matured at 159 mm SL, whereas in 2004 length-at-50 percent maturity was 193 mm SL (Lo et al. 2005) for fish collected during the spring off California. Over a longer period of time (1987-2011), fish collected in both spring and summer seasons exhibited a range of length-at-50 percent maturity from 152.8 mm to 194.1 mm SL (Dorval et al. 2014).

Pacific sardine spawn in loosely aggregated schools in the upper 50 meters of the water column (e.g., Ahlstrom 1959). Spawning occurs year-round in the southern stock and peaks April through August between Point Conception and Magdalena Bay, and January through April in the Gulf of California (Allen et al. 1990). Both eggs and larvae are found near the surface. Off California, Pacific sardine eggs are most abundant in March-April at SST between 12° and 16°C and larvae are most abundant at 13° to 16° C. Temperature requirements are apparently flexible, however, because in the spring small fraction of eggs are also distributed from Punta Eugenia (Mexico) to north of the U.S.-Mexico border in warmer waters between 15°C and 18°C (Valencia-Gasti et al.

2018). Eggs are also commonly found in the Gulf of California at 22ºC to 25ºC off Southern Baja (Lluch-Belda et al. 1991). Takahashi and Checkley (2008) found that hatch distribution of pre-recruits ranged from April to August, with major peaks in late spring and summer, coinciding with the timing of spawning and larval production in the SCB. Further, these authors determined that early juveniles that exhibit faster growth rate during summer and fall may have higher probability to survive to the adult stock. Additionally, Zwolinski and Demer (2014) hypothesized that Pacific sardine have a metabolic deficiency during spawning, and likewise good feeding opportunities are necessary prior to spawning to increase total fecundity, and to enhance reproduction and survival, respectively.

The spatial and seasonal distribution of spawning is highly influenced by temperature. During periods of warm waters, the center of Pacific sardine spawning shifts northward and spawning extends over a longer period of time in the eastern North Pacific from January to July (Ahlstrom 1966). During El Niño events, for example, environmental conditions are more favorable for spawning off the coast of Oregon, Washington, and British Columbia (e.g., McFarlane et al. 2001). In these unusual years, young fish (< 200 mm SL) can be observed throughout the Pacific Northwest up to British Columbia (Ahlstrom 1960, Hargreaves et al. 1994, FOCS 2012), and have been characterized as non-migrants (Lo et al. 2011, Jacobson et al. 2019). The main spawning area for the historical population off the U.S. was between Point Conception and San Diego, California, out to about 100 miles offshore, with evidence of spawning as far as 250 miles offshore (Hart 1973). Similarly, during the 1994-2013 period spawning was concentrated in the SCB and in the region offshore and north of Point Conception (e.g., Lo et al. 2009, 2013, Dorval et al. 2014). However, with the recent decline in biomass, spawning has shifted into areas off northern California and southern Oregon (e.g., Dorval et al. 2016, Hill et al. 2017, Auth et al. 2018).

Age-specific mortality estimates are available for the entire suite of Pacific sardine life history stages (Butler et al. 1993). Mortality is high at the egg and yolk sac larval stages (instantaneous rates in excess of 0.66 d^{-1}). Adult natural mortality rates (M) vary from year to year, but have been estimated to range from 0.4-0.8 year $^{-1}$ (Murphy 1966; MacCall 1979, Clark and Marr 1955, Zwolinski and Demer 2013, Hill et al. 2017). Zwolinski and Demer (2013) estimated M to be 0.52 for the 2006-2011 period, but Hill et al. (2017) used M= 0.6 year^{-1}. A natural mortality of 0.6 year^{-1} means that 45 percent of the adult sardine stock would die each year of natural causes.

2.1.3.3 Relevant Trophic Information

Pacific sardine are omnivorous filter-feeders that consume copepods, diatoms, euphausiids, and a variety of other zooplankton, and occasionally fish larvae (Emmet et al. 2005, King et al. 2011). Prey consumption may vary among cool and warm years. For example, Brodeur et al. (2019) found that the diets of Pacific sardine (among other forage fish) comprised 40 percent to 80 percent of gelatinous zooplankton during the warm year of 2016, whereas this prey taxon was absent in the diet of Pacific sardine in previous cold periods. Decadal-scale changes in stratification and upwelling may cause changes in species composition of phytoplankton, particularly diatoms that determine the growth and survival of Pacific sardine (e.g., McFarlane and Beamish 2001). Hence, the spatial distribution of Pacific sardine has been shown to be spatially correlated with both warm- and cool-water-associated mesopelagic ichthyoplankton species (McClatchie et al. 2018). When biomass is high, Pacific sardine may consume a significant proportion of total organic production in the California Current system. Based on an energy budget for Pacific sardine developed from laboratory experiments and estimates of primary and secondary production in the California Current, Lasker (1970) estimated that annual energy requirements of the Pacific sardine population would have been about 22 percent of the annual primary production and 220 percent of the secondary production during the 1932 to 1934, a period of high Pacific sardine abundance.

Pacific sardine are taken by a variety of predators throughout all life stages. Pacific sardine eggs and larvae are consumed by an assortment of invertebrate and vertebrate planktivores. Although it has not been demonstrated in the field, Northern anchovy predation on Pacific sardine eggs and larvae was postulated as a possible mechanism for increased larval Pacific sardine mortality from 1951 to 1967 (Butler 1987). Recent studies have evaluated the role and importance of Pacific sardine as forage fish in the CCE (e.g., Kaplan et al. 2013, 2019), using long time series of data developed on the contribution of Pacific sardine to the diets of marine mammals, fish, and birds (e.g., Emmett et al. 2005, Preti et al. 2012, Litz et al. 2017, 2019, McClatchie et al. 2016, Robinson et al. 2018). Juvenile and adult Pacific sardine are consumed by a variety of predators, including commercially important fish taxa (e.g., Yellowtail, Barracuda, Bonito, tuna, marlin, mackerel, Hake, salmon, and sharks), seabirds (pelicans, gulls, cormorants, terns, grebes) and marine mammals (sea lions, seals, porpoises, and whales). Seabirds, such as Elegant Tern, Heermann's Gull, and Brown Pelican feed on pre-recruits of Pacific sardine and Northern anchovy, and their population sizes are sensitive to variations in the abundance of these two CPS (Velarde et al. 2015, Kaplan et al. 2019). Further, the increase and southward shift of the Western Grebes in the 1900s was hypothesized to be related to changes in the abundance and availability of Pacific sardine off California (Wilson et al. 2013). During the 1998-2014 period, Pacific sardine and Northern anchovy were the two most important prey of Thresher Sharks, (Preti et al. 2012, 2018). Both juvenile and adult stages of Coho and Chinook salmon have been observed to prey on Pacific sardine (Emmett et al. 2005). Jack mackerel, blue shark, soupfin shark, and thresher shark are also major predators of Pacific sardine off the Oregon and Washington coast (Emmett et al. 2005). Pacific sardine and northern anchovy also occur frequently in the diet of sea lions (Orr et al. 2011). In the 1900s sea lion diets were dominated by Pacific sardine and northern anchovy, but both species were less prominent in recent years (Robinson et al. 2018). However, Kaplan et al. (2019) found that ecosystem model responses of sea lions to Pacific sardine depletion varies among models, with some models predicting strong effects on California sea lions, and other models predicting minor impacts. Kaplan et al. (2020) estimated that a depletion of 40 percent of forage fish in the CCE can impact the abundance of 20-50 percent of other functional groups (e.g., their major predators) by greater than 20 percent.

2.1.4 PACIFIC MACKEREL

2.1.4.1 Distribution and Habitat

Pacific mackerel (*Scomber japonicus*) found off the Pacific coast of the U.S. are often called "chub" mackerel and are distributed across the Pacific Ocean. Classical taxonomy recognized three mackerel species (*S. scombrus, S. australasicus, and S. japonicus*); however, recent morphologic and phylogenetic analyses revealed Scomber mackerel in the Atlantic Ocean is a different species (*S. colias*) from *S. japonicus* in the Pacific Ocean (Infante et al. 2006).

Pacific mackerel in the northeastern Pacific range from Banderas Bay, Mexico, to southeastern Alaska, including the Gulf of California (Hart 1973, Weber and McClatchie 2012). They are common from British Columbia, Washington, Oregon, Monterey Bay, California, to Cabo San Lucas, Baja California, but are most abundant south of Point Conception (e.g., Stierhoff et al. 2020, 2021). Pacific mackerel usually occur within 20 miles of shore but have been taken as far offshore as 250 miles (Fitch 1969; Allen et al. 1990; MBC 1987). Their spatial distributions within the U.S. EEZ during the 1999-2012 and 2013-2020 periods are presented in Figure 2.12 and Figure 2.13.

Three spawning stocks are generally assumed along the Pacific coasts of the U.S. and Mexico: one in the Gulf of California, one in the vicinity of Cabo San Lucas, and one extending along the Pacific coast north of Punta Abreojos, Baja California (e.g., Allen et al. 1990; Gluyas-Millán and Quiñonez-Velázquez 1997). The latter "northeastern Pacific" stock is harvested by fishers in the U.S. and Mexico and included in this FMP. Weber and McClatchie (2012) analyzed CalCOFI data from 1951 to 2008 and postulated the existence of two spawning groups of Pacific mackerel from about Cabo San Lucas (Mexico) to about north of Tillamook Head (Oregon). The first and larger group exhibits peak spawning during April in the SCB at about 15.5°C. The second and smaller group exhibited peak spawning in August near Punta Eugenia, Mexico, at 20°C or greater.

Pacific mackerel juveniles and adults collected from trawl surveys off the U.S. Pacific coast are found in water ranging from 10°C to 23.5°C. Peak spawning occurs in water around 15.5°C in the SCB, which is the core area of spawning (Weber and McClatchie 2012). During the 1951-2008 period, mean temperature-at-catch for larvae collected by CalCOFI and IMECOCAL ranged from 13.21°C to 17.90°C (Lo et al. 2010), indicating the preferred thermal range of Pacific mackerel spawning habitat. As adults, Pacific mackerel may move north in summer and south in winter between Tillamook, Oregon, and Magdalena Bay, Baja California. Northerly movement in the summer peaks during El Niño events (MBC 1987). In recent acoustic trawl surveys, Pacific mackerel mostly ranged from Westport, Washington, to Cape Mendocino and from Monterey to San Diego (e.g., Stierhoff et al. 2019, 2020, 2021). There is an inshore-offshore migration off California, with increased inshore abundance from July to November and increased offshore abundance from March to May (Cannon 1967; MBC 1987). Adult Pacific mackerel are commonly found near shallow banks. Juveniles are found off sandy beaches, around kelp beds, and in open bays. Adults are found from the surface to depths of 300 meters (Allen et al. 1990). Pacific mackerel often school with other pelagic species, particularly jack mackerel and Pacific sardine. Finally, habitat use by life stage for Pacific mackerel is summarized in Table 2.5.

Table 2.5. Summary of habitat information for Pacific mackerel within the U.S. EEZ.

Life Stage	Diet	Season	Location	Water Column	Oceanographic Features
Eggs and larvae	Yolk sac; copepods and fish larvae	Peaks from late April to July	SCB	Surface	13°C - 18°C
Juveniles	Small fishes, fish larvae, squid, and pelagic crustaceans such as euphausiids	Inshore-offshore migration off CA July to Nov.; increased offshore abundance March to May	Off sandy beaches, around kelp beds, and in open bays	N/A	10°C - 24°C
Adults	Small fishes, fish larvae, squid, and pelagic crustaceans such as euphausiids	Inshore-offshore migration off CA July to Nov.; increased offshore abundance March to May	Usually within 20 miles of shore, but as far as 250 miles offshore; near shallow banks	Surface to 300 m	10°C - 24°C

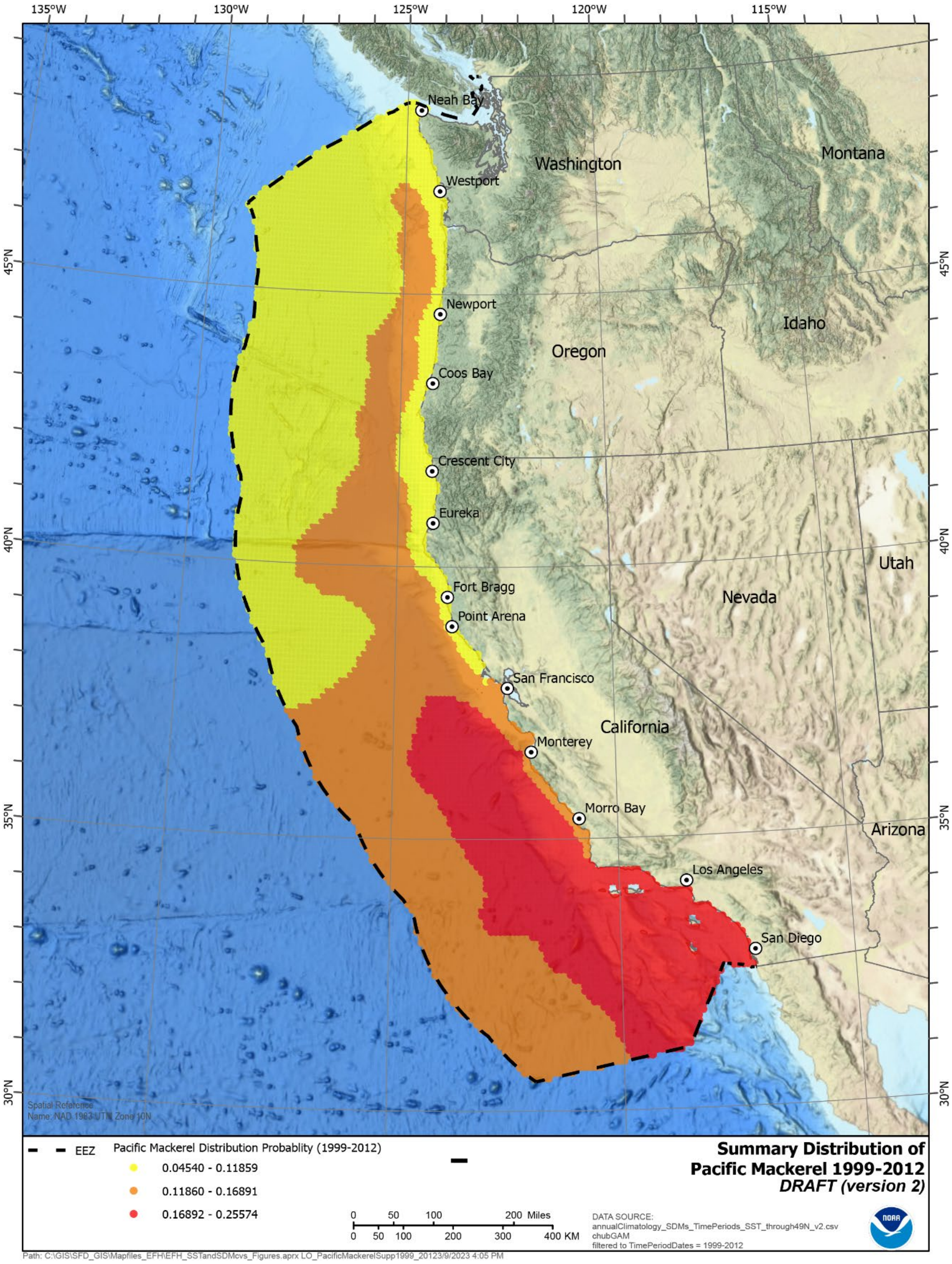


Figure 2.12. Summary distribution of Pacific mackerel within and seaward of the U.S. EEZ during the 1999-2012 period. Probability distribution was computed using Generalized Additive Mixed Model (GAMM) models and provided by B. A. Muhling, using similar data and parameters as in Muhling et al. (2020).

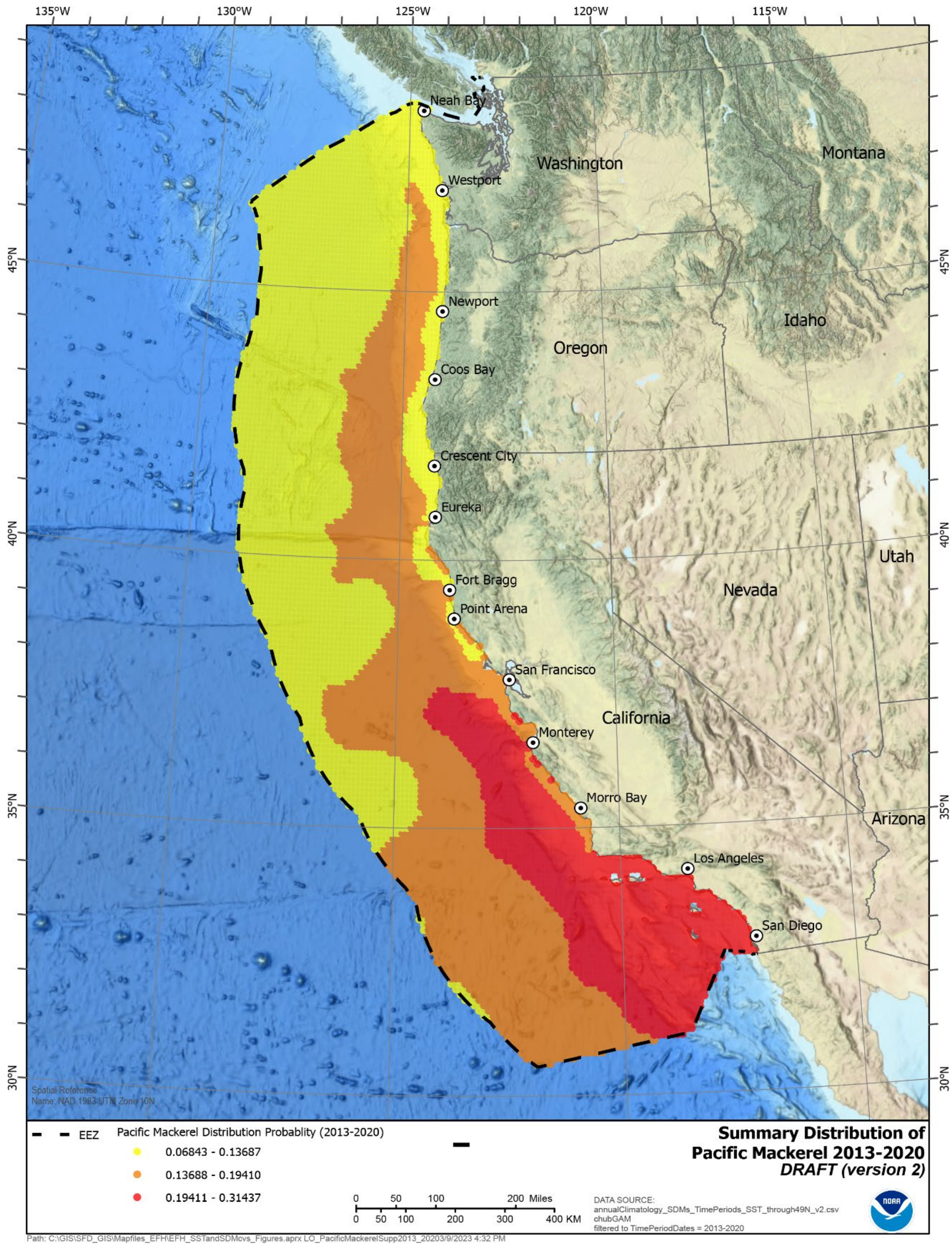


Figure 2.13. Summary distribution of Pacific mackerel within and seaward of U.S. EEZ during the 2013-2020 period. Probability distribution was computed using GAMM models and provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020)

2.1.4.2 Life History

The largest recorded Pacific mackerel was 63 cm FL and weighed 2.8 kg, but Pacific mackerel taken by commercial fishing seldom exceed 40 cm or one kg (Hart 1973). The oldest recorded age in the "CDFW Port Sampling Database" for Pacific mackerel was 14 years and measured 39.6 cm FL and 0.78 kg, but most fish caught commercially are less than four years old (D. Porzio/CDFW, pers. comm.). Pacific mackerel is a fast growing, highly fecund and short-lived species. They accomplish 50 percent of their growth in length by 1.5 years, reaching a maximum length of 39.6 cm by age $6\text{-}8^{+}$ (Crone and Hill 2015). Length-at- 50 percent maturity is estimated to be 274 mm (± 1.29, FL), and females larger than 310 mm (± 2.60 FL) are usually mature (Snodgrass et al., *In Preparation*). Pacific mackerel may start maturing at age 0, but age-at-50 percent maturity occurs between age 1 and 2 (Snodgrass et al., *In Preparation*).

Pacific mackerel are batch spawners, which spawn broadly in the northeastern Pacific stock from Tillamook Head (Oregon) to Cabo San Lucas in Baja California between 3 and 320 km from shore (Moser et al. 1993, Weber and McClatchie 2012). However, the core spawning area is located in the SCB (Weber and McClatchie 2012). Spawning peaks in April in the SCB and in August around Punta Eugenia, Mexico. Weber and McClatchie (2012) found that the SCB had greater zooplankton than Mexican waters, but lower geostrophic flow. However, in cold years Mexican waters were usually of better quality than the SCB. Like most CPS, Pacific mackerel have indeterminate fecundity and spawn whenever sufficient food is available and appropriate environmental conditions prevail. They can spawn up to eight times per year, and actively spawning females are capable of spawning every day or every other day (Dickerson et al. 1992). Egg and larval duration may approximately last 3 weeks, ranging from 33 h at 23 °C to 117 h at 14℃ (Hunter and Kimbrell 1980).

2.1.4.3 Relevant Trophic Information

Pacific mackerel larvae are subject to predation from a number of invertebrate and vertebrate planktivores. Juveniles and adults are eaten by larger fishes, marine mammals, and seabirds. Predators include porpoises, California sea lions (*Zalophus californianus*), brown pelican (*Pelecanus occidentalis*), striped marlin (*Terapturus audax*), black marlin (*Makaira indica*), sailfish (*Istiophorus platypterus*), bluefin tuna (*Thunnus thynnus*), white sea bass *(Atractoscion nobilis)*, yellowtail (*Seriola dorsalis*), giant sea bass (*Stereolepis gigas*), and various sharks (MBC 1987). Although consumed in significant numbers by a wide variety of predators, Pacific mackerel are consumed in lower abundances compared to Pacific sardine or northern anchovy, which are smaller in size (i.e., available to a wider variety of predators) and often more abundant. The annual rate of natural mortality (M) is thought to be about 0.5 year^{-1}, which means that 39 percent of the stock would die each year of natural causes in the absence of fishing (Parrish and MacCall 1978).

Pacific mackerel larvae eat copepods and other zooplankton including fish larvae (Collette and Nauen 1983; MBC 1987). Juveniles and adults feed on small fishes, fish larvae, squid, and pelagic crustaceans such as euphausiids (e.g., Clemens and Wilby 1961; Turner and Sexsmith 1967; Fitch and Lavenberg 1971; Hart 1973; Collette and Nauen 1983).

2.2 Market squid: EFH Description and Identification

Market squid habitat varies with life stage, and hence eggs, larvae, juveniles, and adults occupy different types of habitats. Adults prefer to spawn on flat, soft and sandy substrates where they lay their gelatinous egg capsules in mops (e.g., Foote et al. 2006, Young et al 2011, Zeidberg et al. 2012). Market squid egg mops are distributed in 13-93 m depth in coastal waters (e.g., Zeidberg and Hammer 2002, Hanlon 2004, Foote et al. 2006, Young et al. 2006, Zeidberg et al. 2012, CDFW 2021), although they were also observed in deeper waters (79-98m) along canyon sides (Navarro 2014). Zeidberg et al. (2012) also found spawning occurred directly on benthic substrates in temperatures ranging from 10° to 14.4°C off California. Paralarvae are fully pelagic, occurring most frequently within 300 km from the shoreline between 25-80 m deep (e.g., Zeidberg and Hammer 2002, Koslow and Allen 2011) and at temperatures ranging from 10° to 23.5°C (van Noord and Dorval 2017). Along the U.S. Pacific coast, juveniles (i.e., squid with dorsal mantle length (DML) < 50mm, following Ralston et al. (2018) inhabit pelagic waters on the continental shelf and slope (Reiss et al. 2004, Ralston et al. 2015), but off California they mostly occur at shallow depths < 200m (Ralston et al. 2015). Adults (DML > 50 mm) are also pelagic and have been observed up to 200-300 m (Zeidberg et al. 2011), but once becoming mature, they move into shallow waters to spawn and then die (Macewicz et al. 2004).

EFH for market squid: The east-west geographic boundary of Market Squid EFH is defined to be from the shoreline seaward to the extent of the 5.8 percent market squid distribution probability (Figure 2.14), including waters to a depth of 300 meters, and where the sea surface temperature is between 7° and 24°C along the coasts of California, Oregon, and Washington. Market squid EFH also includes soft, sandy substrates to 93 m of depth for spawning adults and the egg capsule stage. The southern extent of EFH for Market Squid is the U.S.-Mexico maritime boundary, and the northern extent of Market Squid EFH is the U.S.-Canada maritime boundary (Figure 2.14). The distribution of different life stages of market squid is summarized in Table 2.6.

Table 2.6. Summary of distribution and EFH of different life stages of market squid.

Common and Scientific Names	**Life stage**	**San Diego – Pt Conception (California)**	**Pt Conception – Cape Mendocino (California)**	**Cape Mendocino – Puget Sound (California-Oregon-Washington)**	**Benthic Association**
Market squid (*Doryteuthis opalescens*)	Egg capsules	yes*	yes**	yes**	yes
	Paralarvae	yes*	yes**	yes**	no
	Juvenile	yes*	yes**	yes**	no
	Adults	yes*	yes**	yes**	yes

Note: *indicates that during warm years abundance is likely to be lower in this region; and ** indicates that during warm years abundance is likely to be higher in this region.

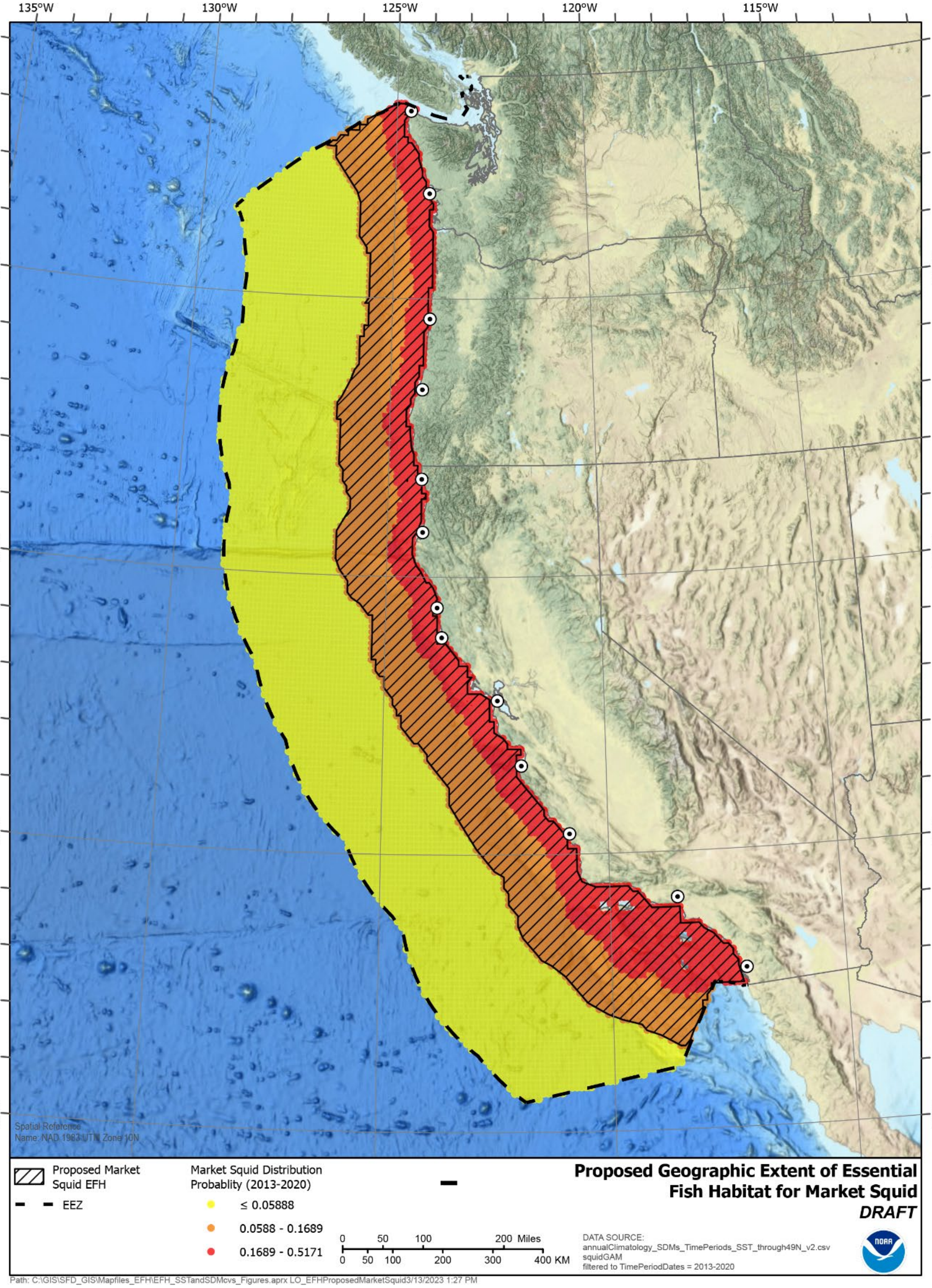


Figure 2.14. Proposed market squid EFH based on distribution probability greater than 5.8 percent during the 2013-2020 period (crosshatched) (based on Muhling et al 2020).

2.2.1 DISTRIBUTION AND HABITAT

Adult and juvenile market squid are distributed throughout the California and Alaska current ecosystems from the southern tip of Baja California, Mexico (23° N. latitude) to southeastern Alaska (55° N. latitude). Examination of phylogenetic relationships among loliginid squids led Anderson (2000) to re-classify market squid into the genus *Doryteuthis* instead of *Loligo*. market squid are most abundant between Punta Eugenia, Baja California and Monterey Bay, central California, (e.g., Zeidberg et al. 2012, Dorval et al. 2013, van Noord and Dorval 2017). The spatial distribution of market squid within the U.S. EEZ for the 1999-2012 and 2013-2020 periods are presented in Figure 2.15 and Figure 2.16.

Adults are generally pelagic and are distributed throughout the continental shelf and slope and have been observed in waters as deep as 300 m (Zeidberg et al. 2013, Ralston et al. 2018). Maturing adults recruit in shallow coastal waters where they concentrate in dense schools near spawning grounds. Spawning adults prefer to deposit their egg capsules in mops (masses of egg capsules) on flat, soft and sandy benthic substrates in depth ranging from 13 to 93 m depth in coastal waters (Hurley 1977, Halon 1998, Zeidberg and Hammer 2002, Halon 2004, Foote et al. 2006, Zeidberg et al. 2012). Eggs have also been observed in deeper waters, 79-98 m along canyon sides in the SCB (Navarro 2014), and at 180 m near the Channel Islands (Roper and Sweeney 1984). Spawning occurs directly on benthic substrates in temperatures ranging from 10-14.4°C off California (Zeidberg et al. 2012). Paralarvae are fully pelagic, occurring most frequently within 300 km from the shoreline between 25 and 80 m deep (Okutani and McGowan 1969, Zeidberg and Homan 2002, Koslow and Allen 2011) and at temperatures ranging from 10.79°-23.5°C (van Noord and Dorval 2017). Coastwide, juveniles are distributed in pelagic waters on the continental shelf and slope, but off California they mostly occur at depths < 200 m (Ralston et al. 2015).

In California, market squid spawning habitats occur in shallow sandy benthic substrates (< 70 m), where spawning peaks in the SCB during La Niña years (e.g., Koslow and Allen 2011, Zeidberg and Hammer 2002, van Noord and Dorval 2017, CDFW 2021). As market squid move northward during El Niño years, market squid are generally more abundant in the Monterey Bay region than in the SCB. In the Monterey Bay region, spawning occurs mostly during the spring and summer, whereas in southern California spawning peaks during fall and winter. Recent genetic studies showed that these spawning groups might not be genetically homogenous, as market squid seemed to exhibit more complex population structures, with the existence of genetically different micro cohorts that spawn off California (Cheng et al. 2020).

Market squid is under the CPS FMP but managed by the states assuming one population and using various regulations including: marine protected areas; a restricted access program; a two days-weekend closure; and a maximum sustainable yield of 30 percent proportional egg-escapement (CDFW 2021). A model was developed to compute proportional egg escapement based on biological parameters (potential fecundity, egg laying rates, natural mortality) and fishery parameters (catch fecundity and fishing mortality) (Macewicz et al. 2004, Maxwell et al. 2005, Dorval et al. 2013). The egg escapement model was extended by Dorval et al. (2013) to estimate spawning stock biomass for three regions, namely Monterey Bay, northern and southern Channel Island regions off California. Finally, information on market squid habitat use by life stage within the U.S. EEZ is summarized in Table 2.7.

Table 2.7. Summary of habitat information for different life stages of market squid within the U.S. EEZ.

Life Stage	Diet	Season	Location	Oceanographic Features
Eggs	N/A	Year-round	Shallow semi-protected nearshore areas with sandy or mud substrates (13-93m); deeper waters along submarine canyon sides (79-180m off California).	10°C - 14°C
Paralarvae	Copepods	Year-round	Coastal waters, 25-80 m	11°C - 24°C
Juveniles	Copepods	Year-round	Continental shelf and shelf break up to 200 m	7°C - 24°C
Pre-recruit Adults	Euphausiids and other small crustaceans, small fish and other squid	Year-round	Continental shelf and slope up to 300 m	7°C - 24°C
Spawning Adults	N/A	Year-round	Shallow semi-protected nearshore areas with sandy or mud substrates (13-93 m); deeper waters along submarine canyon sides (79-180m off California).	7°C - 24°C

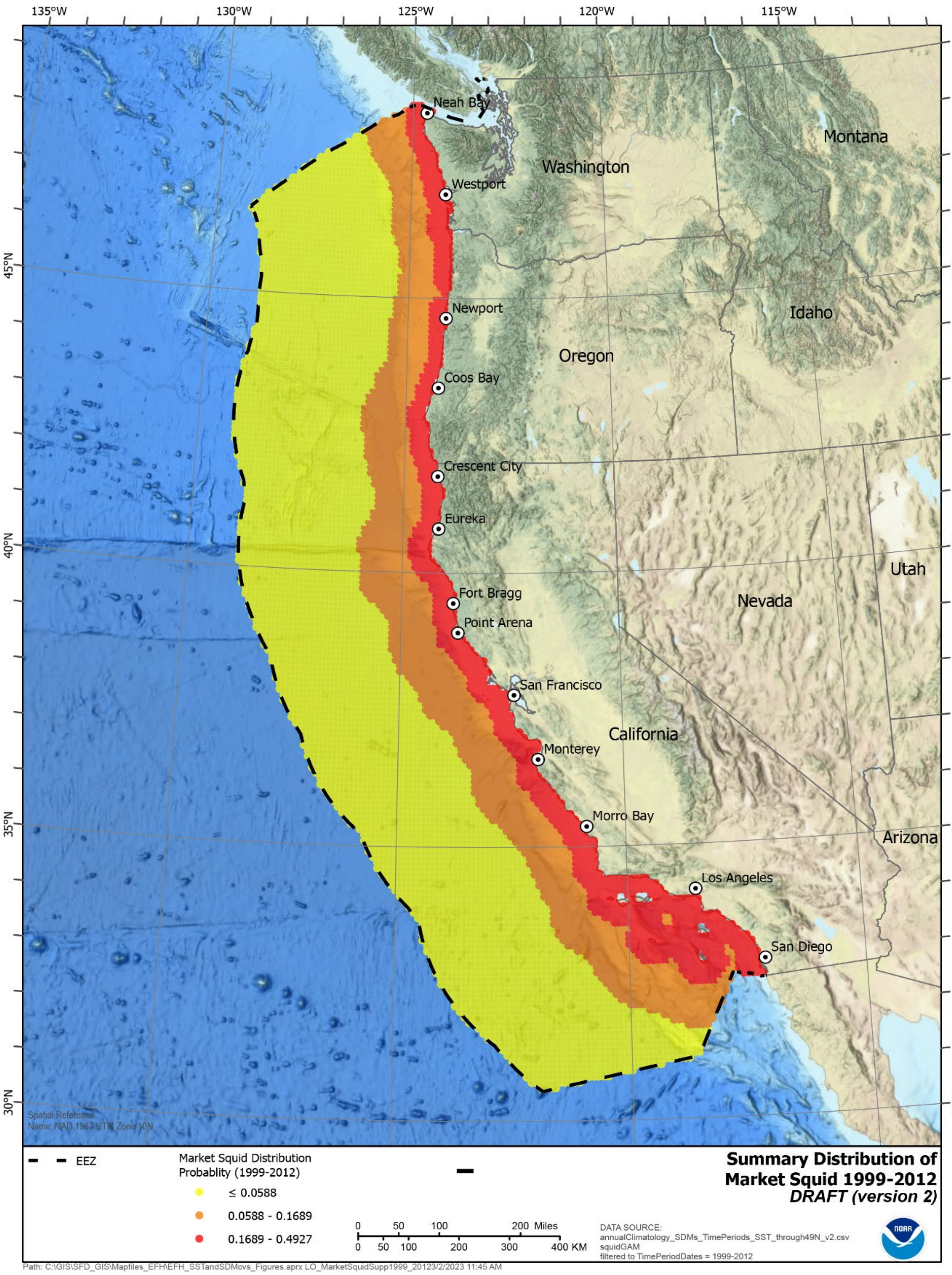


Figure 2.15. Summary distribution of market squid within and seaward of the U.S. EEZ during the 1999-2012 period. Probability distribution was computed using GAMM models and provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

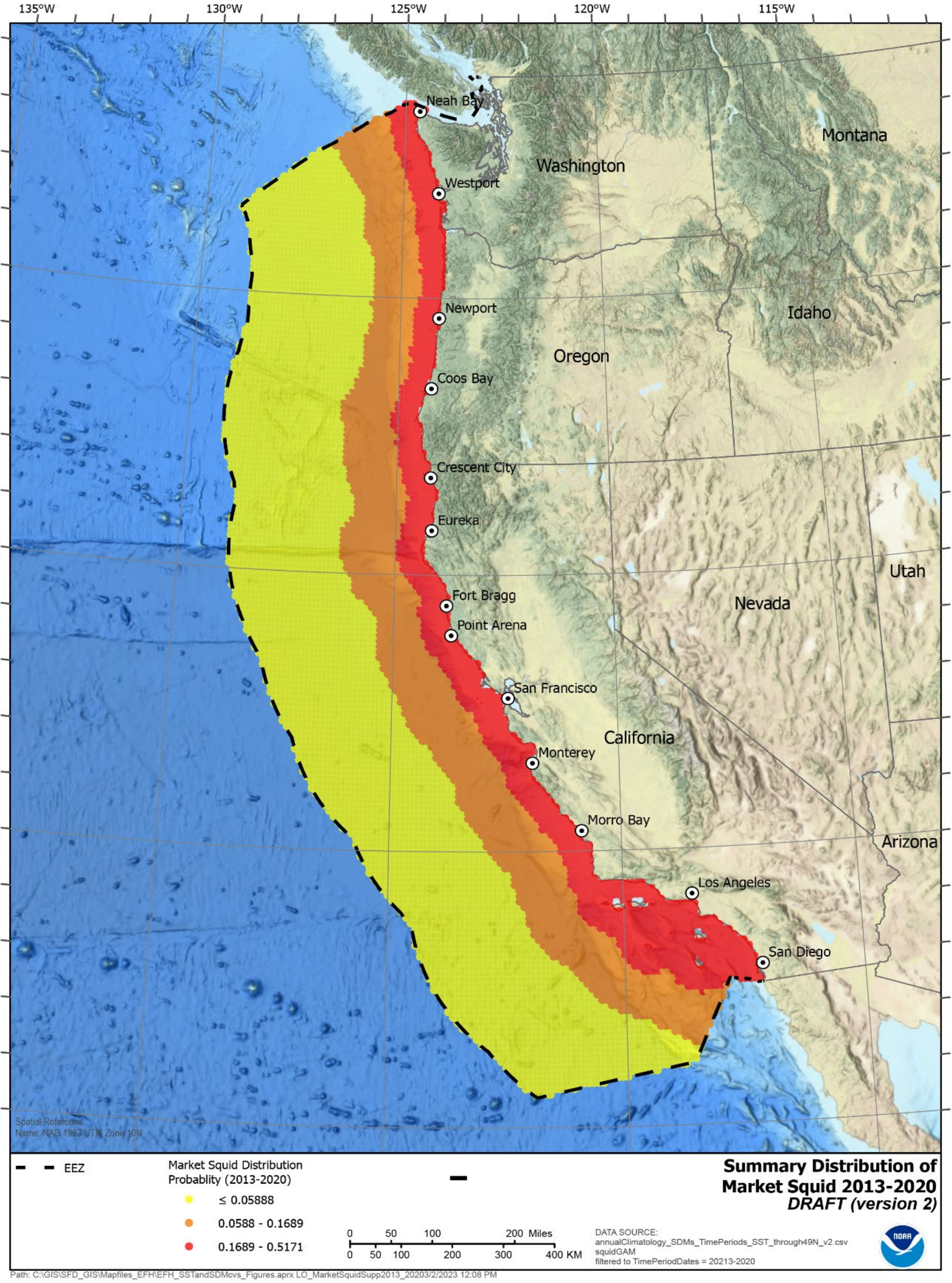


Figure 2.16. Summary distribution of market squid within and seaward of U.S. EEZ during the 2013-2020 period. Probability distribution was computed using GAMM models and provided by B. A. Muhling, using the same data sets and peer-reviewed statistical methods that were published in Muhling et al. (2020).

2.2.2 LIFE HISTORY

Market squid is a short-lived, semelparous species that lives less than a year. Maximum ages observed in survey and port sampling data range from 243-257 days for males, and 225-232 for females (Butler et al. 1998, Jackson and Domeir 2003). From 1998 to 2022, the largest market squid size recorded in the "CDFW Port Sampling Database" was 200 mm dorsal mantle length (DML) (D. Porzio/CDFW, pers. comm.). Males and females start maturing as early as 123 and 127 days-old, respectively (Jackson and Domeier 1998). Mature adults may recruit into spawning grounds 15 days before spawning starts (Maxwell et al. 2006, Perreti et al. 2015). From histological examination of ovaries, Macewicz et al. (2004) confirmed that market squid exhibit determinate fecundity, and females spawn most of their eggs over a short period of time (2-3 days). Dorval et al. (2013) estimated mean potential fecundity to be 3705 oocytes (SE=165) for female market squid collected in southern California and off Oregon and Washington. Macewicz et al. (2004) estimated that the average adult may live 1.67 days after spawning begins.

Recruitment into major fishing grounds typically occurs in a bi-modal period, coinciding with peak spawning between southern and northern California (Reiss et al., 2004, Dorval et al. 2013, CDFW 2021). The first peak usually begins in southern California during the fall-spring season, and the second peak begins off central California and northern California in the spring-fall season. Year-round spawning likely reduces effects of poor temporary local conditions for survival of eggs or paralarvae. In Canadian waters, winter spawning has been observed in the Strait of Georgia and Queen Charlotte Strait, and summer spawning near Victoria and on the West coast of Vancouver Island (FOC 2001). Market squid have been observed off Oregon and Washington and in June (Chasco 2022). The relative contribution of spawning to the maintenance of the population during El Niño periods is not well known, but spawning output, recruitment, and relative abundance off California are typically several orders of magnitude higher during La Niña periods (Dorval et al. 2013, Ralston et al. 2018).

Mating has been observed on spawning grounds just prior to spawning but may also occur before squid move to the spawning grounds. Males deposit spermatophores into the mantle cavity of females and eggs are fertilized as they are extruded (Hurley 1977). Females produce 20 to 70 egg capsules, and each capsule contains 200 to 300 eggs that are suspended in a gelatinous matrix within the capsule. Females attach each egg capsule individually to the substrate (Halon 2004, Perreti et al. 2015). As spawning continues, and depending on annual and seasonal environmental conditions, egg mops observed off California may occupy a surface area from 94 to 3075 m^2 . Egg cases are highly aggregated, and density may reach 1338 capsules per m^2 in favorable conditions (Zeidberg et al.2012). Zeidberg et al. (2012) observed that egg mops were distributed between 20 and 93 m around the Channel Islands, but from 13 to 61 m in Central California. In addition, van Noord (2020) reported that in the SCB, market squid exhibited large-scale synchronous spawning during cool and productive oceanographic conditions, but protracted spawning occurred during warm and oligotrophic conditions.

Spawning of daily cohorts is relatively continuous, lasting a few days, and thus eggs of varying developmental stages may be present at one site over a month during the spawning season. In laboratory experiments, Zeidberg et al. (2011) found that both incubation time and hatch duration were inversely related to temperature. Further, more than 96 percent of paralarvae hatched from eggs reared at temperatures between 9° and 14°C, whereas hatch rate decreased below 90 percent in warmer and colder waters. The minimum and maximum temperatures for hatching were 7°C and nearly 25°C, respectively. Embryonic developmental duration was also found to be affected by environmental oxygen and pH levels (Navarro et al. 2016).

2.2.3 RELEVANT TROPHIC INFORMATION

Juvenile market squid predominantly feed on pelagic crustaceans such as copepods and euphausiids, and gradually switch to larger prey items such as small fish and other squid as they grow and become mature (Field 1965, Karpov and Cailliet 1978). Market squid are probably important as forage to a long list of fish, birds, and mammals including threatened and endangered species (Webb and Harvey 2013, Carle et al. 2015, Lowry et al. 2022). Some of the known squid predators are Chinook salmon, coho salmon, lingcod, rockfish, harbor seals, California sea lions, sea otters, elephant seals, Dall's porpoise, sooty shearwater, Brandt's cormorant, rhinoceros auklet, and common murre, but much more research needs to be done to determine the interaction of market squid with its predators and to quantify its value as a prey item. Nevertheless, prey-predator relationship between market squid and seasons is well documented from a long-time series of diet data. Due to its boom and bust strategy, market squid prevalence in the diet of its predators is highly varied inter-annually. Market squid is one of the primary prey items of the California sea lions, although this marine mammal has a diverse diet comprising 142 taxa (Orr et al. 2011, Robinson et al. 2018, Lowry et al. 2022). In addition, there is a decadal change in the prey-predator relationship between market squid and the California sea lions. For example, off central California (on Año Nuevo Island), Robinson et al. (2018) found that in the 1990s the diet of the California sea lions was dominated by Pacific sardine and northern anchovy but starting in 2010, sea lion diets were more diverse and dominated by rockfishes, Pacific hake, and market squid. In contrast, Lowry et al. (2022) observed that in southern California, sea lions switched from a northern anchovy based-diet in the 1980s to a market squid based-diet in the 1990s and 2000s. Sea birds such as rhinoceros auklets are also primary consumers of market squid, and there are temporal variations and sexual differences in their diets. For example, analyzing stable isotopic composition ($\delta^{15}N$ and $\delta^{13}C$) of auklet parents, Carle et al. (2015) determined that in 2012 chick-rearing female auklets ate more Pacific saury and less market squid than males (Carle et al. 2015). As a result, chick growth and survival to fledging rate were significantly lower in 2012 than in 2013, likely because chicks were fed with less quality prey or fed less frequently than in 2013. According to Webb and Harvey (2014), in the Monterey Bay region, Brandt's Cormorant consumed few market squid during the 2006-2008 period, although previous studies reported that in the 1970s this cephalopod was prevalent in the diet of Brandt's Cormorant. Preti et al. (2021) found that although market squid varied significantly between years in the diet of broadbill swordfish, it was more important in this fish diet in inshore waters than in offshore.

2.3 Krill

The word "krill" comes from a Norwegian term meaning "young fish", but it is now the common term used for all euphausiids, a taxonomic group of shrimp-like marine crustaceans found throughout the oceans of the world. The term krill was probably first applied to euphausiids found in stomachs of whales caught in the North Atlantic, and later became a popular term for Antarctic krill (*Euphausia superba*). For the purpose of this document and analysis, the term 'krill' is synonymous with 'euphausiid'.

All krill species in the U.S. West Coast EEZ are included under the CPS FMP. Distributions and abundances of the highly diverse species vary within the West Coast EEZ due to the diversity of coastal and oceanic populations with cold-northern, warm-western, and tropical and subtropical affinities. Thus, different communities dominate in different regions of the CCE and are affected by varying ocean conditions. Although all krill species are included under the CPS FMP, most of the information presented on krill in this document refers to *E. pacifica* and *T. spinifera*, the species for which there is more substantial information throughout the CCS with respect to abundance, distribution, and life history characteristics.

Eleven species of euphausiids dominate the krill community in the California Current System, including *E. pacifica* and *T. spinifera* (Brinton and Townsend 2003, Lilly and Ohman 2021, E. Bjorkstedt pers. comm. NOAA/SWFSC). The dominance of species in the krill community changes in the northern regions of the California Current with fewer observances of subtropical species and more observances of subarctic species. However, the most dominant species observed in the northern CCE shelf and slope waters are *E. pacifica* and *T. spinifera (e.g.* Gómez-Gutiérrez 2005). Only these two cool-water species, *E. pacifica* and *T. spinifera* form large, dense surface or near-surface aggregations. These two species are also the most common euphausiids reported in the diets of a wide variety of California Current seabird, marine mammal and fish species. The daytime near-surface aggregating behavior of *E. pacifica* and *T. spinifera* has been documented by Boden et al. (1955), Barham (1956), Pearcy and Hosie (1985), Smith and Adams (1988) and others. The sub-tropical and marginally tropical *Nyctiphanes simplex* also aggregates at the surface in large swarms, occurring predominantly to the south in Mexico waters (Gendron 1992, Silva-Dávila et al. 2002, Brinton and Townsend 2003), This species is only abundant in U.S. West Coast waters during strong El Niño years (e.g., Lilly and Ohman 2021). Another euphausiid, *Nematocelis difficilis*, is very abundant in the southern California Current (Decima et al. 2010), but it is not a vertical migrator, preferring the deeper layers of the thermocline where it is less accessible to survey than *E. pacifica* and *T. spinifera*. Remaining species are relatively less abundant (e.g., *T. inspinata* in the northern CCE, and *E. hemigibba* and *Stylocheiron affine* in the southern CCE) and highly variable in space and time. For this reason, and the lack of information on other species throughout the West Coast EEZ, we describe EFH separately for *E. pacifica*, *T. spinifera* and "other" krill.

Larvae, juveniles, and adults of *E. pacifica* are generally distributed from the shoreline seaward to the 1000 fm (1,829 m) isobath, from the surface to 400 m deep (see PFMC 2012). Highest concentrations occur within the inner third of the EEZ but can be advected into offshore waters in phytoplankton-rich upwelling jets that are known to occur seaward to the outer boundary of the EEZ and beyond. In contrast, larvae, juveniles and adults *of T. spinifera* occur in shallower waters from the shoreline up to the 500 fm (914 m) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 100 m deep. Largest concentrations are in waters of less than 200 m deep, although individuals, especially larvae and juveniles, can be found far seaward of the shelf, probably advected there by upwelling jets.

The coastwide distributions of the other six dominant krill species are not well known, but all occur within the U.S. EEZ. The extent of their distribution may vary seasonally, annually, inter-annually and over decadal scales with oceanic conditions. Some of these species (e.g., *N. difficilis*) may be more abundant than *T. spinifera* in some periods and regions of the CCE (see Decima et al. 2010), but they are more difficult to survey. Nevertheless, Lilly and Ohman (2021) analyzed the spatial distribution of ten euphausiids in the southern CCE, using CalCOFI zooplankton data from 1951 to 2018. They found that cool water euphausiid abundance responded to changing in situ habitats conditions during El Niño, whereas subtropical species required initial advection to increase their abundance in the southern CCE. Additionally, they found that cool-water species such as *E. pacifica* and *T. spinifera* compressed shoreward and retracted poleward to upwelling waters during Eastern Pacific El Niño events, likely caused by offshore warming. During eastern Pacific El Niño events, *N. simplex* (a subtropical species) extended poleward nearshore, but during central Pacific Niños the abundance of this species was variable and moderately increased off Southern California. *E. eximia* (a tropical Pacific-Baja California species) was found only off southern California in spring during El Niño years, indicating direct advection and low tolerance for cooler and fresher conditions. Subtropical offshore species such as *E. gibboides and E. recurva* expanded shoreward during most El Niño events (strongest during the 2014–15 Warm Anomaly) and exhibited moderate *in situ* post-event persistence, suggesting combined influence of advection and temporarily favorable habitat nearshore. Further, *N. difficilis and T. gregaria* (regionwide temperate species) contracted only moderately shoreward during some Niños. Furthermore, between 2008 and 2017 cool water species (*E. pacifica, N. difficilis, T. spinifera*) and subtropical species (*N. simplex, E. eximia, E gibboides*) occurred in the southern CCE in the spring, and their abundance was strongly and positively correlated with "time-lagged flows from the preceding November-December" (Lilly et al. 2022). Finally, the size structure of each of these species are likely to be altered during an El Niño and other closely coupled atmospheric-oceanographic events such as marine heatwaves, as shown by Robertson and Bjorkstedt (2020) *for E. pacifica*. Therefore, habitat preference for the other six krill species can be assumed to overlap with the geographic distribution of *E. pacifica* and/or *T. spinifera,* although the occurrence of each species within the U.S. EEZ is variable in space and time. Information on the distribution of these common for krill is summarized in Table 2.8.

Reviews of the literature and available data on krill aggregating areas and reproductive swarms, with high densities of predators such as salmon, seabirds and large baleen whales, revealed certain krill-rich upwelling areas to be especially important. Off Oregon, *E. pacifica* and *T. spinifera* spawn mainly in waters of < 40 km from the coastline*,* but *E. pacifica* also spawn regularly at offshore oceanic locations (Gómez-Gutiérrez et al. 2010). Dense krill swarms and predator aggregations are reported most consistently within the ocean boundaries of the following NOAA National Marine Sanctuaries (NMS): Olympic Coast NMS off Washington (Calambokidis 2004) and Cordell Bank NMS, Gulf of the Farallones NMS (Chess et al 1988, Smith and Adams 1988, Kieckhefer 1992, Schoenherr 1991, Adams 2001, Howard 2001) and Channel Islands NMS in California (Armstrong and Smith 1997, Fiedler et al. 1998, Croll et al 1998). Additionally, the following other high-density krill and krill predator areas have been reported: Heceta Bank and Cape Blanco areas, Oregon (Ainley et al. 2005, Ressler 2005, Tynan et al 2005) and Bodega Canyon (Howard 2001). A confluence within these areas of rich, upwelled unstratified water and topological features such as submarine canyons, banks, and island shelves may not only provide rich feeding areas for krill, but may also contain features necessary for krill patches to be exploited by baleen whales, fish and seabirds, by concentrating and trapping krill over the shelf as they attempt to descend to the depths during the day (e.g., Chess et al. 1988, Fieldler et al. 1998, Ressler et al. 2005, Santora et al., 2018, Nickels et al. 2019).

Table 2.8. Distributions of different life stages of eight common krill species in the U.S. West coast EEZ. Descriptions of pelagic habitat for each species are based on Lilly and Ohman (2021).

Scientific name	**Pelagic habitat**	**Life stage**	**San Diego – Pt Conception (California)**	**Pt Conception – Cape Mendocino (California)**	**Cape Mendocino - Puget Sound (California-Oregon-Puget Sound)**	**Benthic Association**
Euphausia pacifica	Cool-water coastally associated species	Eggs/Larvae	yes	yes	yes	no
		Juveniles/Adults	yes	yes	yes	no
Thysanoessa spinifera	Cool-water coastally associated species	Eggs/Larvae	yes	yes	yes	no
		Juveniles/Adults	yes	yes	yes	no
Nyctiphanes simplex	Subtropical coastal species	Eggs/Larvae	yes	no	no	no
		Juveniles/Adults	yes	no	no	no
Nematocelis difficilis	Region wide temperate species	Eggs/Larvae	yes	yes	yes	no
		Juveniles/Adults	yes	yes	yes	no
Thysanoessa gregaria	Region wide temperate species	Eggs/Larvae	yes	yes	yes	no
		Juveniles/Adults	yes	yes	yes	no
Euphausia recurva	Subtropical offshore species	Eggs/Larvae	yes	no	no	no
		Juveniles/Adults	yes	no	no	no
Euphausia gibboides	Subtropical offshore species	Eggs/Larvae	yes	no	no	no
		Juveniles/Adults	yes	no	no	no
Euphausia eximia	Tropical Pacific-Baja California species	Eggs/Larvae	yes *	no	no	no
		Juveniles/Adults	yes *	no	no	no

Note: * Indicates the life stage occurs only in this region during warm waters conditions (e.g., El Niño and/or marine heat wave events).

2.3.1 *E. PACIFICA*: EFH DESCRIPTION AND IDENTIFICATION

EFH for E. pacifica: EFH for *E. pacifica, including larvae, juveniles and adults, is defined as U.S. West Coast EEZ waters from the shoreline to the 1000 fm (1,829 m) isobath, from the U.S.-Mexico border north to the U.S.-Canada border, from the surface to 400 m deep, from the U.S.-Mexico north to the U.S.-Canada border.* Figure 2.17 shows the geographic extent of EFH for *E. pacifica* within the U.S. EEZ.

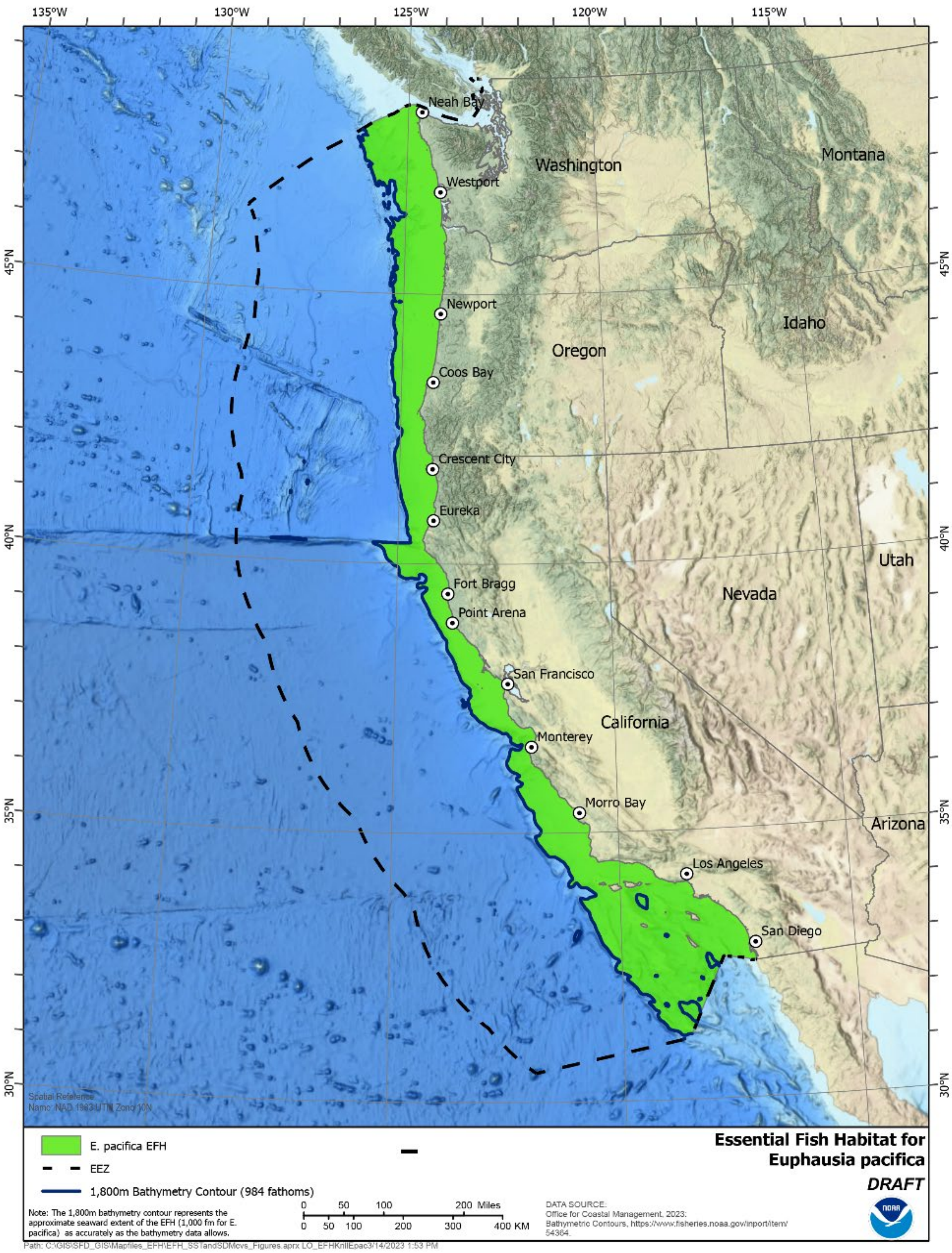


Figure 2.17. Proposed geographic extent of EFH for *E. pacifica.*

2.3.1.1 Distribution and Habitat

E. pacifica ranges throughout the subarctic Pacific, including the Gulf of Alaska as far south as 25º N. latitude (Brinton 1962b, 1981). Highest concentrations of *E. pacifica* occur within the inner third of the U.S. EEZ but can be advected into offshore waters in phytoplankton-rich upwelling jets that are known to occur seaward to the outer boundary of the EEZ and beyond. Distribution of this species within the U.S. EEZ is thought to be closely related to bathymetric, topological and oceanographic features favorable for retaining adults, juveniles and larvae in optimum grazing areas. For example, in the central CCE Cimino et al. (2020) reported that the distribution of this species was influenced by depth and bottom rugosity; chlorophyll-a concentration increased in winter upwelling conditions; and spring surface currents and wind stress (Cimino et al. 2020). Periodically, distribution and occurrence can also be strongly affected by changes in local and large-scale physical and biological conditions such as anomalously strong upwelling events or extreme El Niño conditions. It is not known whether animals advected offshore are lost to the system, or whether transport of some individuals to the south and west via upwelling filaments or eddies may help to interconnect regional subpopulations and enhance gene flow among isolated stocks. Nevertheless, Dorman et al. (2011) showed that both physical process (anomalous northern advection) and biological processes (greater starvation and less weight per individual) contributed to reduced krill availability to predators in the northern California region in 2005.

Across its most preferred habitats *E. pacifica* are distributed by body size, and these spatial ontogenetic patterns and associated biomass are regulated by oceanographic processes, climate forcing (e.g., Briton 1976, Gomez-Gutierrez 2005, Decima 2011, Robertson and Bjorkstedt 2020), and the presence of predators (e.g., Fielder et al. 1998, Gladics et al. 2014, Manugian et al. 2015, Sydeman et al. 2013). *E. pacifica* generally occurs within the U.S. EEZ over bottom depths greater than 100 fathoms (183 m). It can also occur (especially in the larval form) further shoreward on the continental shelf. It is known to occur seaward to the outer boundary of the EEZ from the U.S.-Mexico border north to the U.S.-Canada border and beyond (Boden 1955). Within this area (< 60-100 nm from the coast), adults and juveniles reportedly can be found throughout both the inshore and offshore area, whereas larvae are often most abundant in upwelled areas much nearer the coast, generally inshore of the 1000 fm (Brinton 1976; Brinton 1967; Smiles and Pearcy 1971; Gómez-Gutiérrez et al. 2005). Off Oregon, the greatest concentration of adults appears to be located near the shelf break (~200 m isobath) (e.g., Gómez-Gutiérrez et al. 2005). From experimental data, *E. pacifica* egg development to metanauplius stage is 4.8 and 3.2 days at 8° and 12°C, respectively; but egg development occurs from 1° to 20°C (Dorman 2011). In the northern CCE, juvenile and adult *E. pacifica* collected at the top 50m from the surface were observed at a mean temperature range of 5°C to 11°C (NWFSC, Estuarine and Ocean Ecology Program, Newport, Oregon).. In southern CCE, Lilly and Ohman (2021) reported a range of temperatures from 8° to 15°C for *E. pacifica* collected at the top 50m from the surface during El Niño and non-El Niño years. Aspects of its life history may differ south of 40°N than to the north of that latitude, where environmental conditions show stronger seasonality than to the south (Brinton 1976).

Gómez-Gutiérrez et al (2005) have described the cross-shelf-life stage segregation off central Oregon of both *E. pacifica and T. spinifera*, which appear to be more tightly associated with the shelf break than in other areas. Off southern California, *E. pacifica* tends to be more offshore extending from 3 to 60 nm miles (5.6-111 km) and beyond from the coast. High densities of early life stages (nauplius to juveniles) of *E. pacifica* and *T. spinifera* were primarily recorded in the inshore shelf zone (<18 km from the coast), but older stages were mainly recorded in the outer shelf, slope, and to some extent, beyond. Adult *E. pacifica* (and to some extent, older larval stages) were distributed over the shelf, slope and beyond, with reproductive swarms common along the shelf- break area. These authors concluded that a strong cross-shelf gradient in euphausiids assemblages and age-segregated distributions for *E. pacifica* may represent maintenance of egg, nauplius, and metanauplius stages in the rich nearshore area; the offshore drift of older larval stages; and concentration of reproductive adults at the shelf break linking inshore and offshore segments of the populations. Off southern California, larvae of *E. pacifica* occur offshore beyond the shelf as well as inshore (Brinton 1967, 1973).

Accordingly, Gómez-Gutiérrez et al. (2005) and other authors have suggested that the shelf-break is an important ecological region for both *E. pacifica and T. spinifera*, with larger euphausiid patches often recorded there. Off Oregon, the main populations are thought to be concentrated within 10 to 20 nm either side of the shelf break, though distribution may be further offshore to the south off central and southern California. Additionally, certain features have been associated with important “hot spots” of krill concentration. These are islands, banks, canyons, and promontories that enhance retentive water circulation patterns that tend to retain and concentrate krill and phytoplankton biomass in nutrient-rich upwelled water. Sometimes, these “hot spots” can also occur far offshore, contained in the meanders of upwelling jets that originate further inshore over the shelf or slope. Known high krill and krill predator areas include, but may not be limited to the Olympic Coast, Washington (Calambokidis et al. 2004); Heceta Bank and Cape Blanco areas, Oregon (Ainley et al. 2005; Ressler 2005; Tynan et al 2005); Bodega Canyon, Cordell Bank, Gulf of the Farallones, Pescadero Canyon, Ascension Canyon, and Monterey Bay Canyon off northern California (Chess et al 1988; Smith and Adams 1988; Kieckhefer 1992; Schoenherr 1991; Adams 2001; Howard 2001); and around the southern California Channel islands (Armstrong and Smith 1997; Fieldler et al. 1998; Croll et al 1998).

E. pacifica performs extensive vertical migrations. The adults live at a daytime depth of 200-400 m (occasionally down to 1000 m) rising to near the surface at night (Brinton, 1976; Youngbluth 1976), often concentrating in the upper 20 to 50 m. It occasionally amasses near the surface during the day as well (Hanamura et al 1984, Endo et al. 1985, Brinton and Townsend 1991). The abundance and distribution of both *E. pacifica* and *T. spinifera* fluctuates highly depending on seasonal, annual, or multi-annual oceanographic conditions and regimes. Responses of these two species to these oceanic conditions and atmospheric/climatic events off California and Oregon are reported above in Section 2.3.3. Finally, information on *E. pacifica* habitat use within the U.S. EEZ is summarized in Table 2.9.

Table 2.9. Summary of habitat information for *E. pacifica* within the U.S. EEZ.

Life Stage	Diet	Season	Location	Water Column	Oceanographic Features
Eggs/Larvae	N/A	Off Oregon egg densities are highest in July-August during upwellings; but may also occur in September in period of delay-upwellings.	Spring and summer recruitment (May-July) off southern California Monterey Bay; Fall and winter recruitment off Oregon (August-December).	Pelagic and associated with upwellings; Larvae are mostly concentrated in upwelled areas near the coast (inshore of the 1000 fathoms)	1°C - 20°C*
Juveniles and Adults	Phytoplankton, zooplankton	Year-round off California and Oregon, but peak abundance in each region is associated with upwellings. Off Washington, there are two peaks of recruitment, a larger one in spring and a smaller one in late summer.	Spring and summer recruitment (May-July) off southern California Monterey Bay; Fall and winter recruitment off Oregon (August-December). Individuals are distributed from coastal to offshore waters (seaward to the outer boundary of the EEZ)	Pelagic in depths > 100 fathoms (183m), over the continental shelf, slope and beyond.	5°C - 15°C Hotpots typically associated with marine canyons, Islands and Banks off California.

Note: * indicates spawning temperature range of laboratory-reared *E. pacifica* (Dorman 2011).

2.3.1.2 Life history

Krill exhibit great plasticity in their life history by adapting to environmental conditions. Thus, analysis of length at age is complicated by the fact that krill can shrink in size as an ecological adaptation to temporarily unfavorable environments (Marinovic and Mangel 1999). *E. pacifica* are known to shrink in winter when food is scarce, and in summer during the reproductive season (Shaw et al. 2010, Shaw et al. 2021). California Current krill can also regressively lose their sexual characteristics, skip developmental stages, or molt several times while remaining at the same stage. Further, *E. pacifica* can exhibit a large range of ages at any given size, and females at a given age can vary in size as much as 10 mm. These characteristics can have a big impact on field calculations and complicate length frequency progression analysis.

Throughout its range, *E. pacifica* exhibits large variation in longevity and age at first sexual maturity. According to Brinton (1976), the more abundant spring-summer cohort of *E. pacifica* off southern California generally reaches a maximum length of 22 mm in about 12 or 13 months and has a one-year life span. Life expectancy for the lesser abundant winter cohort off southern California is shorter, lasting 8 months. Individuals from 10 to 15 mm carapace length tend to predominate in the population. Coastal size distribution of *E. pacifica* size off northern California was found to be related to temperature and chlorophyll-a concentration (Robertson and Bjorkstedt 2020). These authors found that warm climate events can disrupt and suppress typical seasonal dynamics, resulting in persistent shifts towards populations dominated by smaller juveniles and adults. For example, during the 2014-16 marine heatwave, mature individuals were smaller than previously reported in the literature, and larger sizes were mostly absent or rare, particularly during the period when the heatwave was strongest in coastal waters. Shaw et al. (2021) found that *E. pacifica* cohorts that exhibited slower growth were associated with delayed upwelling and moderate chlorophyll concentrations, indicating that extended duration and slower growth were related to suboptimal environmental conditions. Further, these authors determined that cohorts can exhibit negative growth, particularly after individual *E. pacifica* reach a total length of 10 mm (Shaw et al., 2021). From an experimental study, Shaw et al. (2010) concluded that negative growth rates during winter downwelling were probably related to poor feeding conditions, whereas negative growth during summer upwelling likely resulted from investment of energy towards reproduction rather than somatic growth. Under optimum conditions, sexual maturity could be attained at 11.6 mm (Brinton 1976), and adult cohorts off southern California can reproduce about three times over a lifespan of about three years. Growth is thought to be slower and of longer duration to the north in the Subarctic North Pacific.

Recruitment of *E. pacifica* can occur year-round off Oregon and California, but distinct peaks are associated with upwelling periods (Brinton 1967; Brinton 1973; Barham 1957). *E. pacifica* appears to be more seasonal in the subarctic North Pacific and off Japan (Nemoto 1957; Ponomareva 1966). Recruitment typically peaks off mid Baja California in February-April; off southern California in May-July; in Monterey Bay in spring and summer; and off Oregon, in August-December (Brinton 1976). It may be that under optimal feeding conditions, a female, carrying 20-250 eggs which hatch into larvae could spawn every two months – first at about 11.5 mm length; second at about 16 mm, and third at 20 mm – during which time it might produce a maximum of 650 eggs. The long duration of maturity (about half of the species' short life expectancy) is thought to contribute to population stability and continuity. Recruitment in California occurs after about 30 days when larvae enter the juvenile phase. There are at least four generations each year, at least off southern California. Due to the short life span and relatively few cohort pulses, the maximum stock size is reached immediately after successful recruitment of a single cohort (Brinton 1976, Siegel and Nicol 2000). In general, there is no spawning stock-recruitment relationship. In most years highest recruitment occurs from spring and summer cohorts, and lesser recruitment occurs in autumn and winter. Off Washington, there is one large recruitment pulse in spring, and a lesser one in late summer (Bollens et al. 1992) and none in winter. This pattern is attributed to reduced phytoplankton levels in summer and low survival of adults into winter to spawn at that time.

E. pacifica are batch spawners that freely broadcast eggs into the water, which sink in the water column. Males must transfer a spermatophore packet to the female for fertilization to take place. After hatching, larvae move toward the food-rich surface layers. Off Oregon the highest densities of *E. pacifica* eggs typically occur during the upwelling months of July and August, which coincides with the periods of highest chlorophyll (Shaw et al. 2021). However, in some years highest densities of eggs may occur in September when there is a delay in the onset of upwellings. Evans et al. (2021) modeled the seasonal distribution of adult *E. pacifica* and *T. spinifera* along the Pacific coast of Canada and determined that the two species formed persistent hotspots along the 200 m depth contour of the continental shelf. Further, the shallower Dixon shelf, off British Columbia, Canada, was a key area of occurrence for *T. spinifera*, whereas hotspots of *E. pacifica* were observed within the Juan de Fuca Eddy system (Evans et al. 2021). These authors determined that the continental slope along the west coast of Vancouver Island was the only persistent hotspot region commonly used by adults and larvae of euphausiids.

Brinton (1976) estimated that only 16 percent of *E. pacifica* larvae survive per month. Survival increases to 67 percent per month after the larval stage is complete, then mortality increases once again in adulthood, with only about 60 percent of individuals surviving per month. Siegel and Nicol (2000) calculated M values based on data published in Brinton (1976) and Jarre-Teichmann (1996) and found $M = 3.0 \text{ x year}^{-1}$ off California, and much higher ($M = 8.7 \text{ x year}^{-1}$) off Oregon. Siegel and Nicol (2000) suggested the high mortality rates off Oregon may have been due to data collected under unusually severe El Niño conditions and may not be representative of an ‘average’ year. Shaw et al. (2021) derived survivorship curves for *E. pacifica* and estimated that *E. pacifica* juvenile stages last on average six months and the total lifespan of this species off Oregon to be approximately two years.

2.3.2 *T. SPINIFERA:* EFH DESCRIPTION AND IDENTIFICATION

EFH for T. spinifera: EFH for *T. spinifera, including larvae, juveniles and adults, is defined as the U.S. West Coast EEZ from the shoreline to the 500 fm (914 m) isobath, from the U.S.- Mexico border north to the U.S.-Canada border, from the surface to 100 m deep.* (Figure 2.18).

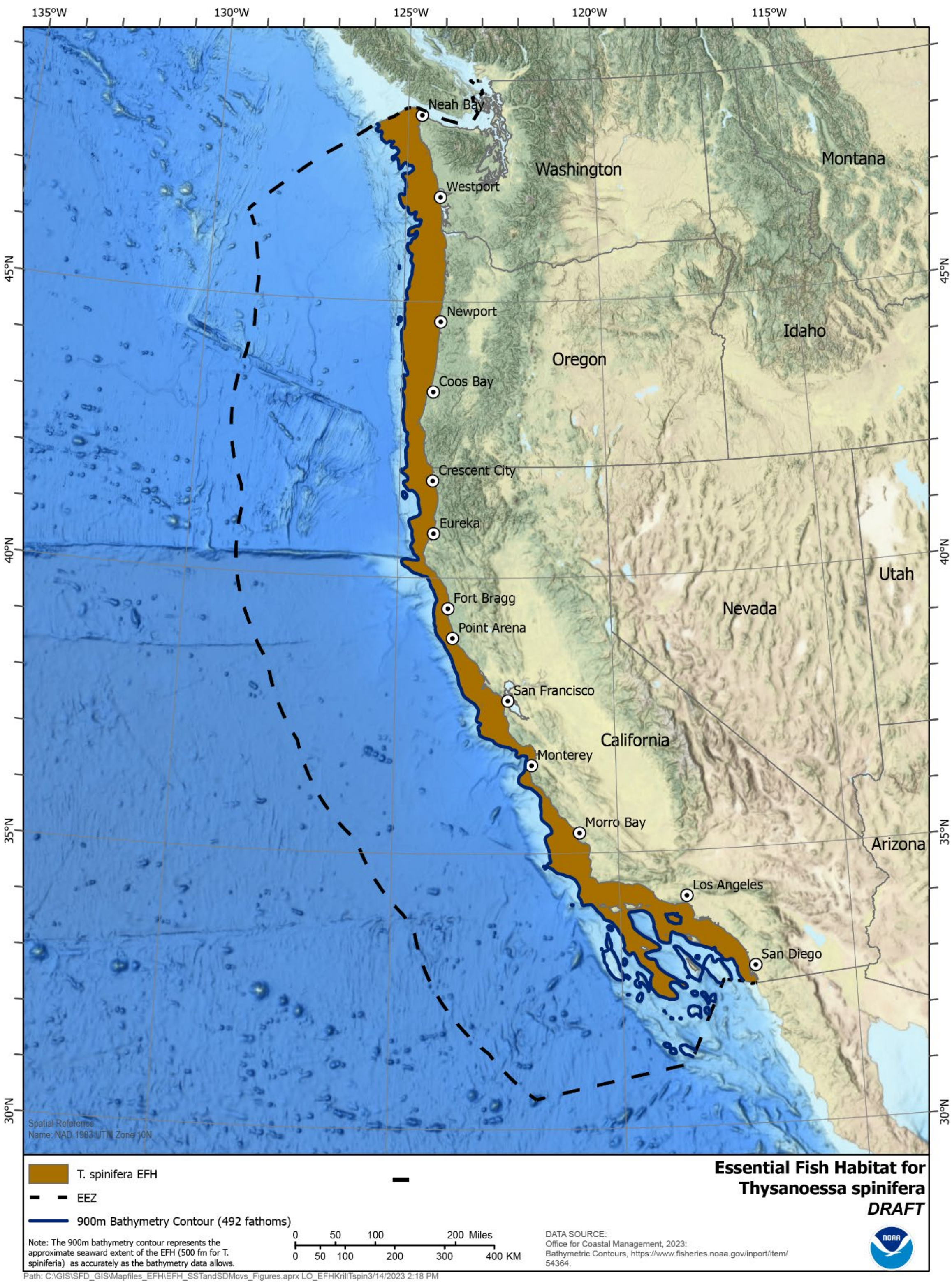


Figure 2.18. Geographic extent of EFH for *T. spinifera.*

2.3.2.1 Distribution and Habitat

T. spinifera occurs from the southeastern Bering Sea south to northern Baja California, with regions of high density associated with centers of upwelling (Boden et al. 1955; Brinton 1962b). As for other krill species, the distribution of this species within the EEZ has been found to be strongly associated with bathymetric, topological, and oceanographic features favorable for retaining adults, juveniles and larvae in optimum grazing areas. Cimino et al. (2020) found that in the central CCE the distribution of both *T. spinifera* and *E. pacifica* was influenced by depth and bottom rugosity; chlorophyll-a concentration increased in winter upwelling conditions; and spring surface currents and wind stress. As for *E. pacifica*, the distribution and occurrence of *T. spinifera* can also be strongly affected by changes in local and large-scale physical and biological conditions such as anomalously strong upwelling events or extreme El Niño conditions. Nevertheless, Dorman et al. (2011) showed that both physical process (anomalous northern advection) and biological processes (greater starvation and less weight per individual) contributed to reduced krill availability to predators in the northern California region during 2005.

T. spinifera is more coastal than *E. pacifica*, occurring mainly shoreward of the shelf break, usually over bottom depths less than 200 m deep, although catches can occur further offshore beyond the shelf, especially off central California. Daytime surface swarms have been observed off California in the San Diego, Santa Barbara Channel Islands, Monterey Bay, Gulf of the Farallones, Cordell Bank, and Tomales Bay areas, and off Oregon (Pearcy and Hosie 1985, Smith and Adams 1988, Brinton et al. 2000, Adams 2001, Howard 2001). In the northern CCE, juvenile and adult *T. spinifera* collected at the top 50m from the surface were observed at a mean temperature range of 5°C to 11°C (NWFSC, Estuarine and Ocean Ecology Program, Newport, Oregon). In southern CCE, Lilly and Ohman (2021) reported a range of temperatures from 8° to 14°C for *T. spinifera* collected at the top 50m from the surface during El Niño and non-El Niño years.

Gómez-Gutiérrez et al (2005) have described the cross-shelf life stage segregation of both *T. spinifera* and *E. pacifica* off Central Oregon. The densities of early life stages of both species were highest in the inshore shelf zone (<18 km from the coast), whereas older stages of both species were mainly observed in the outer shelf, slope, and to some extent, beyond. Adult *T. spinifera* occurred primarily over the shelf and shelf-break waters from 2-74 km (1- 40 nm) from the coast, especially between 5.6 and 27.8 km (3 and 15 nm) from shore in water less than 100 m deep. Larvae and juveniles of *T. spinifera* were also generally restricted to relatively shallow inner shelf waters within < 18 km from the coast; while adults occurred generally in outer shelf, shelf break and slope waters beyond 18 km from the coast. These authors concluded that a strong cross-shelf gradient in euphausiids assemblages and age-segregated distributions for both *T. spinifera* and *E. pacifica* may represent maintenance of egg, nauplius, and metanauplius stages in the rich nearshore area; the offshore drift of older larval stages; and concentration of reproductive adults at the shelf break linking inshore and offshore segments of the populations. Off southern California, *T. spinifera* larvae occur offshore beyond the shelf as well as inshore (Brinton 1967, 1973). Brinton and Townsend (2003) reported *T. spinifera* (mostly furcilia; rarely adults) disperses extensively offshore toward the main flow of the California Current. While it is possible that these individuals may be advected there by currents and represent individuals lost from the coastal population (Brinton and Townsend 2003), there may also be significant latitudinal differences in the inshore-offshore dispersion patterns and retention mechanisms off Oregon and California.

As reported for *E. pacifica*, Gómez-Gutiérrez et al (2005) and others have suggested that the shelf-break is an important ecological region for both *T. spinifera* and *E. pacifica*, with larger euphausiid patches often recorded there. Off Oregon, the main populations are thought to be concentrated within 10 to 20 nm either side of the shelf break, though distribution may be further offshore to the south off central and southern California. Additionally, certain features have been associated with important "hot spots" of krill concentration. These are islands, banks, canyons, and promontories that enhance retentive water circulation patterns that tend to retain and concentrate krill and phytoplankton biomass in nutrient-rich upwelled water. Sometimes, these "hotpots" can also occur far offshore, contained in the meanders of upwelling jets that originate further inshore over the shelf or slope. Known high krill and krill predator areas include, but may not be limited to the Olympic Coast, Washington (Calambokidis et al. 2004); Heceta Bank and Cape Blanco areas, Oregon (Ainley et al. 2005, Ressler 2005, Tynan et al 2005); Bodega Canyon, Cordell Bank, Gulf of the Farallones, Pescadero Canyon, Ascension Canyon, and Monterey Bay Canyon off northern California (Chess et al 1988, Smith and Adams 1988, Kieckhefer 1992, Schoenherr 1991, Adams 2001, Howard 2001); and around the southern California Channel islands (Armstrong and Smith 1997; Fieldler et al. 1998; Croll et al 1998).

T. spinifera generally occurs from the surface to about 200 m deep but most frequently at vertical depths of less than 100 m (Ponomareva 1966; Brinton et al 2000; Alton and Blackburn 1972). It also undertakes diel vertical movements within its relatively shallow range (Alton and Blackburn 1972; Chess et al. 1988). It is the most predictable and extensive daytime surface swarmer along coastal California from Tomales Bay south to the Channel Islands off southern California (Brinton 1962b, Smith and Adams 1988, Fielder et al 1998, Howard 2001, Adams 2001). Mass strandings of the species have also been reported along Oregon beaches (Pearcy and Hosie 1985) and as far south as La Jolla, California (Brinton 1962a). The abundance and distribution patterns of *T. spinifera* are highly variable depending on seasonal, annual, or multi-annual oceanographic conditions and regimes. Responses of these two species to these oceanic conditions and atmospheric/climatic events off California and Oregon are reported above in Section 2.3.3. Finally, information on *T. spinifera* habitat use within the U.S. EEZ is summarized in Table 2.10.

Table 2.10. Summary of habitat information for *T. Spinifera* within the U.S. EEZ.

Life Stage	**Diet**	**Season**	**Location**	**Water Column**	**Oceanographic Features**
Eggs/Larvae	N/A	Off Oregon egg densities are highest in July-September during upwellings, but small peaks also occur in winter (February-March) and/or spring (April-May); Off California from April through May-July. Fall spawning may also occur off San Francisco (August-October).	Spring and summer recruitment (May-July) off southern California Monterey Bay; Fall and winter recruitment off Oregon (August-December). Distributed mostly on mid-continental shelf spawning location.	Pelagic waters, with larvae occurring in the inshore shelf zone (< 18 km from the coast)	N/A
Juveniles and Adults	Phytoplankton, zooplankton	Year-round off California and Oregon, but peak abundance in each region is associated with upwellings.	Spring and summer recruitment (May-July) off southern California Monterey Bay; Fall and winter recruitment off Oregon (August-December).	Mostly in coastal waters < 100 m, shoreward of the continental shelf and shelf-break. Juveniles are mostly restricted in waters of < 18 km from the coast.	5°C-14°C Hotpots typically associated with marine canyons, Islands and Banks off California.

2.3.2.2 Life history

Krill exhibit great plasticity in their life history by adapting to environmental conditions. *T. spinifera* shrinks in size in winter when food is scarce (Shaw et al. 2010, Shaw et al. 2021) as a mechanism to adapt under these unfavorable seasonal conditions, which complicate the estimation of length-at-age (Marinovic and Mangel 1999). *T. spinifera* grows to a larger size than *E. pacifica* — males to 20 mm, females to 38 mm. The difference in male and female growth is observed from the first year. Life span has been variously reported at from 10 months to two years or more (Boden et al. 1955; Nemoto 1957; Summer 1993; Tanasichuk 1998). In subarctic Alaskan waters, Nemoto

(1957) reported a two-year life cycle (or at least 1+ years), with individuals growing to 10 mm in the first year and attaining sexual maturity at about 20-24 mm at one year of age, with a spawning season from June to September. Nemoto (1957) found large unfertilized specimens (26-30 mm) in mid-July and was unsure whether these specimens represented ages 2^+. Mauchline (1980) also estimated the maximum life span to be 2^+ years with breeding maturity reached at 2 years of age. Summers (1993), using length frequency analyses of individuals collected in Barkley Sound, British Columbia, found that *T. spinifera* matures in one year, and some individuals survive to 2 years of age; although most maximum-sized adults observed in the field were closer to 1-year old). Monitoring *T. spinifera* population structure in Barkley Sound, British Columbia, Tanasichuk (1998b) estimated a shorter life span of 10 months using length frequency progressions and certain initial assumptions about larval stage durations and furcilia growth. Tanasichuk (1998b) also found more variable and protracted spawning. Annual and seasonal progression in size classes observed in *T. spinifera* collected in the Gulf of the Farallones and Channel Islands off southern California indicate that a one - two year life span may also be true for populations to the south, but more work is needed.

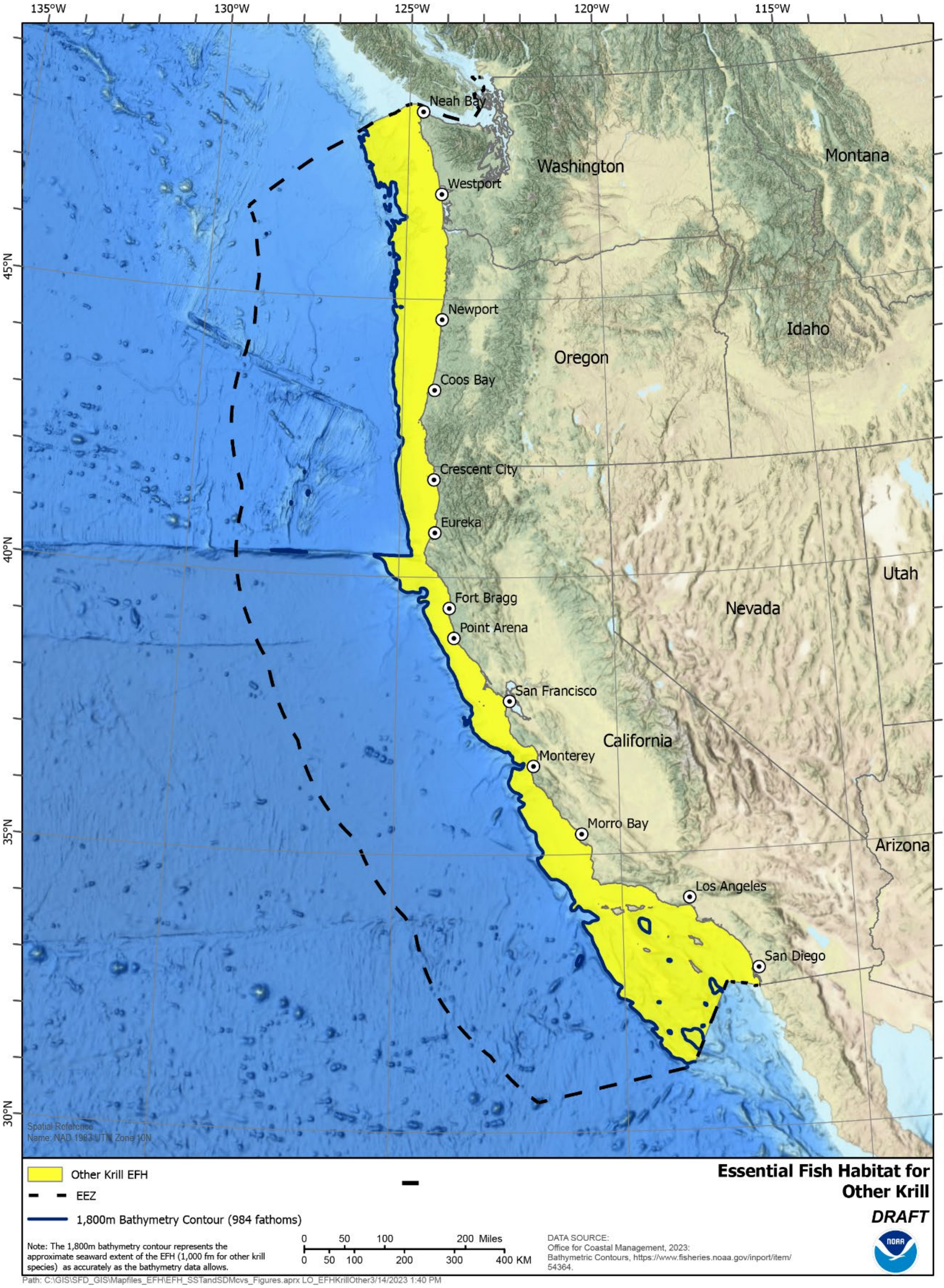
Brinton (1981) reported that the *T. spinifera* spawning season off California extended from May to July, coincident with the strongest upwelling. During this time, fully mature adults form extensive inshore surface swarms during the peak of the upwelling season off California (Brinton 1981, Smith and Adams 1988). These adults are thought to swarm, breed over a protracted spawning season, then presumably die at the end of their life cycle (Nemoto 1957). Off San Francisco, breeding appears to occur primarily from April through June-July. Spring reproductive swarms in this area contain mostly 18-30 mm fertilized adults in breeding condition, which presumably spawn (probably at intervals) and then die by late summer, when specimens of the size disappear from seabird and salmon diets, and from plankton collections. Swarms off central and southern California have also been sampled during late summer and fall (August-October) in association with blue and humpback whales, but these late summer and fall individuals are mostly immature or sexually developing individuals (14-20 mm). Maturing subadults are also known to swarm near the surface in late summer and fall (Schoenherr 1991; Kieckhefer 1992; Fiedler et al. 1998).

T. spinifera are batch spawners. Eggs are broadcast freely into the water, which sink in the water column. Unlike *E. pacifica*, the eggs of *T. spinifera* are quite adhesive and often covered in adhered debris (Summers 1993, Gomez-Gutierez et al. 2007, Feinberg et al. 2010), a possible mechanism to maintain recruits in the neritic zone and prevent offshore dispersal to less productive waters (Summers 1993). Off the Oregon coast, *T. spinifera* eggs are typically found in greatest abundance over shallower mid-shelf spawning sites, with lowest abundance observed offshore on deep-water spawning locations beyond the shelf break (Feinberg et al. 2010). In most years (from 1997-2005) small peaks of egg density were observed in late winter (February-March) and/or spring (April-May), but large and prolonged peaks were observed in summer, from July to September (Feinberg et al. 2010). In most years, *T. spinifera* can continue to spawn off Oregon until the upwelling season ends in the fall, but in other years spawning may cease early in the season. Feinberg et al. (2010) postulated that *T. spinifera* may be an intermittent spawner, whose ovaries are not constantly matured and capable of spawning, even if environmental conditions are suitable for spawning. Summers (1993) describes a distinct and extended spawning period off British Columbia from March through July with a late May peak. Evans et al. (2021) modeled the seasonal distribution of both adult *E. pacifica* and *T. spinifera* along the Pacific coast of Canada and determined that both species formed persistent hotspots along the 200m depth contour of the continental shelf. However, there were differences on the shallower Dixon shelf, where *T. spinifera* occurs and within the Juan de Fuca Eddy system where hotspots of *E. pacifica* were observed. The continental slope along the west coast of Vancouver Island was determined to be the only persistent hotspot region commonly used by adults and larvae of euphausiids.

2.3.3 OTHER KRILL: EFH DESCRIPTION AND IDENTIFICATION

EFH for other krill: *EFH for other krill species, including larvae, juveniles and adults, is defined as the U.S. West Coast EEZ waters from the shoreline to the 1000 fm (1,829 m) isobath, from the U.S.-Mexico north to the U.S.-Canada border, from the surface to 400 m deep, from the U.S.-Mexico north to the U.S.-Canada border* (Figure 2.19).

The designation of EFH for the other krill assemblage is based on information for the principal species, *E. pacifica* and *T. spinifera* (see section 2.3.3. and 2.3.4). Isobath (depth contours) are used as outer boundaries of krill EFH, but only because they roughly approximate the outer bounds of reported densest concentrations of the populations, and because static boundaries are preferred for the legal definition of EFH. These contours also roughly form the outer boundaries of some of the major upwelling areas (though perhaps not some of the larger offshore jets), within which consistently high concentrations of phytoplankton occur. The boundaries are not meant to imply the strict association of these highly dynamic macroplanktonic species with fixed bottom topography. The geographic extent of the EFH for the other krill is described in Figure 2.19.



Essential Fish Habitat for Other Krill

Note: The 1,800m bathymetry contour represents the approximate seaward extent of the EFH (1,000 fm for other krill species) as accurately as the bathymetry data allows.

DATA SOURCE:
Office for Coastal Management, 2023:
Bathymetric Contours, https://www.fisheries.noaa.gov/inport/item/54364.

Path: C:\GIS\SFD_GIS\Mapfiles_EFH\EFH_SSTandSDMcvs_Figures.aprx LO_EFHKrillOther3/14/2023 1:40 PM

Figure 2.19. Geographic extent of EFH for the other krill.

2.3.4 RELEVANT TROPHIC INFORMATION FOR KRILL

Both *E. pacifica and T. spinifera* are grazers on microscopic plants and animals and provide an important link in the oceanic food web between phyto- and nanoplankton and upper trophic levels. Phytoplankton is thought to be a major component of the diet, but fish eggs and larvae are also thought to be consumed in large quantities. Theilacker et al (1993) suggests this predation may significantly affect fish recruitment. Field et al (2001), using a top-down Ecopath assessment model for the northern CCE, estimated euphausiid average annual phytoplankton biomass consumption to be 650 g wet weight m^{-2} during the early 1960s (a cool, productive regime), and 400 g wet weight m^{-2} in the mid-1990s (a warm regime characterized by low productivity). In the northern CCE, Fisher et al. (2020) found that *T. spinifera* had higher length-weight, Fulton's K, hepato-somatic index, carbon to nitrogen ratio, total lipid per wet weight, and storage lipid compared to *E. pacifica*. These results would indicate that *T. spinifera* has a higher energetic value for predators, but more data are needed to validate these results across the whole CCE. The phytophagous role of krill may also have a negative aspect. Bargu et al. (2002) found evidence that California krill (e.g., *E. pacifica*) may be a potential transfer agent of the phycotoxin domoic acid to higher trophic levels in the marine food web in Monterey Bay.

Juvenile and adult krill are consumed by a variety of predators, including fish (e.g., Albacore, Salmon, Pacific Hake, Jack mackerel), seabirds such as Cassin's Auklet, and marine mammals such as blue and humpback whales. Chinook salmon is a major predator of krill, and particularly of *T. spinifera*. Off central California, Wells et al. (2012) found there was a lag of one year in the relationship between the abundance of *T. spinifera* and the volume of krill in the diet of juvenile Chinook salmon. They also determined that the body condition of juvenile Chinook salmon was positively related to the abundance of adult krill the year before and specifically to the proportion of *T. spinifera* in the diet. Nickels et al. (*In review*) found that some environmental conditions (e.g., when Biologically Effective Upwelling Transport was moderate), euphausiids may dominate the diets of albacore by as much as 37 percent on average. Analyzing data collected from 1998-2004 off the U.S. Pacific Northwest, Emmett and Krutzikowsky (2008) found that Euphausiids and fishes were among the most abundant prey items in the diets of Pacific hake and jack mackerel. However, Pacific hake had relatively low percentages of empty stomachs during cool-ocean years (2000 through 2002) and high percentages during 1998, a warm-ocean year.

The two principal krill species (*E. pacifica* and *T. spinifera)* also constitute a substantial proportion of the diet of Cassin's auklet off California. Accordingly, radio-marking of auklet parents off southern California showed that during breeding seasons the core foraging area of these seabirds was within 30 km of their colony. Parents were aggregated in shelf waters of < 200 m, although occasionally they foraged in deeper waters (Adams et al. 2004). Individual parents fed mostly on euphausiids, pelagic larval and juvenile fishes, and minor amounts of cephalopod and other crustaceans. Further, Adams et al. (2004) found krill species selected by auklet varied among years. For example, *T. spinifera* was most important in the diet of auklet in 1999 and 2001; whereas *E. pacifica* replaced adult *T. spinifera* in 2000. However, temporal differences in chick-diets did not significantly affect fledging success and growth among first chicks; although the proportion of pairs successfully fledging an alpha chick and initiating a second clutch was highest in 1999 (63 percent) and 2000 (75 percent), and less in 2001 (7 percent). In the Gulf of Farallones off California, Abraham and Sydeman (2006) found that the proportion of *E. pacifica* adults in auklet diet decreased over the chick-rearing period but increased with increasing SST and an upwelling index. In contrast, *T. spinifera* in auklet diets showed an increase over the chick-rearing period, but no relationship with the upwelling index and SST. While the proportion of *E. pacifica juveniles* in auklet diets showed no seasonal variations and relation with upwelling and temperature, *T. spinifera juveniles* in the diet of auklet did increase seasonally and with the upwelling index. Finally, Manugian et al. (2015) determined that Cassin's auklets utilized consistent areas in the upper water column (95 percent of dives < 30m) where krill could be found. As in previous studies, they found that these seabirds primarily preyed on *T. spinifera and E. pacifica*, and that auklet could be a valuable indicator of krill abundance and distribution.

Krill are also an important prey for whales in the CCE. Blue whales consume both *E. pacifica* and *T. spinifera*, but these marine mammals strongly prefer *T. spinifera* (Fielder et al. 1998, Nickels et al. 2019). Krill aggregations around the California Channels are important forage resources of Blue Whales, particularly during summer-fall season. In Monterey Bay, large concentrations of blue whales have been observed to be feeding on euphausiids that were distributed in deep scattering layers and daytime surface swarms. Schoenherr (1991) estimated that these scattering layers contained primarily *T. spinifera*, which accounted for 45.4 percent of the total biomass of zooplankton samples across these layers. These authors also observed that "surface-lunging blue whales" were feeding on daytime surface swarms of *T. spinifera* near the head of Monterey Bay Submarine Canyon. Large concentrations of blue whales feeding on euphausiids have been also observed around marine banks. Nickels et al. (2019) reported that *T. spinifera* was consistently more abundant on the Nine Mile Bank, near San Diego California, or inshore of it than offshore. In contrast, *E. pacifica* was more abundant and dispersed more evenly around this bank. In addition, Nickels et al. (2019) determined that adults of both *E. pacifica* and *T. spinifera* were distributed within a narrow layer between 200 and 250 m that corresponded to typical feeding depth distribution of Blue Whales. These two krill species were also shown to be important to humpback whale diets, being the dominant component during periods of positive phases of the North Pacific Gyre Oscillation (NPGO), when SST are cool, upwelling is strong and krill biomass is high (Fleming et al. 2015). Under opposite conditions, when Pacific sardine and northern anchovy biomass increased, humpback whale diets were dominated by these fish species, demonstrating their prey switching capabilities.

In sum, these new data on the relationship between krill species and their predators have allowed not only to elucidate the mechanisms that control the formation of *E. pacifica and T. spinifera* hotspots, but also to resolve essential krill species habitats by modeling seasonal upwelling, interannual and decadal changes in oceanic and atmospheric conditions (Dorman et al. 2015, Fiechter et al. 2020, Santora et al. 2011, 2013, 2018, Cimino et al. 2020, Guo et al. 2014, Kaplan et al. 2013, Rockwood et al. 2020). Recent modeling research has shown that *E. pacifica* hotpots coincided with hotpots of various species of marine mammals, birds, and fishes. For example, krill hotpots (dominated by *E. pacifica*) have been found in the vicinity of marine canyons and this association between krill and canyon has been proposed as a potential "hot spot network'' that could enhance foraging opportunities for marine predators (Santora et al. 2018). Specifically, Santora et al. (2018) found that 76 percent of krill hotspots that occurred in the CCE were within and adjacent to canyons. In addition, most of these hotspots were associated with large shelf-incising canyons. In another study, Redwood et al. (2020) found that both whales (blue and humpback) and krill consistently used the northeast region of Cordell Bank, the Farallon

Escarpment, and the shelf-break waters. Their model identified that blue whale hotspots were also krill hot spots, whereas co-occurrence between humpback whales and krill were more limited and varied seasonally. Finally, risk assessments have also shown that the depletion of euphausiids and forage species in the CCE could lead to dramatic declines in the abundance of top marine predators, and in particular of commercial fishes (Kaplan et al. 2013). Data from these recent studies underscore the critical role that the krill assemblage plays in the maintenance of the CCE.

3 FISHING ACTIVITIES THAT MAY ADVERSELY AFFECT CPS EFH

FMPs must contain an evaluation of the potential adverse effects of fishing activities on EFH designated under the FMP and describe actions that could be taken to minimize adverse effects to EFH. This includes effects from fishing activities regulated under this FMP as well as other Federal FMPs. FMPs must also identify any fishing activities not managed under the MSA that may adversely affect EFH. The EFH regulations state that "Councils must act to prevent, mitigate, or minimize any adverse effects from fishing, to the extent practicable, if there is evidence that a fishing activity adversely affects EFH in a manner that is more than minimal and not temporary in nature…"

Fishing activities in the West Coast EEZ (both MSA and non-MSA) use gear such as midwater trawl, bottom trawl, purse seine, long line, pot/trap, and others. In the pelagic environment there is no evidence that any fishing gear used in the West Coast EEZ has more than a negligible and temporary effect on the quality or quantity of EFH. However, to the extent that the presence of prey species can contribute to making waters function as feeding habitat, removal of prey species could conceivably affect the quality or quantity of CPS EFH. Although prey species are not defined as EFH themselves, the presence of prey can contribute to waters being EFH for the purposes of functioning as feeding habitat. Some CPS species (Pacific mackerel, jack mackerel, and market squid) are piscivorous as adults, and could be potentially affected by removal of other CPS species. To the extent that other CPS could be considered a component of CPS EFH, removal of those species through fishing could conceivably adversely affect the EFH. However, the EFH review produced no information indicating that fishing adversely affects CPS EFH via removal of CPS species.

MSA and non-MSA fishing gears that are intended to have contact with the benthos could potentially adversely affect benthic habitat used by market squid for parts of their life cycle. Soft sediments where squid spawning and egg case development occur have shorter recovery periods than biogenic and hard bottom habitats that are impacted by fishing activities (PFMC 2019). Most of the SCB is closed to MSA-managed bottom trawling activities, and bottom trawling for state-managed species such as California halibut is relatively limited. The EFH review produced no literature describing fishing impacts to CPS EFH. Scant information on CPS fishing gear impacts to EFH exists, and any impacts are likely to be no more than minimal and temporary in nature.

FMPs must minimize to the extent practicable adverse effects from fishing on EFH, including EFH designated under other Federal FMPs. In addition to identifying potential measures to restrict fishing gears and methods, NMFS' regulatory guidance on EFH also suggests time/area closures as possible habitat protection measures. These measures could include but would not be limited to closing areas to all fishing effort or specific equipment types during spawning, migration, foraging, and nursery activities; and designating zones for use as marine protected areas to limit adverse effects of fishing practices on certain vulnerable or rare areas/species/life history stages. There are many examples of area-based closures designed to minimize fishing impacts to habitats and ecosystem services. These include numerous state marine reserves, Federal bottom trawl closures, and several closures to all bottom contact fishing. Most of the SCB is covered by the 17,000 square mile SCB EFH Conservation Area (EFHCA), and numerous other EFHCAs are present in the West Coast EEZ, described in Federal Pacific Coast Groundfish regulations (Figure 3.1 and Figure 3.2).

Based on the limited circumstances in which fishing activities would potentially adversely affect CPS EFH and recognizing that numerous area-based restrictions are already in place, no additional fishery management measures are necessary to adequately protect and conserve CPS EFH.

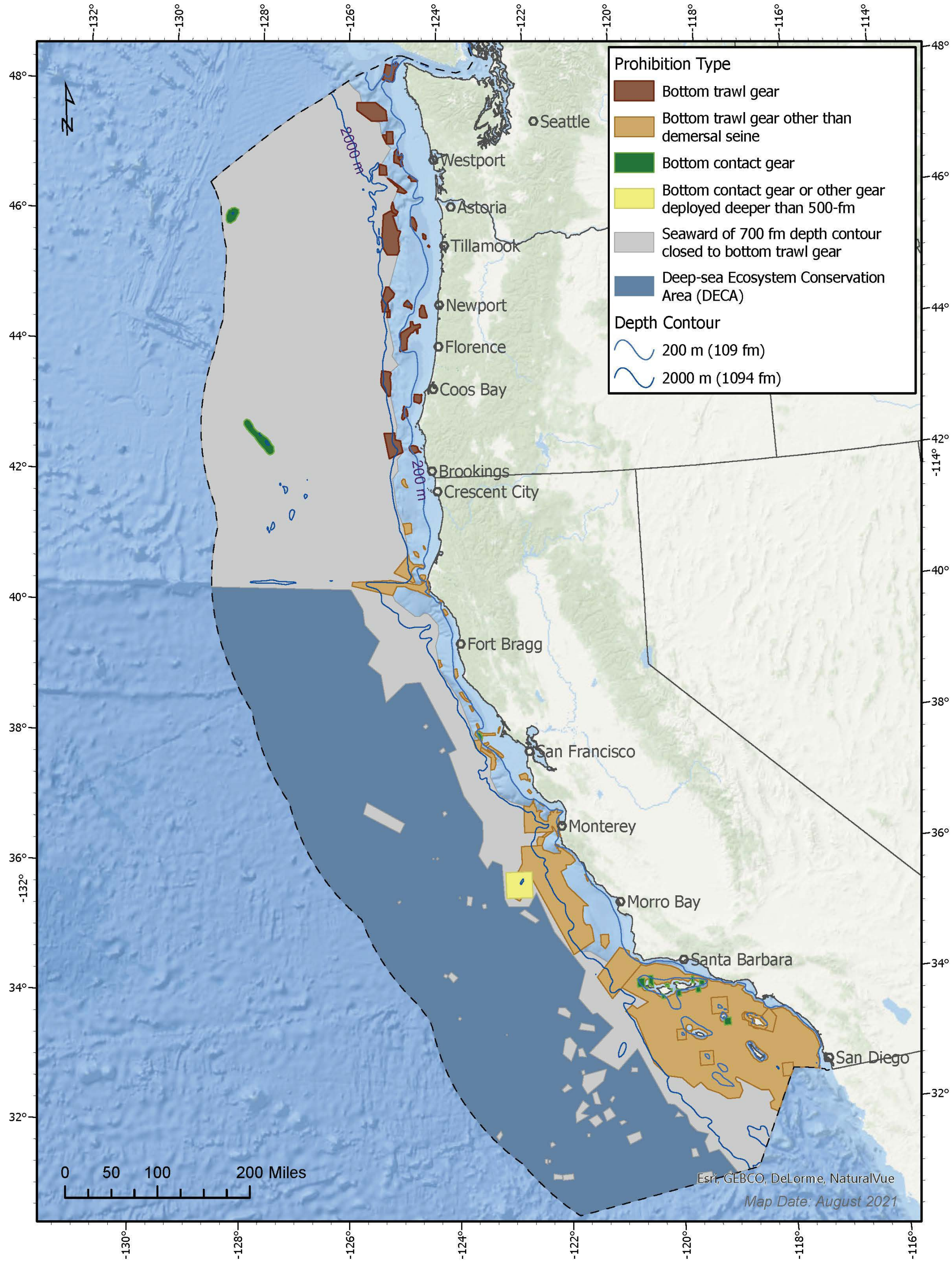


Figure 3.1. Bottom trawl and bottom contact closures in the U.S. West Coast EEZ described in Pacific Coast Groundfish regulations as of 2023 (50 CFR Part 660 Subpart C).

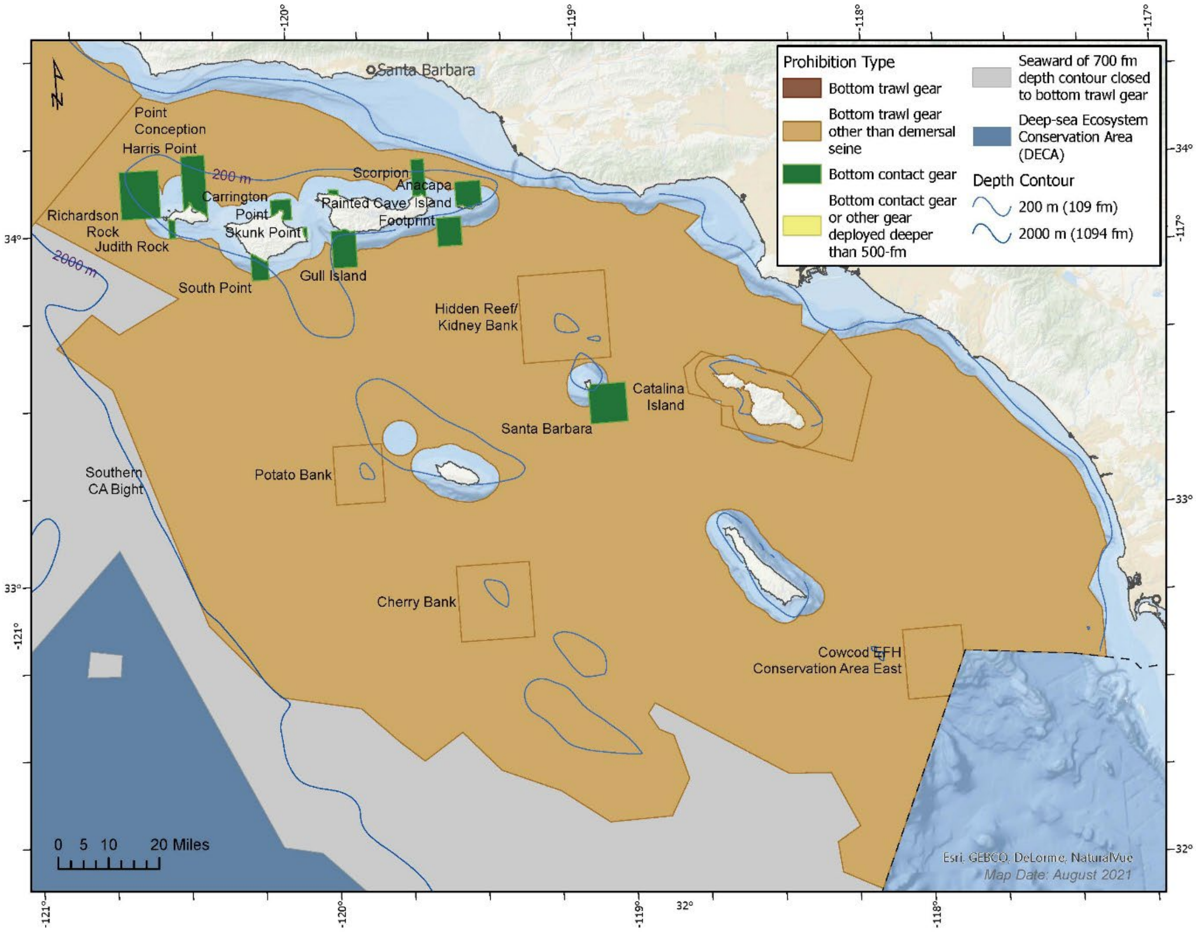


Figure 3.2. Bottom trawl and bottom contact closures in the SCB described in Pacific Coast Groundfish regulations as of 2023 (50 CFR Part 660 Subpart C).

4 NON-FISHING ACTIVITIES THAT MAY ADVERSELY AFFECT EFH

FMPs are required to identify non-fishing activities that may adversely affect EFH and to provide conservation recommendations to avoid, minimize, or compensate for adverse effects. The description of non-fishing activities and conservation measures are used primarily as a reference in non-fishing activity consultations by NMFS biologists, for federally permitted activities that may adversely affect EFH. Consulting biologists use the document(s) to develop conservation recommendations, which are then conveyed to the action agency. It is important to note that while the descriptions of non-fishing impacts and associated conservation recommendations are designed to assist in the consultation process, consulting biologists are not bound by those specific activities or conservation recommendations. Other literature, subject matter expertise, and professional judgment are used in EFH consultations. The EFH regulations provide further details on conducting EFH consultations.

The CPS FMP currently describes several non-fishing activities and provides conservation recommendations. A recent NMFS White Paper (Kiffney et al. 2022) identifies a wide range of non-fishing activities, several of which would potentially adversely affect CPS EFH. Table 4.1 below lists both sets of non-fishing activities, which are proposed for incorporation into the CPS FMP.

Table 4.1. Non-fishing activities proposed for inclusion in the CPS FMP.

Currently in CPS FMP	**Kiffney et al. 2022**
• Dredging and dredge material disposal/fill • Oil and gas exploration • Water intake • Aquaculture • Wastewater discharge • Discharge of oil/hazardous substances • Coastal development impacts	• Climate change • Upland and urban development • Road construction and operation • Stormwater and urban runoff • Silviculture • Dam operations and removal • Mineral mining • Oil extraction, shipping, and production • Energy-related activities (wave/tidal, OSW, cables & pipelines, LNG) • Agriculture and grazing • Shoreline and bank stabilization • Marine and freshwater transportation • Coastal development • Dredging • Aquaculture • Overwater structures • Water intake and discharge facilities • Pile driving and removal • Noise pollution

5 REFERENCES

Abraham C.L., and Sydeman W.J. 2006. Prey-switching by Cassin's auklet ptychoramphus aleuticus reveals seasonal climate-related cycles of *Euphausia pacifica* and *Thysanoessa spinifera*. Mar Ecol Prog Ser, 313:271-283.

Aceves-Medina G., Jiménez-Rosenberg S.P.A., Saldierna-Martínez R.J., Durazo, R., Hernandez-Rivas, M., Gonzalez-Rodriguez, E., and Gaxiola-Castro, G. 2018. Distribution and abundance of the ichthyoplankton assemblages and its relationships with the geostrophic flow along the southern region of the California current. Latin American Journal of Aquatic Research, 46(1):104-119. doi: http://dx.doi.org/10.3856/vol46-issue1-fulltext-12.

Adame, K., Elorriaga-Verplancken, F.R., Beier, E., Acevedo-Whitehouse, K., and Pardo, A.M. 2020. The demographic decline of a sea lion population followed multi-decadal sea surface warming. Scientific Reports, 10:10499. doi.org/10.1038/s41598-020-67534-0

Adams, P. 2001. Salmon. In: H. A. Karl, et al. (eds.), Beyond the Golden Gate: oceanography, geology, biology, and environmental issues in the Gulf of the Farallones (full-length technical version), p. 146-149. U.S. Geological Survey Circular 1198.

Adams J.N., Brodeur R.D., Daly E.A., and Miller T.W. 2017. Prey availability and feeding ecology of juvenile chinook (*Oncorhynchus tshawytscha*) and coho (O. kisutch) salmon in the northern California current ecosystem, based on stomach content and stable isotope analyses. *Mar Biol.*, 164(5):1-14. doi: http://dx.doi.org/10.1007/s00227-017-3095-z.

Adams J., Takekawa J.Y., and Carter H.R. 2004. Stable foraging areas and variable chick diet in Cassin’s auklets (ptychoramphus aleuticus) off southern California. Can J Zool., 82(10):1578-1595.

Ahlstrom, E.H. 1966. Co-occurrences of sardine and anchovy larvae in the California Current region off California and Baja California. California Cooperative Oceanic Fisheries Investigative Reports 11:117–135.

Ahlstrom, E.H. 1960. Synopsis on the biology of the Pacific sardine (*Sardinops caerulea*). Proc. World Sci. Meet. Biol. sardines and Related Species. FAA, Rome, 2: 415-451.

Ahlstrom, E.H. 1959. Vertical distribution of pelagic eggs and larvae off California and Baja California. Fishery Bulletin 161 from Fishery Bulletin of the Fish and Wildlife Service, vol 60.

Ainley, D. G., L.B. Spear, C.T. Tynan, J. A. Barth, S.D. Pierce, R. G. Ford, and T.J. Cowles. 2005. Physical and biological variables affecting seabird distributions during the upwelling season of the northern California Current. Deep-sea Research II 52: 123-143.

Allen, M.J., Wolotira, R.J., Jr., Sample, T.M., Noel, S.F., and Iten. C.R. 1990. West coast of North America coastal and oceanic zones strategic assessment. Data atlas. Invertebrates and fish. N.O.A.A. Seattle, WA

Allen S.E., Vindeirinho C., Thomson R.E., Foreman M., and Mackas D.L. 2001. Physical and biological processes over a submarine canyon during an upwelling event. Can J Fish Aquat Sci /J Can Sci Halieut Aquat. 58(4):671-684.

Anaya-Godínez E., Funes-Rodríguez R., Hinojosa-Medina A., González-Acosta, A.F., Ortiz-Galindo, J.L., González-Rodriguez, E., and Landaeta, M.F. 2017. Identification of suitable areas for the larval development of the Pacific mackerel (*Scomber japonicus*) in the southern portion of the California current. Revista de Biologia Marina y Oceanografia, 52(1):143-157.

Anderson, D.W., Gress, F., and Mais, K.F. 1982. Brown pelicans: influence of food supply on reproduction. OIKOS 39: 23-31.

Anderson, D.W., Gress, F., Mais, K.F., and Kelly, P.R. 1980. Brown pelicans as anchovy stock indicators and their relationships to commercial fishing. CalCOFI Reports, XXI: 54-61.

Andruszkiewicz, E.A., Sassoubre, L.M., and Boehm, A.B. 2017. Persistence of marine fish environmental DNA and the influence of sunlight. PLOS ONE. doi.org/10.1371/journal.pone.0185043

Armstrong W.A., and Smith S.E. 1997. Plankton sampling during the whale habitat and prey study 10 July-4 August 1996. NOAA-TM-NMFS-SWFSC-242.

Asch R.G. 2013. Interannual-to-decadal changes in phytoplankton phenology, fish spawning habitat, and larval fish phenology. [Order No. 3596005]. University of California, San Diego.

Asch R.G., and Checkley, D.M., Jr. 2013. Dynamic height: A key variable for identifying the spawning habitat of small pelagic fishes. *Deep Sea Research (Part I, Oceanographic Research Papers)*. 71:79-91. doi: http://dx.doi.org/10.1016/j.dsr.2012.08.006.

Auth, T.D., and Brodeur, R.D. 2020. Predictability of species distributions deteriorates under novel environmental conditions in the California current system. *Frontiers in Marine Science*. 2020. doi: http://dx.doi.org/10.3389/fmars.2020.00589

Auth, T. D, Daly E.A., Brodeur R.D., and Fisher J.L. 2018. Phenological and distributional shifts in ichthyoplankton associated with recent warming in the northeast Pacific ocean. *Global Change Biol.* , 24(1):259-272. doi: http://dx.doi.org/10.1111/gcb.13872.

Balcerak E. El Niño related to changes in sardine spawning. *EOS Trans Am Geophys Union*. 2012;93(17):176. doi: http://dx.doi.org/10.1029/2012EO170008

Baldwin R.E., Rew M.B., Johansson M.L.., Banks MA., and Jacobson K.C. 2011. Population structure of three species of anisakis nematodes recovered from Pacific sardines (*Sardinops sagax*) distributed throughout the California current system. *J Parasitol*., 97(4):545-554. doi: http://dx.doi.org/10.1645/GE-2690.1.

Baumgartner, T., A. Soutar, and V. Ferreira-Bartrina (1992), Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California, *Calif. Coop. Oceanic Fisher. Invest. Rep.*, *33*, 24–40.

Bargu, S., C.L. Powell, S.L. Coale, M. Busman, G.J. Doucette, and M.W. Silver. 2002. krill: a potential vector for domoic acid in marine food webs. Marine Ecology Progress Series, 237: 209-216.

Barham, E.G., 1956. The ecology of sonic scattering layers in the Monterey Bay Area, California. PhD Thesis Stanford Univ.

Barlow, D.R., Bernard, K.S., Escobar-Flores, P., Palacios, D.M., and Torres, L.G. 2020. Links in the trophic chain: modeling functional relationships between in situ oceanography, krill, and blue whale distribution under different oceanographic regimes. Mar. Ecol. Prog. Ser., 642: 207-225.

Barnes, J., MacCall, A.D., Jacobson, L.D., and Wolf, P. 1992. Recent population trends and abundance estimated for the Pacific sardine (Sardinops sagax) CalCOFI Rept., 33: 60-75.

Bentley, P.J., Emmett, R.L. Lo, N.C.H., and Moser, H.G. 1994. Egg production of Pacific sardine (*Sardinops sagax*) off Oregon in 1994. Calif. Coop. Oceanic. Fish. Invest. Rep. 37: 193-200.

Boden, B.P., Johnson, M.W., and Brinton, E. 1955. The Euphausiacea (Crustacea) of the North Pacific. Bull. Scripps Inst. Oceanogr. 6(8): 287-400

Bograd S.J., Kang S., Di Lorenzo E., Horii T., Katugin O.N.., King J.R., Lobanov V.B., Makino M., Na G., Perry R.I., Qiao F., Rykaczewski R.R., Saito H., Therriault T.W., Yoo S. and Batchelder H. 2019. Developing a social–ecological–environmental system framework to address climate change impacts in the North Pacific. Front. Mar. Sci., 6: 333. doi: 10.3389/fmars.2019.00333

Bollens, S. M., Frost, B. W., and Lin, T.S. 1992. Recruitment, growth, and diel vertical migration of *Euphausia pacifica* in a temperate fjord. Mar.Biol. 114, 219-228.

Betstelmeyer, B.T., Ellison A.M., Fraser W.R., Gorman K.B., Holbrook, S.J., Laney C.M., Ohman M.D. Peters, D.P.C, Pillsbury F.C., Rassweiler A., Schmitt R.J., and Sharma S. 2011. Analysis of abrupt transitions in ecological systems. Ecosphere, 2(12), article 129.

Brinton, E. 1981. Euphausiid distributions in the California Current during the warm winter–spring of 1977–1978, in context of a 1949–1966 time series. California Cooperative Oceanic Fisheries Investigations Reports 22, 135–154.

Brinton, E. 1973. Distributional atlas of Euphausiacea (Crustacea) in the California Current region, Part II. California Cooperative Oceanic Fisheries Investigations Reports, Atlas 18, 1–336.

Brinton, E. 1967. Distributional atlas of Euphausiacea (Crustacea) in the California Current region, Part I. California Cooperative Oceanic Fisheries Investigations Reports, Atlas 5, 1–275.

Brinton, E. 1962a. Variable factors affecting the apparent range and estimated concentration of euphausiids in the North Pacific. Pacific Sci.16, 374-408.

Brinton, E. 1962b. The distribution of Pacific euphausiids. *Bulletin of the Scripps Institution of Oceanography, University of California, San Diego,* 8:51-270.

Brinton, E., Ohman, M.D., Knight, M.D., and Bridgeman, A.L.. 2000. Euphausiids of the World Ocean., World Biodiversity Database CD-ROM Series, Windows version 1.0, Expert Center for Taxonomic Identification, Amsterdam, and UNESCO, Paris.

Brinton E., and Townsend A. 2003. Decadal variability in abundances of the dominant euphausiid species in southern sectors of the California current. Deep Sea Research (Part II, Topical Studies in Oceanography), 50(14- 16):2449-2472.

Brinton E., and Wyllie J.G. 1976. Distributional atlas of euphausiid growth stages off southern California, 1953 through 1956. CCOFI, La Jolla, CA (USA).

Brewer, G.D. 1976. Thermal tolerance and resistance of the northern anchovy *Engraulis mordax*. Fish. Bull. U.S. 74: 433-445.

Briscoe D.K., Fossette S., Scales K.L., Hazen, E.L., Bograd, S., Maxwell, S. M, Mchuron, E.A., Robinson, P.W., Kuhn, C., Costa, D.P., Crowder, L.B., and Lewison, R. 2018. Characterizing habitat suitability for a central-place forager in a dynamic marine environment. Ecology and Evolution. 2018;8(5):2788-2801. doi: http://dx.doi.org/10.1002/ece3.3827.

Brodeur R.D., Hunsicker M.E., Hann A., and Miller T.W. 2019. Effects of warming ocean conditions on feeding ecology of small pelagic fishes in a coastal upwelling ecosystem: A shift to gelatinous food sources. *Mar Ecol Prog Ser.*, 617/618:149.

Brodeur R.D., Barcelo C., Robinson K.L., Daly E.A.., and Ruzicka J.J. 2014. Spatial overlap between forage fishes and the large medusa Chrysaora fuscescens in the northern California current region. *Mar Ecol Prog Ser.*, 510:167-181. doi: http://dx.doi.org/10.3354/meps10810.

Calambokidis, J., G. H. Steiger, B. L. Troutman, and C. E. Bowlby. 2004. Distribution and abundance of humpback whales (*Megaptera novaeangliae*). Fishery Bulletin 102:563- 580.

Cannon, R. 1967. How to fish the Pacific Coast. 3rd edition. Lane Books, Menlo Park, CA. 160 p.

Capitolo P.J., McChesney G.J., Carter H.R., Parker M.W., Eigner L.E., and Golightly R.T. 2014. Changes in breeding population size of Brandt's cormorants *Phalacrocorax penicillatus* in the Gulf of the Farallones, California, 1979-2006. *Mar Ornithol.*, 42(1):35-48.

Catanese, G., Manchado, M., Infante, and C. 2010. Evolutionary relatedness of mackerels of the genus Scomber based on complete mitochondrial genomes: Strong support to the recognition of Atlantic *Scomber colias* and Pacific *Scomber japonicus* as distinct species. Gene 452: 35-43.

Carle R. 2014. Seasonal and sex-specific diet in rhinoceros auklets. Master thesis, San Jose State University. pp. 59.

Carle RD, Beck J.N.., Calleri D.M., and Hester M.M. 2015. Temporal and sex-specific variability in rhinoceros auklet diet in the central California current system. *J Mar Syst.*, 146:99-doi: http://dx.doi.org/10.1016/j.jmarsys.2014.08.020.

CDFW. (California Department of Fish and Wildlife). 2021. market squid, *Doryteuthis* (*Loligo*) *opalescens*, Enhanced Status Report. https://marinespecies.wildlife.ca.gov/market-squid/

Chamberlain, D.W. 1975. The role of fish cannery waste in the ecosystem, p. 1-22. *In*: D. Soule and M. Oguri (eds.). Marine Studies of San Pedro Bay. Part VIII. Allan Hancock Foundation and California Sea Grant Program, University of Southern California.

Chasco B., Hunsicker M., Jacobson K., Welch O., Morgan C., Muhling B., and Harding J. 2020. Evidence of temperature driven-shifts in market squid (*Doryteuthis opalescens*) densities and distribution in the California Current Ecosystem. Marine and Coastal Fisheries. DOI: 10.1002/mcf2.10190

Cheng, S.H., Gold M., Nicolas R., and Barber P.H. 2020. Genome-wide SNPs reveal complex fine scale population structure in the California market squid fishery (*Doryteuthis opalescens*). *Conserv. Genet*., 22(1): 97-110. https://doi.org/10.1007/s10592-020-01321-2

Chess, J., S.E. Smith and P.C. Fischer. 1988. Trophic relationships of the shortbelly rockfish *Sebastes jordani* off central California. CalCOFI Rep. Vol XXIX, p. 129-136.

Cimino, M.A., Santora, J.A., Schroeder, I., Sydeman, W., Jacox, M.G., Hazen, E.L., and Bograd, S.J. 2020. Essential krill species habitat resolved by seasonal upwelling and ocean circulation models within the large marine ecosystem of the California Current System. *Ecography* 43, 1536–1549.

Clark, F. N. and Janssen, J.F. 1945. Movements and abundance of the sardine as measured by tag returns.
Calif. Fish. Game Bull. 61:1–42.

Clark, F.N., and Phillips, J.B. 1952. The northern anchovy (*Engraulis mordax mordax*) in the California fishery. California Fish and Game Bulletin 38:189–207.

Clemmens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Fish. Res. Board Can., Bull. 68. 443 p.

Collette, B. B., and Nauen, C.E. 1983. Scombrids of the world. FAO Fish. Synop. 125. 137 p.

Cotero-Altamirano C., Valles-Rios H., Venegas B. Reproductive biology of Pacific sardine *Sardinops sagax* in western coast of baja California, mexico. *Ciencia pesquera*. 2015;23(1):25-43. https://search.proquest.com/docview/1855077021?accountid=28257.

Cooper H.L., Potts D.C., and Paytan A. 2016. Metabolic responses of the north pacific krill, *Euphausia pacifica*, to short- and long-term pCO2 exposure. Mar Biol.,163(10):1-13.

Checkley, D.M. Jr, and Lindegren, M. 2014. Sea surface temperature variability at the Scripps Institution of Oceanography Pier. American Meteorological Society., 44:2877-2892. doi: 10.1175/JPO-D-13-0237.1

Croll, D.A., Tershy, B., Hewitt, R., Demer, D., Fiedler, P., Smith, S., Armstrong, W., Popp, J., Kieckhefer, T., Lopez, V., Urban, J., and Grendon D. 1998. An integrated approach to the foraging ecology of marine birds and mammals. Deep-Sea Research II:1353-1371.

Dale KE, Daly E.A., Brodeur R.D. 2017. Interannual variability in the feeding and condition of subyearling chinook salmon off Oregon and washington in relation to fluctuating ocean conditions. *Fish Oceanogr*., 26(1):1-16. doi: http://dx.doi.org/10.1111/fog.12180.

Daly EA, Brodeur R.D., Auth T.D. 2017. Anomalous ocean conditions in 2015: Impacts on spring chinook salmon and their prey field. *Mar Ecol Prog Ser*., 566:169-182. doi: http://dx.doi.org/10.3354/meps12021.

Decima M. 2011. Mesozooplankton trophic variability in a changing ocean. Dissertation thesis. University California San Diego. 220pp.

Decima M, Ohman M.D., De Robertis A. 2010. Body size dependence of euphausiid spatial patchiness. Limnol Oceanogr. 55(2):777-788.

Del Río-Zaragoza, O.B., Hernández-Rodríguez M, Vivanco-Aranda M, Zavala-Hamz V. 2018. Blood parameters and parasitic load in *Sardinops sagax* (jenyns, 1842) from todos santos bay, baja California, mexico. *Latin American Journal of Aquatic Research*. ,46(5):1110-1115. doi: http://dx.doi.org/10.3856/vol46-issue5-fulltext-23

Demer D.A., Zwolinski J.P., Byers K.A., Cutter, G.R, Renfree, J.S., Sessions, T.S., and Macewicz, B.J. 2012. Prediction and confirmation of seasonal migration of Pacific sardine (*Sardinops sagax*) in the California current ecosystem. *Fish Bull*. 110(1):52-70.

De Robertis A. 2002. Small-scale spatial distribution of the euphausiid *Euphausia pacifica* and overlap with planktivorous fishes. J Plankton Res., 24(11):1207.

Dorman J.G. 2011. The influence of seasonal and decadal trends in coastal ocean processes on the population biology of the krill species *Euphausia pacifica*: Results of a coupled ecosystem and individual based modeling study. [3498805th]. University of California, Berkeley.

Dorman, J.G., Bollens, S.M., and Slaughter, A.M., 2005. Population biology of euphausiids off northern California and effects of short time-scale wind events on *Euphausia pacifica*. Marine Ecology Progress Series 288, 183–198.

Dorman, J.G., Sydeman, W.J., García-Reyes, M., Zeno, R.A., and Santora, J.A. 2015. Modeling krill aggregations in the central-northern California Current. Marine Ecology Progress Series 528, 87–99.

Dorval E, Macewicz B.J., Griffith D.A., Lo, N.C.H, and Gu Y. 2014. Spawning biomass of Pacific sardine (Sardinops sagax) estimated from the daily egg production method off California in 2013. NOAA-TM-NMFS-SWFSC-535

Dorval E, Macewicz, B.J., Griffith, D.A., Lo, N.C.H, and Gu, Y. 2016. Spawning biomass of Pacific sardine (Sardinops sagax) estimated from the daily egg production method off California in 2015. NOAA-TM-NMFS-SWFSC-560.

Dorval E, Macewicz B.J., Griffith, D.A., and Gu, Y. 2018. Spawning biomass of the central stock of northern anchovy (*Engraulis mordax*) estimated from the Daily Egg Production Method off California in 2017. NOAA-TM-NMFS-SWFSC-607.

Dorval E, Crone, P.R., and McDaniel, J.D. 2013. Variability of egg escapement, fishing mortality and spawning population in the market squid fishery in the California current ecosystem. Mar Freshwat Res., 64(1):80-90. doi: http://dx.doi.org/10.1071/MF12085

Dorval E, McDaniel J.D., Macewicz B.J., and Porzio, D.L. 2015. Changes in growth and maturation parameters of Pacific sardine *Sardinops sagax* collected off California during a period of stock recovery from 1994 to 2010. *J Fish Biol*. 87(2):286-310. https://search.proquest.com/docview/1701952355?accountid=28257. doi: http://dx.doi.org/10.1111/jfb.12718

Dorval E., Piner K., Robertson, L., Reiss, C.S., and Javor, B., and Vetter R. 2011. Temperature record in the oxygen stable isotopes of Pacific sardine otoliths: Experimental vs. wild stocks from the southern California bight. *J Exp Mar Biol Ecol*. 397(2):136-143. doi: http://dx.doi.org/10.1016/j.jembe.2010.11.024.

Diaz-Viloria N., Sanchez-Velasco, L., and Perez-Enriquez, R. 2012. Recent population expansion in the evolutionary history of the Californian anchovy *Engraulis mordax*. Hidrobiologica (Iztapalapa), 22(3):258-266.

Dickerson, T.L., Macewicz, B.J., and Hunter, J.R. 1992. Spawning frequency and batch fecundity of Chub mackerel Scomber japonicus, during 1985. CalCOFI Reports, 33: 130-140.

Duffy, L.M., Olson, R.J., Lennert-Cody, C.E., Galvan-Magana, F. Bocanegra-Castillo, N., and Kuhnert, P.M. 2015. Foraging ecology of silky sharks, *Carcharhinus falciformis*, captured by the tuna purse-seine fishery in the eastern Pacific Ocean. Mar. Biol. 162:571-593.

Drazen J.C., Bailey D.M., Ruhl H.A., and Smith, K. L., Jr. 2012. The role of carrion supply in the abundance of deep-water fish off California. PLOS One. 7(11). doi: dx.doi.org/10.1371/journal.pone.0049332.

Elliott M.L., Schmidt A.E., Acosta S., Bradley, R., Warzybok, P., Sakuma, K.M., Field, J., and Jahncke, J. 2016. Brandt's cormorant diet (1994-2012) indicates the importance of fall ocean conditions for northern anchovy in central California. *Fish Oceanogr*., 25(5):515-528. doi: http://dx.doi.org/10.1111/fog.12169.

Elliott M.L., Bradley R.W., and Robinette D.P., Jahncke J. 2015. Changes in forage fish community indicated by the diet of the brandt's cormorant (*Phalacrocorax penicillatus*) in the central California current. *J Mar Syst*.,146:50-58.

Emmett, R.L., and Krutzikowsky, G.K., 2008. Nocturnal Feeding of Pacific Hake and Jack mackerel off the Mouth of the Columbia River, 1998-2004: Implications for Juvenile Salmon Predation. Transactions of the American Fisheries Society 137, 657–676. http://dx.doi.org/10.1577/T06-058.1

Emmett, R.L., Brodeur, R.D., Miller, T.W, Pool, S.S., Krutzikowsky, G.K., Bentley, P.L., McCrae, J. 2005. Pacific sardine (Sardinops sagax) abundance, distribution, and ecological relationships in the Pacific Northwest. CalCOFI. Rep., 46:122-143.

Enciso-Enciso, C., and Nevarez-Martinez, M.O. Sanchez-Cardenas, R., Marin-Enriquez, E., Salcido-Guevara, L.A., and Minte-vera, C. Fishes: 7:236. https://doi.org/10.3390/fishes7050226

Endo, Y., Hanamura, Y., and Taniguchi, A. 1985. In situ observations on surface swarming Euphausia pacifica in Sendai Bay in early spring with special reference to their biological characteristics. La Mer 23, 135-140.

Ermakov Y., and Badaev O.Z. 2012. California jack mackerel (stavrida *trachurus symmetricus*) -- perspective species at high fisheries. *Voprosy rybolovstva*., 13(2):263-277.

Evans, R., English, P.A., Anderson, S.C., Gauthier, S., and Robinson, C.L.K. 2021. Factors affecting the seasonal distribution and biomass of *E. pacifica* and *T. spinifera* along the Pacific coast of Canada: A spatiotemporal modelling approach. PLoS ONE 16(5): e0249818. https://doi.org/10.1371/journal.pone.0249818

Félix-Uraga, R., C. Quiñónez-Velázquez, K. T. Hill, V. M. Gómez-Muñoz, F. N. Melo-Barrera, and W. García-Franco. 2005. Pacific sardine (*Sardinops sagax*) stock discrimination off the west coast of Baja California and southern California using otolith morphometry. Calif. Coop. Oceanic Fish. Invest. Rep. 46: 113–121.

Félix-Uraga, R., Gomez-Munoz, Garcia-Franco, W., Quinonez-Velazquez, C., and Melo-Barrera, FN. 2004. On the existence of Pacific sardine groups off the west coast of Baja California and Southern California. CalCOFI Rep., 45: 146-151.

Feinberg, L.R., Peterson, W.T., and Shaw, C.T. 2010. The timing and location of spawning for the Euphausiid *Thysanoessa spinifera* off the Oregon coast, USA. Deep-Sea Research II, 57:572-583.

Fitch, J. E. 1969. Offshore fishes of California. 4th revision. Calif. Dep. Fish and Game, Sacramento, CA. 79 p.

Fitch, J. E., and Lavenberg, R.J. 1971. Marine food and game fishes of California. Univ. Calif. Press, Berkeley, CA. 179 p.

Fiechter, J., Santora, J.A., Chavez, F., Northcott, D., and Messié, M., 2020. krill hotspot formation and phenology in the California Current Ecosystem. Geophysical research letters 47, e2020GL088039.

Fielder P.C., Methot, R.D., and Hewitt. R. P. 1986. Effects of California El Niño 1982-1984 on the northern anchovy. J. Mar. Res. 44, 317-338.

Fiedler P.C., Reilly S.B., Hewitt R.P., Demer, D., Philbrick, V.A., Smith, S., Armstrong, W., Croll, D.A., Tershy, B.R, and Mate, B.R. 1998. Blue whale habitat and prey in the California channel islands. Deep-Sea Research (Part II, Topical Studies in Oceanography). 45(8-9):1781-1801.

Fields, W. G. .1965. The structure, development, food relations, reproduction, and life history of the squid *Loligo opalescens* Berry. *Fishery Bulletin*, *131*, 6–108.

Fisher, J.L., Menkel, J., Copeman, L., Shaw, C.T., Feinberg, L.R., Peterson, W.T. 2020. Comparison of condition metrics and lipid content between *Euphausia pacifica* and *Thysanoessa spinifera* in the northern California Current, USA. Progress in Oceanography 188, 102417.

Fissel B.E., Lo N., Herrick S.J. 2011. Daily egg production, spawning biomass and recruitment for the central subpopulation of northern anchovy 1981-2009. *CalCOFI Rep*orts, 52:116-135.

Fissel B.E. 2011. Modeling and estimation of financial and bioeconomic settings in a dynamic environment. [Order No. 3445253]. University of California, San Diego.

Fleming, A.H., Clark, C.T., Calambokidis, J.,Barlow, J. 2016. Humpback whale diets respond to variance in ocean climate and ecosystem conditions in the California Current. Global Change Biology 22, 1214–1224, doi: 10.1111/gcb.13171

FOC. 2001. Fish stocks of the Pacific coast. Fisheries and Oceans Canada. Printed in Canada. Cat. no. Fs23-397/2001E.

FOCS. 2012. Pacific sardine 2011 seasonal biomass and migration in British Columbia and harvest advice for 2012. Fisheries and Ocean Canada Science. Canadian Science Advisory Secretariat Report 2012/026.

Funes-Rodriguez R., Cervantes-Duarte, R., Lopez-Lopez, S., Hinojosa-Medina, A., Zarate-Villafranco, A., Esqueda-Escarcega ,G. 2012. Abundance patterns of early stages of the Pacific sardine (*Sardinops sagax*) during a cooling period in a coastal lagoon south of the California current. *Sci Mar (Barc)*, 76(2):247-257.

Freire K.M.F., Belhabib, D., Espedido J.C., Hood, L., Kleisner, K.M., Lam, V.W.L., Machado M.L., Mendonça, J.T., Meeuwig, J.J., Moro P.S., Motta F.S., Palomares, M-L.D.., Smith N,Teh L., Zeller, D., Zylich, K. and Pauly, D. 2020. Estimating global catches of marine recreational fisheries. Front. Mar. Sci. 7:12. doi: 10.3389/fmars.2020.00012

Frey, H.W. (Ed.). 1971. California's living marine resources and their utilization. Calif. Dept. Fish and Game. 148 p.

Garcia-Morales, R., Shirasago-German B., Felix-Uraga, R., Perez-Lezama, E. 2012. Conceptual models of Pacific sardine distribution in the California current system. *Current Development in Oceanography*, 5(1):23.

Garcia-Rodriguez, F., Garcia-Gasca S., Cruz-Agueero, J., Cota-Gomez, V. 2011. A study of the population structure of the Pacific sardine *Sardinops sagax* (jenyns, 1842) in Mexico based on morphometric and genetic analyses. *Fish Res*. 107(1-3):169-176. doi: http://dx.doi.org/10.1016/j.fishres.2010.11.002.

Gibble, C.M. 2011. Food habits of harbor seals (Phoca vitulina richardii) in San Francisco bay, California. [Order No. 1500623]. San Jose State University.

Gladics, A.J., Suryan, R.M., Brodeur R.D., Segui, L.M., and Filliger L.Z. 2014. Constancy and change in marine predator diets across a shift in oceanographic conditions in the northern California current. Mar Biol., 161(4):837-851. doi: http://dx.doi.org/10.1007/s00227-013-2384-4

Glaser, S.M. 2011. Do albacore exert top-down pressure on northern anchovy? estimating anchovy mortality as a result of predation by juvenile north Pacific albacore in the California current system. *Fish Oceanogr*., 20(3):242-257.

Gluyas-Millán, M.G., and Quiñonez-Velázquez. C. 1997. Age, growth, and reproduction of Pacific mackerel, *Scomber japonicus* in the Gulf of California. Bulletin of Marine Science, 61(3):837-847.

Grantham H.S., Game E.T., Lombard A.T., Hobday A.J., Richardson A.J., Beckley, L.E., Pressey, R.L., Hugget, J.A., Coatzee, J.C., van der Lingen, C.D., Petersen, S., Merkel, D., and Possingham, H.P. 2011. Accommodating dynamic oceanographic processes and pelagic biodiversity in marine conservation planning. PLoS ONE 6(2): e16552. doi:10.1371/journal.pone.0016552

Guo, C. Ito, S., Wegner, N.C., Frank, L., Dorval, E., Dickson, K.A., and Klinger, D.H. 2020. Metabolic measurements and parameter estimations for bioenergetics modelling of Pacific Chub mackerel *Scomber Japonicus.* Fisheries Oceanography. DOI: 10.1111/fog.12465

Guo C., Ito S., Yoneda M., Kitano H., Kaneko H., Enomoto M., Aono T.,Nakamura M., Kitagawa T., Wegner N.C. and Dorval E. 2021. Fish specialize their metabolic performance to maximize bioenergetic efficiency in their local environment: Conspecific comparison between two stocks of Pacific Chub mackerel *(Scomber japonicus).* Front. Mar. Sci. 8:613965. doi: 10.3389/fmars.2021.613965

Guo L, Chai F, Xiu P, Xue, H., Rao, S., Liu, Y., and Chavez, F.P. 2014. Seasonal dynamics of physical and biological processes in the central California current system: A modeling study. Ocean Dynamics, 64(8):1137-1152. doi: http://dx.doi.org/10.1007/s10236-014-0721-x.

Grant W.S., Lecomte F., and Bowen B.W. 2010. Biogeographical contingency and the evolution of tropical anchovies (genus Cetengraulis) from temperate anchovies (genus Engraulis). *J Biogeogr*. ,37(7):1352-1362. doi: http://dx.doi.org/10.1111/j.1365-2699.2010.02291.x.

Gomez Gutierrez J. 2004. Comparative study of the population dynamics, secondary productivity, and reproductive ecology of the euphausiids *Euphausia pacific*a and *Thysanoessa spinifera* in the Oregon upwelling region. Dissertation thesis. 2004:1-596.

Gomez-Gutierrez J. 2002. Hatching mechanism and delayed hatching of the eggs of three broadcast spawning euphausiid species under laboratory conditions. J Plankton Res., 24(12):1265-1276.

Gómez-Gutiérrez J., Feinberg L.R., Shaw T.C., and Peterson W.T. 2007. Interannual and geographical variability of the brood size of the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera* along the Oregon coast (1999-2004). Deep - Sea Research, 54(12):2145.

Gomez-Gutierrez J., Gonz lez-Chavez G., Robinson C.J., and Arenas-Fuentes, V. 1999. Latitudinal changes of euphausiid assemblages related to the morphological variability of the sound scattering layer along Baja California, October 1994. Sci Mar (Barc). 63(1):79-91.

Gomez-Gutierrez J., Peterson W.T., and Miller C.B. 2010. Embryo biometry of three broadcast spawning euphausiid species applied to identify cross-shelf and seasonal spawning patterns along the Oregon coast. J Plankton Res., 32(6):739-760.

Gomez-Gutierrez J, Peterson W.T., and Morado J.F. 2006. Discovery of a ciliate parasitoid of euphausiids off Oregon, USA: *Collinia oregonensis n. sp.* (apostomatida: Colliniidae). Dis Aquat Org., 71(1):33-49.

Gómez-Gutiérrez J., Peterson W.T., De Robertis A.., and Brodeur RD. Mass mortality of krill caused by parasitoid ciliates. Science. 301(5631):339.

Gendron, D., 1992. Population structure of daytime surface swarms of *Nyctiphanes simplex* (Crustacea: Euphausiacea) in the Gulf of California, Mexico. Marine Ecology Progress Series 87, 1–6.

Harada A.E., Lindgren E.A., Hermsmeier M.C., Rogowski P.A., Terrill E., and Burton R.S. 2015. Monitoring spawning activity in a southern California marine protected area using molecular identification of fish eggs. *PLOS One*. 10(8).

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180. 740 p.

Hanlon, R.T., Kangas, N., Forsythe, J.W., 2004. Egg capsule deposition and how behavioral interactions influence spawning rate in the squid *Loligo opalescens* in Monterey Bay, California. Mar. Biol. 145, 923–930.

Hanamura, Y., Endo, Y., and Tanaguchi, A. 1984. Underwater observations on the surface swarm of an euphausiid, *Euphausia pacifica* in Sendai Bay, northeastern Japan. La Mer 22(2), 63-68.

Haugen, C.W., Messersmith, J.D., and Wickwire, R.H. 1969. Progress report on anchovy tagging off California and Baja California, March 1966 through May 1969. California Department of Fish and Game. Fish Bull. 147: 75-89.

Hedgecock, D., E. S. Hutchinson, G. Li, F. L. Sly, and K. Nelson. 1989. Genetic and morphometric variation in the Pacific sardine, *Sardinops sagax caerulea*: comparisons and contrasts with historical data and with variability in the northern anchovy, *Engraulis mordax.* Fish. Bull. 87: 653-671.

Hewitt R.P. 1985. The 1984 spawning biomass of the northern anchovy. Calif. Coop. Oeanic. Invest. Rep., 26:17-25.

Howard, D. 2001. krill. In: H. A. Karl, et al. (eds.), Beyond the Golden Gate: oceanography, geology, biology, and environmental issues in the Gulf of the Farallones, p. 133-140. U.S. Geological Survey Circular 1198.

Hunter, J.R., and Goldberg, S.R. 1980. Spawning incidence and batch fecundity in northern anchovy, *Engraulis mordax*. Fishery Bulletin 77:641–652.

Hunter, R.J., and Kimbrell, C.A. 1980. Early life history of Pacific mackerel, *Scomber japonicus*. Fish. Bull., 78: 89-101.

Hunter, J.R., and Leong, R. 1981. The spawning energetics of female northern anchovy, *Engraulis mordax*. Fishery Bulletin 79:215–230.

Hunter, J.R., and B.J. Macewicz. 1985. Measurement of spawning frequency in multiple spawning fishes. In An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*. Ed. by R. Lasker. NOAA Technical Report NMFS 36:67–77.

Hunter, J.R. and Macewicz, B.J. 1980. Sexual maturity, batch fecundity, spawning frequency, and temporal pattern of spawning for the northern anchovy, *Engraulis mordax*, during the 1979 spawning season. California Cooperative Oceanic Fisheries Investigative Reports 21:139–149.

Hurley A.C. 1978. School structure of the squid *Loligo opalescens*.Fish Bull 76:433–442

Infante, C., Blanco, E., Zuasti, E., Crespo, A., and Manchado, M. 2007. Phylogenetic differenciation between Atlantic Scomber colias and Pacific Scomber Japonicus based on nuclear DNA sequences. Genetica, 130:1-8.

Jacobson, L. D., N. C. H. Lo, and M. Yaremko. 1997. Status of the northern anchovy (*Engraulismordax*) stock (central subpopulation) during the 1996-1997 season. NMFS, SWFSC, Admin. Rep. DR. JACOBSON-97-08.

Jarre-Teichmann A. 1996. Small pelagics. Fisheries Centre research repor*ts. Vancouver BC FISH. CE*NT. RES. REP. 4 (1).

Javor B, Lo N, and Vetter R. 2011. Otolith morphometrics and population structure of Pacific sardine (*Sardinops sagax*) along the west coast of north america. *Fish Bull*., 109(4):402-415.

Javor B.J. 2013. Do shifts in otolith morphology of young Pacific sardine (*Sardinops sagax*) reflect changing recruitment contributions from northern and southern stocks? *CalCOFI Rep*., 54:85-96.

Jefferts, K. 1983. Squid distribution, biology, and life history. p. 3-10. In Proceedings of the West Coast Squid Symposium. Newport, Oregon. Oregon State Univ. Sea Grant Rep.

Jacobson K., Baldwin, R., Banks, M., and Emmett, R. 2019. Use of parasites to clarify residency and migration patterns of Pacific sardine (*Sardinops sagax*) in the California current. *Fish Bull*. 2019;117(3):72. doi: http://dx.doi.org/10.7755/FB.117.3.7.

Johnson C.J.., Emmett, R.L., and McFarlane, G. 2007. Jack mackerel (Trachurus symmetricus) abundance, distribution, diet, and associated relationships to oceanographic conditions in the northern California current. North Pacific Marine Science Organization (PICES), P.O. Box 6000 Sidney B.C. V8L 4B2 Canada; 2007:1-190.

Jones W.A. 2016. The Santa Barbara basin fish assemblage in the last two millennia inferred from otoliths in sediment cores. [Order No. 10044147]. University of California, San Diego.

Ju S., Harvey H.R., Gomez-Gutierrez J., Peterson W.T. 2006. The role of lipids during embryonic development of the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera*. Limnol Oceanogr. 51(5):2398-2408.

Kaltenberg AM, Emmett, R.L., and Benoit-Bird, K. 2010. Timing of forage fish seasonal appearance in the columbia river plume and link to ocean conditions. *Mar Ecol Prog Ser*., 419:171-184. doi: http://dx.doi.org/10.3354/meps08848.

Kaplan I.C., Francis T.B., Punt A.E., Koehn, L.E., Curchitser, E., Hurtado-Ferro, F., Johson, K.F., Lluch-Cota, S.E., Syderman, W.J., Essington, T.E., Taylor, N., Holsman, K., and MacCall, A.D., and Levin, P.S. 2019. A multi-model approach to understanding the role of Pacific sardine in the California current food web. *Mar Ecol Prog Ser*., 617/618:307. doi: http://dx.doi.org/10.3354/meps12504.

Kaplan I.C., Brown C.J.., Fulton E.A., Gray I.A., Field J.C., and Smith A.D.M. 2013. Impacts of depleting forage species in the California current. Environ Conserv., 40(4):380-393. http://dx.doi.org/10.1017/S0376892913000052.

Karpov, K. A., and Cailliet, G. M. (1979). Prey composition of the market squid, *Loligo opalescens* Berry, in relation to depth and location of capture, size of squid, and sex of spawning squid. *CalCOFI Reports*, *20*, 51–57.

Kieckhefer, T. 1992. Feeding ecology of humpback whales in continental shelf waters near Cordell Bank, California. MSc. Thesis, Moss Landing Marine Laboratories, San Jose State Univ., San Jose, CA, 86 p.

King J.R., Agostini, V.N., and Harvey, C.J. 2011. Climate forcing and the California current ecosystem. *ICES J Mar Sci*., 68(6):1199-1216. 68(6), 1199–1216. doi:10.1093/icesjms/fsr009

Koehn L.E., Essington T.E., Marshall K.N., Kaplan, I., Syderman, W.J., Szoboszlai, A.I., and Tayer, J.A. 2016. Developing a high taxonomic resolution food web model to assess the functional role of forage fish in the California current ecosystem. *Ecol Model*., 335:87-100.

Konchina Y., Glubokov A.I., and Arkhipov AG. 2011. On Pacific jack mackerel *Trachurus symmetricus murphyi* distribution in the notal zone of the SEPO in 2009-2011. Rybnoe Khozyajstvo (Moscow). 2011(6):57-60.

Koslow J.A., and Allen C. 2011. The influence of the ocean environment on the abundance of market squid, Doryteuthis (loligo) opalescens, paralarvae in the southern California bight. CalCOFI Rep., 52:205-213.

Koslow JA, Goericke, R., and Watson, W. 2013. Fish assemblages in the southern California current: Relationships with climate, 1951-2008. *Fish Oceanogr.*, 22(3):207-219. doi: http://dx.doi.org/10.1111/fog.12018.

Kuriyama, P.T., Zwolinski, J.P., Teo, S.T.L., and Hill, K.T. 2022. Assessment of Northern anchovy (*Engraulis mordax*) Central Subpopulation in 2021 for U.S. management. NOAA-TM-NMFS-SWFSC-665

Kuriyama, P.T., Zwolinski, J.P., Hill, K.T., and Crone, P.R. 2020. Assessment of the Pacific sardine resource in 2020 for U.S. management in 2020-2021, U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-628.

Lance M.M., Chang W, Jeffries S.J., Pearson SF, and Acevedo-Gutierrez A. 2012. Harbor seal diet in northern puget sound: Implications for the recovery of depressed fish stocks. *Mar Ecol Prog Ser.* , 464:257-271. doi: http://dx.doi.org/10.3354/meps09880

Lara-Lopez A., Davison P., and Koslow J.A. 2012. Abundance and community composition of micronekton across a front off southern California. *J Plankton Res*. 34(9): 828-848. doi: http://dx.doi.org/10.1093/plankt/fbs016.

Lewis O.H., and Lema S.C.. 2019. Sequence and phylogenetic analysis of the mitochondrial genome for the northern anchovy (engraulidae: Clupeiformes). Mitochondrial DNA.Part B, Resources, 4(1): 14-16. doi: http://dx.doi.org/10.1080/23802359.2018.1535846.

Lewison, R.L., and Deutschman, D.H. 2014. Long-term analysis of California least tern data. Department of Biology, Instituted for Ecological Monitoring and Management (IEMM), San Diego State University. Final Report to the State of California Department of Fish and Wildlife, South Coast Region, 3883 Ruffing Road, San Diego CA 921123. 49 pp.

Litz M.N.C., Miller J.A., Brodeur R.D., Daly, E.A., Weitkamp, L.A., Hansen, A.G., and Clairbone, A.M. 2019. Energy dynamics of subyearling chinook salmon reveal the importance of piscivory to short-term growth during early marine residence. *Fish Oceanogr*. 28(3):273-290. doi: http://dx.doi.org/10.1111/fog.12407

Lavaniegos, B.E., and Ambriz-Arreola, I., 2012. Interannual variability in krill off Baja California in the period 1997–2005. Progress in Oceanography 97–100, 164–173. https://doi.org/10.1016/j.pocean.2011.11.008

Lilly L.E., Cornuelle, B.D., and Ohman M.D. Using a Lagrangian particle tracking model to evaluate impacts of El Niño-related advection on euphausiids in the southern California Current System. Deep-Sea Research Part I, 187:1033835. doi: doi.org/10.1016/j.dsr.2022.103835

Lilly L.E., and Ohman M.D. 2021. Euphausiid spatial displacements and habitat shifts in the southern California Current System in response to El Niño variability. Progress in Oceanography. 193: 102544. doi: 10.1016/j.pocean.2021.102544

Lindsey, B.J., and Batchelder, H.P., 2011. Cross-shelf distribution of *Euphausia pacifica* in the Oregon coastal upwelling zone: field evaluation of a differential transport hypothesis. Journal of plankton research 33, 1666–1678.

Litz M.N.C., Miller J.A., Copeman L.A., Miller, J.A., Copenan, L.A., Teel, D.J., Weitkamp, L.A., Daly, E.A., and Clairbone, A.M. 2017. Ontogenetic shifts in the diets of juvenile chinook salmon: New insight from stable isotopes and fatty acids. *Environ Biol Fishes*., 100(4):337-360. doi: http://dx.doi.org/10.1007/s10641-016-0542-5

Litz M.N.C, Brodeur R.D., Emmett R.L., Heppell, S.S., Rasmusen, R.S., O'Higgins, L., Morris, M.S. 2010. Effects of variable oceanographic conditions on forage fish lipid content and fatty acid composition in the northern California current. *Mar Ecol Prog Ser*. 405:71-85.

Litz, M.N.C., Heppell, S.S., Emmett, R.T.L. and Brodeur, R.D. 2008. Ecology and distribution of the northern subpopulation of northern anchovy (*Engraulis mordax*) off the U.S. west coast. California Cooperative Oceanic Fisheries Investigative Reports 49:167–182.

Lo, N. C. H, Macewicz, B.J., and Griffith, D. A. 2013. Spawning biomass of Pacific sardine(*Sardinops sagax*) off U.S. in 2012. U.S. Dep. Commer., NOAA Tech. Memo. NMFSSWFSC-505, 43 p.

Lo, N.C., Macewicz B.J., and Griffith DA. 2011. Migration of Pacific sardine (*Sardinops sagax*) off the west coast of united states in 2003-2005. *Bull Mar Sci*. 87(3):395-412. doi: http://dx.doi.org/10.5343/bms.2010.1077

Lo, N.C.H., Dorval, E., Funes-Rodriquez, R. Hernandez-Rivas, M.E., Huang, Y., and Fan, Z. 2010. Utilities of larval densities of Pacific mackerel (*Scomber japonicus*) off California, USA and west coast of Mexico from 1951 to 2008, as spawning biomass indicres. Ciencia Pesquera, 18(2): 59-75.

Lo, N.C.H., Y.A. Green-Ruiz, M Jacob-Cervantes, H.G. Moser, and R. J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) in 1994, determined by the daily egg production method. Calif. Coop. Oceanic. Fish. Invest. Rep. 37: 160-174.

Lo, N. C. H., B. J. Macewicz, and D. A. Griffith. 2009. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2009. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-449. 31 pp.

Lluch-Belda D., Lluch-Cota, D.B., Hernandez-Vazquez, S., Salinas-Zavala, C., and Schwartzlose, R.A. 1991. Sardine and anchovy spawning as related to temperature and upwelling in the California Current System. Calif. Coop. Oceanic. Fish. Invest. Rep. 32: 105-111.

Lluch-Belda, D., Crawford, R. J. M., Kawasaki, T., MacCall, A.D., Parrish, R.H., Schwartzlose, R.A., and Smith, P.E. 1989. World-wide fluctuations of sardine and anchovy stocks: The regime problem. S. Afr. J. Mar. Sci. 8: 195-205.

MacCall, A. D., and Stauffer, G. D.. 1983. Biology and fishery potential of jack mackerel (*Trachurus symmetricus*) CalCOFI Rep. 24: 46-56.

MacCall A.D., Sydeman, W.J., Davison P.C., and Thayer, J.A. 2016. Recent collapse of northern anchovy biomass off California. *Fish Res*., 175:87-94. doi: dx.doi.org/10.1016/j.fishres.2015.11.013

MacFarlane R.B. 2010. Energy dynamics and growth of chinook salmon (Oncorhynchus tshawytscha) from the central valley of California during the estuarine phase and first ocean year. *Can J Fish Aquat Sci*., 67(10):1549-1565. doi: http://dx.doi.org/10.1139/F10-080.

Macewicz, B.J., Hunter, J.R., Lo, N.C.H., and La Casella, E.L. (2004). Fecundity, egg deposition, and mortality of market squid (*Loligo opalescens*). Fishery Bulletin 102: 306–327.

Macewicz, B.J., and Hunter, J.R. 1993. Spawning frequency and batch fecundity of Jack mackerel, Trachurus symmetricus, off California during 1991. CalCOFI Rep. 34: 112-121.

McFarlane, G. A., and R. J. Beamish. 2001. The reoccurrence of sardines off British Columbia characterize the dynamic nature of regimes. Progr. Oceanogr. 49: 151–165.

McFarlane, G., Schweigert, J., Hodes, V., and Detering, J. Preliminary study on the use of polished otoliths in the age determination of Pacific sardine (Sardinops sagax) in British Columbia waters. CalCOFI Rep., 51: 162-168.

McFarlane, G.A., MacDougall, L., Schweigert, J., and Hrabok, C. 2005. Distribution and biology of Pacific sardine (*Sardinops sagax*) off Brittish Columbia, Canada. CalCOFI Rep., 46: 144-160.

Mais, K.F. 1974. Pelagic fish surveys in the California Current. Calif. Dept. Fish. and Game Fish. Bull. 162: 79p.

Mallicoate, D.L., and Parrish, R.H. 1981. Seasonal growth patterns of California stocks of northern anchovy, *Engraulis mordax*, Pacific mackerel, *Scomber japonicus*, and jack mackerel, *Trachurus symmetricus*. California Cooperative Oceanic Fisheries Investigative Reports 22:69–81.

Manugian S, Elliott M.L., Bradley R., Howar J., Karnovsky N., Saenz B., Studwell, A., Warzybok, P., Nur, N., and Jahncke, J. 2015. Spatial Distribution and Temporal Patterns of Cassin's Auklet Foraging and Their Euphausiid Prey in a Variable Ocean Environment. PLoS ONE 10(12): e0144232. doi:10.1371/journal.pone.0144232

Marinovic, B. B., Croll, D.A., Gong, N., Benson, S.R., and Chavez, F.P. 2002. Effects of the 1997-1999 El Niño and La Niña events on zooplankton abundance and euphausiid community composition within the Monterey Bay coastal upwelling system. Progress in Oceanography 54(1-4): 265-277.

Marinovic, B. and M. Mangel. 1999. krill can shrink as an ecological adaptation to temporarily unfavorable environments. Ecology Letters (1999) 2: 338-343.

Martin C.J.B, and Lowe C.G. 2010. Assemblage structure of fish at offshore petroleum platforms on the San Pedro shelf of southern California. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*. 2010:180-194. doi: https://doi.org/10.1577/C09-037.1

Massie G.N., Ware, M.W., and Villegas E.N., Black, M.W. 2010. Uptake and transmission of toxoplasma gondii oocysts by migratory, filter-feeding fish. *Vet Parasitol.*, 169(3-4):296-303. doi: http://dx.doi.org/10.1016/j.vetpar.2010.01.002.

Maxwell, M. R., Jacobson, L. D., and Conser, R. (2005). Eggs-per-recruit for management of the California market squid (*Loligo opalescens*). *CanadianJournal of Fisheries and Aquatic Sciences* **62**, 1640–1650. doi:10.1139/F05-037

MBC. 1987. Ecology of important fisheries species offshore California. Applied Environmental Sciences. OCS-Study, MMS 86-0093. 252 p.

McClatchie S., Gao J., Drenkard E.J., Thompson, A. Watson, W., Ciannelli, L., Bogard, S., and Thorson, J.T. 2018. Interannual and secular variability of larvae of mesopelagic and forage fishes in the southern California current system. *Journal of Geophysical Research.Oceans.*, 123(9):6277-6295. doi: http://dx.doi.org/10.1029/2018JC014011.

McClatchie S., Hendy I.L., Thompson A.R., and Watson W. 2017. Collapse and recovery of forage fish populations prior to commercial exploitation. *Geophys Res Lett.*, 44(4):1877-1885. http://dx.doi.org/10.1002/2016GL071751.

McClatchie, S., Field, J., Thompson A., Gerrodette T., Lowry, M., Fiedler, P.C., Watson, W., Nieto, K.M. and Vetter, R.D. 2016. Food limitation of sea lion pups and the decline of forage off central and southern California. Royal Society Open Science: 150628. http://dx.doi.org/10.1098/rsos.150628

McClatchie S., Cowen R., Nieto K., Greer, A., Luo, J.Y., Guigand, L.C., Demer, D., Griffith, D., and Rudnick, D. 2012. Resolution of fine biological structure including small narcomedusae across a front in the southern California bight. *Journal of Geophysical Research.Oceans.*,117(4). doi: http://dx.doi.org/10.1029/2011JC007565.

McDaniel J., Piner K., Lee H.H., and Hill K. 2016. Evidence that the Migration of the Northern Subpopulation of Pacific sardine (*Sardinops sagax*) off the West Coast of the United States Is Age-Based. PLoS ONE 2016, 11(11): e0166780. doi:10.1371/journal.pone.0166780

Methot, R.D. 1981. Growth rates and age distributions of larval and juvenile northern anchovy, Engraulis mordax, with inferences on larval survival. Ph.D. thesis, University of California, San Diego, CA.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. Am. Fish. Soc. Symp. Ser. 6: 66-82.

Moser, H. G., Charter, R. L., Smith, P. E., Ambrose, D. A., Charter, S. R., Meyer, C. A. E., Sandknop, M., and Watson, W. 1993. Distributional atlas of fish larvae and eggs in the California Current region: taxa with 1000 or more total larvae, 1951 through 1984. CalCOFI Atlas 31. 233 p.

Morley J.W., Selden R.L., Latour R.J., and Frölicher T.L., Seagraves R.J., Pinsky M.L. 2018. Projecting shifts in thermal habitat for 686 species on the north American continental shelf. *PLoS One*. 2018;13(5). https://doi.org/10.1371/journal.pone.0196127

Muhling B.A., Brodie S., Smith J.A., Tomassi, D., Gaitan, C.F., Hazen, E., Jacox, M.G., Auth, T.D., and Brodeur, R.D. 2020. Predictability of species distributions deteriorates under novel environmental conditions in the California current system. *Frontiers in Marine Science*. 2020. doi: http://dx.doi.org/10.3389/fmars.2020.00589.

Muhling, B.A., Brodie S, Smith J.A., Thommasi, D., Gaitan, C.F., Hazen, E.L., Jacox, M.G., Edwards, C.A., and Xu, Y. 2019. Dynamic habitat use of Albacore and their primary prey in the California current system. *California Cooperative Oceanic Fisheries Investigations, Reports*. 60:79-93.

Navarro M.O., Bockmon E.E., Frieder C.A., Gonzalez J..P, and Levin L.A. 2014. Environmental pH, O2 and capsular effects on the geochemical composition of statoliths of embryonic squid *Doryteuthis opalescens*. Water, 6(8):2233-2254. doi: http://dx.doi.org/10.3390/w6082233.

Navarro M.O., Kwan, G.T., Batalov, O., Choi C..Y, Pierce, N.T., and Levin, LA. 2016. Development of embryonic market squid, *Doryteuthis opalescens*, under chronic exposure to low environmental pH and [O2]. PLoS One.,11(12). doi: http://dx.doi.org/10.1371/journal.pone.0167461.

Navarro M.O., Parnell, P.E., and Levin, L.A. 2018. Essential market squid (*Doryteuthis opalescens*) embryo habitat: a baseline for anticipated climate change. Journal of Shellfish Research, 2018. 37(3): 601–614.

Nevárez-Martínez M.O., Arzola-Sotelo E., López-Martínez J., Santos-Molina J., Martínez-Zavala, and María De Los Ángeles. 2019. Modeling growth of the Pacific sardine *Sadinops Caeruleus* in the Gulf of California, Mexico, using the multimodel inference approach. *California Cooperative Oceanic Fisheries Investigations, Reports*, 60:1-13. https://search.proquest.com/docview/2339021115?accountid=28257.

Nebenzahl, D.A. 1997. Age, growth, and population structure of Jack mackerel (*Trachurus symmetricus*) from the northeastern Pacific ocean. Master's thesis, San Francisco State Univ., San Francisco, CA.

Nemoto, T. 1957. Foods of baleen whales in the northern Pacific. Sci. Rep. Whales Res. Inst. Tokyo, 12: 33-89.

Nieto K., McClatchie S., Weber E.D., and Lennert-Cody C. 2014. Effect of mesoscale eddies and streamers on sardine spawning habitat and recruitment success off southern and central California. *Journal of Geophysical Research.Oceans*., 119(9):6330-6339. doi: http://dx.doi.org/10.1002/2014JC010251.

Nishikawa H., Curchitser E.N., Fiechter J., Rose K.A., and Hedstrom K. 2019. Using a climate-to-fishery model to simulate the influence of the 1976–1977 regime shift on anchovy and sardine in the California current system. *Progress in Earth and Planetary Science*, 6(1):1-20. doi: http://dx.doi.org/10.1186/s40645-019-0257-2

Nickels, C.F., Sala, L.M., and Ohman, M.D., 2018. The morphology of euphausiid mandibles used to assess selective predation by blue whales in the southern sector of the California Current System. Journal of Crustacean Biology 38, 563–573. https://doi.org/10.1093/jcbiol/ruy062

Nickels, C.F., Sala, L.M., and Ohman, M.D. 2019. The euphausiid prey field for the blue whales around a steep bathymetric feature in the southern California current system. Limnol. Oceanogr., 64: 390-405.

Nickels, C., Portner, E.J., Snograss, O., Muhling, B., and Dewar, H. *In Review.* Juvenile Albacore Tuna (*Thunnus alalunga*) foraging ecology varies with environmental conditions in the California Current Large Marine Ecosystem.

Orr AJ, VanBlaricom, G.R., DeLong, R.L., Cruz-Escalona V., and Newsome, SD. 2011. Intraspecific comparison of diet of California sea lions (*Zalophus californianus*) assessed using fecal and stable isotope analyses. Can J Zool., 89(2):109.

Palance, D.G., Macewizc, B., Stierhoff, K., Demer, D.A., and Zwolinski, J.P. 2018. Juvenile Albacore Tuna (*Thunnus alalunga*) foraging ecology varies with environmental conditions in the California Current Large Marine Ecosystem. Journal of Fish Biology, doi: 10.1111/jfb.14105

Parés-Escobar, F., Lavaniegos, B.E., and Ambriz-Arreola, I., 2018. Interannual summer variability in oceanic euphausiid communities off the Baja California western coast during 1998–2008. Progress in Oceanography 160, 53–67. https://doi.org/10.1016/j.pocean.2017.11.009

Parrish, R.H, and MacCall, A.D. Climate variation and exploitation in the Pacific mackerel fishery. Cal. Dep. Fish. Game Bull. 167. 10p.

Parrish, R.H., D.L. Mallicoate, and K.F. Mais. 1985. Regional variations in the growth and age composition of northern anchovy, Engraulis mordax. Fish. Bull. 83: 483-496.

Picquelle S. J., and Hewitt, R.P. 1984. The 1983 spawning biomass of the Northern anchovy. Calif. Coop. Oeanic. Invest. Rep., 25:16-27.

Pearcy, W., Fisher, J., Brodeur, R., and Johnson, S. 1985. Effects of the 1983 El Niño on coastal neckton off Oregon and Washington. p. 188-204. In: El Niño North: Niño effects in the eastern subarctic Pacific Ocean. W.S. Wooster and D.L. Fluharty [ed.] Washington Sea Grant Program. Univ. of Washington, Seattle.

Pearcy, B., and Hosie, M. 1985. Mass stranding of krill off Bandon. Oregon Wildlife Vol. 40(5) Sept-Oct, p. 14.

Pellowe K.E., Leslie H.M. 2017. Seasonal variability shapes resilience of small-scale fisheries in Baja California Sur, Mexico. PLoS ONE 12(8): e0182200. https://doi.org/10.1371/journal.pone.0182200

Perretti C.T., and Sedarat M. 2016. The influence of the el nino southern oscillation on paralarval market squid (*Doryteuthis opalescens*). Fish Oceanogr. 2016;25(5):491-499. doi: http://dx.doi.org/10.1111/fog.12167.

Perretti, C.T., Zerofski, P.J., and Sedarat, M. 2015. The spawning dynamics of California market squid (*Doryteuthis opalescens*) as revealed by laboratory observations. J. Molluscan Stud. 82:37–42.

Peterson S.H., Ackerman J.T., Eagles-Smith C., Herzog M.P., and Hartman C.A. 2018. Prey fish returned to Forster's tern colonies suggest spatial and temporal differences in fish composition and availability. *PLoS One*., 13(3). doi: http://dx.doi.org/10.1371/journal.pone.0193430.

Piatt J.F., Parrish J.K., Renner H.M., Parrish, J.K., Renner, H.M., Schoen, S.K., Jones, T.T. Arimitsu, M.L., Kuletz, K.J., Bodenstein, B., Garcia-Reyes, M., Duerr, R.S., Corcoran, R.M., Kaler, R.S.A., McChesney, G.J., Golightly, R.T., Coletti, H.A., Suryan, R.M., Burgess, H.K., Lindsey, J., Lindquist, K., Warzybok, P.M., Jahncke, J., Roletto, J., Syderman, W.J. 2020. Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016. *PLoS One*. 2020;15(1). doi: http://dx.doi.org/10.1371/journal.pone.0226087.

PFMC. 2020. Status of the Pacific coast coastal pelagic fishery and recommended acceptable biological catches. Stock assessment and fishery evaluation in 2019, including data through June 2019. Pacific Fisheries Management Council. 7700, NE Ambassador Place, Suite 101, Portland OR 97220.

PFMC 2019. Coastal pelagic species fishery management plan, as amended through Amendment 17. Pacific Fisheries Management Council. 7700, NE Ambassador Place, Suite 101, Portland OR 97220.

PFMC. 1998. Appendix D: description and identification of essential fish habitat for the coastal pelagic species, pp. 46. In Amendment 8 to the Northern anchovy Fishery Management Plan, Incorporating a change of name to: The Coastal Pelagic Species Fishery Management Plan. Pacific Fisheries Management Council, 2130 SW Fifth Ave, Suite 224, Portland Oregon.

Phillips, E., Chu, D., Gauthier, S., Parker-Stetter, S.L., Shelton, A.O., and Thomas, R.E. 2022. Spatiotemporal variability of euphausiids in the California Current Ecosystem: insights from a recently developed time series. *ICES Journal of Marine Science*, 2022, 79, 1312–1326

Phillips E.M., Horne, J.K., and Zamon, J.E. 2017. Predator-prey interactions influenced by a dynamic river plume. *Can J Fish Aquat Sci*., 74(9):1375.

Pierce, N.T. 2017. Developmental transcriptomics of the California market squid, *Doryteuthis opalescens*. PhD dissertation. UC San Diego: Marine Biology. Available at: http://escholarship.org/uc/item/ 3z71g769.

Politikos D.V., Curchitser E.N., Rose K.A., Checkley, D.M.,Jr, and Fiechter J. 2018. Climate variability and sardine recruitment in the California current: A mechanistic analysis of an ecosystem model. *Fish Oceanogr*., 27(6):602-622. doi: http://dx.doi.org/10.1111/fog.12381.

Pondella, Daniel J., II, Robart MJ, Claisse JT, Williams, J., Williams, C.M., Zellimer, A.J., and Piacenza, S.E. 2018. Spatial and temporal fishing patterns at the outer banks of the southern California bight. West N Am Nat. 78(3):341-357. S

Ponomareva, L.A. 1966. Euphausiids of the North Pacific, their distribution and ecology. Translation from Russian (Idatel'stvo Akademii Nauk SSSR, Moskva, 1963) by Israeli Program for Scientific Translations, Jerusalem, 1966, 154 p.

Protasio, CQ, Holder A.M., and Brady B.C. 2014. Changes in biological characteristics of the California market squid (*Doryteuthis opalescens*) from the California commercial fishery from 2000-01 to 2012-13. Calif Fish Game, 100(2):276-288.

Prager, M.H., and A.D. MacCall. 1993. Detection of contaminant and climate effects on spawning success of three pelagic fish stocks off southern California: northern anchovy *Engraulis mordax*, Pacific sardine *Sardinops sagax*, and chub mackerel *Scomber japonicus*. Fish. Bull. U.S. 91: 310-327.

Preti, A. Stoh, S., Dinardo, G.T., Saavedra, C., MacKenzie, K, Noble, L., Jones, C.S., and Pierce, G.J. 2021. Feeding ecology of broadbill swordfish (*Xiphias gladius*) in the California Current. doi: https://doi.org/10.1101/2021.09.16.460689

Preti A, Soykan C.U., Dewar H., Wells, R.J.D., Spear, and N., Kohin, S. 2012. Comparative feeding ecology of shortfin mako, blue and thresher sharks in the California current. Environ Biol Fishes. 95(1): 127-146. http://dx.doi.org/10.1007/s10641-012- 9980-x.

Qiu Y. 2015. Iron fertilisation by asian dust influences north Pacific sardine regime shifts. *Prog Oceanogr*. 134:370-378. doi: http://dx.doi.org/10.1016/j.pocean.2015.03.011

Ralston, S., Dorval, E., Ryley, L., Sakuma K.M.; and Field, J.C. 2018. Predicting market squid (*Doryteuthis opalescens*) landings from pre-recruit abundance. Fisheries Research, 199: 12-18. https://doi.org/10.1016/j.fishres.2017.11.009

Ralston, S, Field, J.C., and Sakuma, K.M. 2015. Long time variation in a central California pelagic fish assemblage. J. Mar. Syst., 146: 26-37.

Rankin C. 2016. Colony dynamics of elegant terns (*Thalasseus elegans*) in the southern California bight in relation to prey availability, oceanographic conditions, and predator disturbance. [Order No. 10106055]. California State University, Fullerton.

Riemer S.D, Wright, B.E, and Brown, R.F. 2011. Food habits of steller sea lions (eumetopias jubatus) off Oregon and northern California, 1986-2007. *Fish Bull.*,109(4):369-381.

Rice C.A., Duda J.J., Greene C.M., and Karr J.R. 2012. Geographic patterns of fishes and jellyfish in puget sound surface waters. *Marine and Coastal Fisheries*, 4(1):117-128.

Reiss, C.S., Checkley D.M., and Bograd, S.J. 2008. Remotely sensed spawning habitat of Pacific sardine (*Sardinops sagax*) and Northern anchovy (*Engraulis mordax*) within the California Current. Fish Oceanography, 17(2): 126–136.

Reese, D.C., O'Malley R.T.D, Brodeur, R.D., and Churnside, J.H. 2011. Epipelagic fish distributions in relation to thermal fronts in a coastal upwelling system using high resolution remote sensing techniques. ICES J. Mar. Science, 68(9):1865-1874. doi:1093/icesjms/fsr107

Ressler, P. H., Brodeur, R. D., Peterson, W. T., Pierce, S. K., Vance, P. M., Rostad, A. R., and Barth, J. A. 2005. The spatial distribution of euphausiid aggregations in the northern California Current during August 2000. Deep Sea Research Part II: Topical Studies in Oceanography, 52(1-2):89-108.

Robinson, H., Thayer J., Sydeman, W.J, and Weise, M. 2018. Changes in California sea lion diet during a period of substantial climate variability. *Mar Biol.*, 165(10):1-12. http://dx.doi.org/10.1007/s00227-018-3424-x.

Robertson, R.R., and Bjorkstedt, E.P., 2020. Climate-driven variability in *Euphausia pacifica* size distributions off northern California. Progress in Oceanography 188, 102412.

Rockwood C.R., Elliott M.L., Saenz B., Nur N., and Jahncke J. 2020. Modeling predator and prey hotspots: Management implications of baleen whale co-occurrence with krill in central California. PLoS One, 15(7). doi: http://dx.doi.org/10.1371/journal.pone.0235603.

Rogers-Bennett, L., and Juhasz, C. I. 2014. The rise of invertebrate fisheries and the fishing down of marine food webs in California. Calif. Fish Game 100:218–233.

Roper, C.F.E and Sweeney, M.J. 1984. FAO Species Catalogue Vol.3 Cephalopods of the world. FAO Fisheries Synopsis 125:3. 277p.

Rubio-Rodriguez, U., Villalobos, H., and Nevárez-Martínez, M.O. 2018. Acoustic observations of the vertical distribution and latitudinal range of small pelagic fish schools in the Midriff Islands Region, Gulf of California, Mexico. Lat. Am. J. Aquat. Res., 46(5): 989-1000.

Saba, G.K., and Steinberg, D.K. 2012. Abundance, composition, and sinking rates of fish fecal pellets in the Santa Barbara channel. Scientific Reports (Nature Publisher Group), 2:716. doi: http://dx.doi.org/10.1038/srep00716.

Santora, J.A., Zeno, R., Dorman, J.G., and Sydeman, W.J., 2018. Submarine canyons represent an essential habitat network for krill hotspots in a Large Marine Ecosystem. Scientific Reports 8. https://doi.org/10.1038/s41598-018-25742-9

Santora J.A., Sydeman W.J., Messie M., Chai, F., Chao, Y., Thompson, S.A., Wells, B.K., and Chavez, F.P. 2013. Triple check: Observations verify structural realism of an ocean ecosystem model. Geophys Res Lett., (7):1367-1372. doi: http://dx.doi.org/10.1002/grl.50312

Santora, J. A., Sydeman, W.J., Schroeder, I.D., Reiss, C.S., Wells, B.K., Field, J.C., Cossio, A.M., and Loeb, V.J., 2012. krill space: a comparative assessment of mesoscale structuring in polar and temperate marine ecosystems. ICES Journal of Marine Science, 69:1317–1327. https://doi.org/10.1093/icesjms/fss048

Santora J.A., Ralston, S., and Sydeman, W.J. 2011. Spatial organization of krill and seabirds in the central California current. ICES J Mar Sci., 68(7):1391-1402. doi: http://dx.doi.org/10.1093/icesjms/fsr046.

Santora, J.A., Sydeman, W.J., Schroeder, I.D., Wells, B.K., and Field, J.C. 2011. Mesoscale structure and oceanographic determinants of krill hotspots in the California Current: Implications for trophic transfer and conservation. Progress in Oceanography 91, 397–409. https://doi.org/10.1016/j.pocean.2011.04.002

Schultz, L. P., Hart, J. L., and Gunderson, F. J..1932. New records of marine west coast fishes. Copeia 1932 (2):65–68.

Schwartzkopf, B.D., Dorval, E. James, K.C., Walker, J.M., Snodgrass, O.E., Porzio, D.L., and Erisman, B.E. A summary report of the central subpopulation of Northern anchovy (Engraulis mordax) for the 2021 stock assessment. NOAA-TM-NMFS-SWFSC-659. 78 pp.

Scofield, W.L. 1951. Purse seines and other roundhaul nets in California. Calif. Dept. of Fish and Game Fish Bulletin no. 81.

Shaw, C.T., Bi, H., Feinberg, L.R., and Peterson, W.T. 2021. Cohort analysis of *Euphausia pacifica* from the Northeast Pacific population using a Gaussian mixture model. Progress in Oceanography, 191: 102495.

Shaw, C.T., Peterson, W.T., and Feinberg, L.R. 2010. Growth of *Euphausia pacifica* in the upwelling zone off the Oregon coast. Deep Sea Research II, 57: 584-593.

Shaw, C.T., Feinberg, L.R., and Peterson, W.T. Interannual variations in vital rates of copepods and euphausiids during the RISE study 2004–2006. Journal of Geophysical Research, 114: C00B08. doi:10.1029/2008JC004826

Shaw W, and Robinson C. 1998. Night versus day abundance estimates of zooplankton at two coastal stations in British Columbia, Canada. Mar Ecol Prog Ser. 1998;175:143-153.

Shen S. 2016. The effects of ocean acidification on the development, behavior and survival of marine fish eggs and larvae inferred from laboratory and natural experiments. [Order No. 10241274]. University of California, San Diego.

Schoenherr, J.R. 1991. Blue whales feeding on high concentrations of euphausiids around Monterey Submarine Canyon. Can. J. Zool. 69: 583-594.

Schoenherr, J.R. 1988. Blue whales feeding on high concentrations of euphausiids around Monterey submarine canyon. Moss Landing Marine Laboratories, 8272 Moss Landing Road Moss Landing CA 95039 USA, URL: http://www.mlml.calstate.edu/library/library.htm]; 1988.

Siegel V. 2000. krill (Euphausiacea) demography and variability in abundance and distribution. Can J Fish Aquat Sci., 57:151-167.

Siegel, V., and Nicol, S. 2000. Population parameters, p. 103-149. In (Everson, I., ed.) krill Ecology, Biology and Fisheries. Fish and Aquatic Resource Series 6. Blackwell Science Ltd. 372 p.

Silva-Dávila, Palomares-Garcia, R., Martinez-Lopez, A., and Carballido-Carranza, M.A. 2002. Standing stock of Nyctiphanes simplex in the southern region of the California Current System. Journal of Plankton Research, 24(10): 1057-1066.

Simonis A.E. 2017. By the light of the moon: North Pacific dolphins optimize foraging with the lunar cycle. [10620176th]. University of California, San Diego.

Simard Y., Mackas DL. Mesoscale aggregations of euphausiid sound scattering layers on the continental shelf of Vancouver island. Can J Fish Aquat Sci. 1989;46(7):1238-1247.

Skrivanek, A. and Hendy, I.L. 2015. A 500 year climate catch: Pelagic fish scales and paleoproductivity in the Santa Barbara Basin from the Medieval Climate Anomaly to the Little Ice Age (AD 1000e1500). Quaternary International 387: 36-45. http://dx.doi.org/10.1016/j.quaint.2015.07.044

Smith SE, and Adams P.B. 1988. Daytime surface swarms of *Thysanoessa spinifera* (Euphausiacea) in the gulf of the Farallones, California. Bull Mar Sci., 42(1):76-84.

Smith, J.A., Muhling, B., Sweeney, J., Tommasi, D., Buil, M.P., Fiechter, J., Jacox, M.G. 2020. The potential impact of a shifting Pacific sardine distribution on U.S. west coast landings. Fisheries Oceanography*,* 00:1–18.

Smith, P.E. 1985. Year-class strength and survival of O-group clupeioids. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1): 69-82.

Song H, Miller A.J, McClatchie S, Weber, E.D, Nieto KM, and Checkley, D.M. 2012. Application of a data-assimilation model to variability of Pacific sardine spawning and survivor habitats with ENSO in the California current system. *Journal of Geophysical Research: Oceans*.,117: C03009. doi: http://dx.doi.org/10.1029/2011JC007302

Snodgrass et al., *In Preparation. Pacific mackerel ageing and reproductive biology. Appendix to the Pacific mackerel assessment for US Management in 2023.*

Soule, D.F., and M. Oguri. 1979. Ecological changes in the outer Los Angeles-Long Beach harbors following initiation of secondary treatment and cessation of fish cannery waste effluent. *In*: Marine studies of San Pedro Bay, California. Part 16. Allan Hancock Foundation and California Sea Grant Programs, Institute of Marine and Coastal Studies. University of Southern California: 597 p.

Soule, D.F., and Oguri, M. 1982. Evaluation of the outer Los Angeles Harbor benthos in 198 compared with conditions from 1971-78 investigations. Special report part B. Harbors Environmental Projects, University of Southern.

Soule, D.F., and Oguri, M. 1980. The marine environment in Los Angeles and Long Beach harbors during 1978. Marine studies of San Pedro Bay, California. Part 17. Allan Hancock Foundation, California Sea Grant Program, Institute of Marine and Coastal Studies, University of Southern California, and U.S. Army Corps of Engineers: 688 p. + appendix.

Soule, D.F., and Oguri, M. 1979. Ecological changes in the outer Los Angeles-Long Beach harbors following

Soule, D.F., and Oguri, M. 1976. Executive summary, p. iv. *In*: D. Soule and M. Oguri (eds.). Bioenhancement studies of the receiving waters in outer Los Angeles Harbor. Marine Studies of San Pedro Bay, California. Part 12. Allan Hancock Foundation and California Sea Grant Program, Institute of Marine and Coastal Studies, University of Southern California.

Soule, D.F., and Oguri, M. 1973. Introduction. In: D. Soule and M. Oguri (eds.). Biological investigations, p. 1-20. Marine Studies of San Pedro Bay, California. Part XVI. Allan Hancock Foundation and California Sea Grant Program, Institute of Marine and Coastal Studies, University of Southern California.

Soutar, A., and Isaacs, J. 1973. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment of the Californias. Fishery Bull. 72(2): 257-273.

Stierhoff, K.L., J.P. Zwolinski, and D.A. Demer. 2021. Distribution, biomass, and demography of coastal pelagic fishes in the California Current Ecosystem during summer 2016 based on acoustic-trawl sampling. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-649. 79 pp.

Stierhoff, K.L., J.P. Zwolinski, and D.A. Demer. 2020. Distribution, biomass, and demography of coastal pelagic fishes in the California Current Ecosystem during summer 2019 based on acoustic-trawl sampling. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-626. 87 pp.

Stierhoff, K.L., Zwolinski, J.P., and Demer, D.A. 2019. Distribution, biomass, demography of coastal pelagic fishes in the California Current Ecosystem during summer 2018 based on acoustic-trawl sampling. NOAA-TM-NMFS-SWFSC-613.

Sturdevant. M.V., and Orsi, J.A., Fergusson E.A. 2012. Diets and trophic linkages of epipelagic fish predators in coastal southeast Alaska during a period of warm and cold climate years, 1997–2011. *Marine and Coastal Fisheries*, 4(1):526-545.

Sydeman, W.J., Dedman, S., Garcia-Reyes, M., Thompson, S., Thayer, J.A., Bakun, A., and MacCall, A.D. 2020. Sixty-five years of northern anchovy population studies in the southern California Current: a review and suggestion for sensible management. ICES Journal of Marine Science 77:486–499.

Sydeman W.J., Santora J.A., Thompson S.A., Marinovic B., and Di Lorenzo E. 2013. Increasing variance in north Pacific climate relates to unprecedented ecosystem variability off California. Global Change Biol., 19(6):1662-1675. doi: http://dx.doi.org/10.1111/gcb.12165.

Sydeman W.J., Thompson S.A., Santora J.A., Koslow J.A., Goericke R., and Ohman M.D. 2015. Climate-ecosystem change off southern California: Time-dependent seabird predator-prey numerical responses. *Deep Sea Research (Part II, Topical Studies in Oceanography)*, 112:158-170. doi: http://dx.doi.org/10.1016/j.dsr2.2014.03.008

Sydeman W.J., Hester M.M., Thayer J.A., Gress F., Martin P., and Buffa J. 2001. Climate change, reproductive performance and diet composition of marine birds in the southern California current system, 1969-1997. Prog Oceanogr. 49(1- 4):309-329.

Takahashi, M., Watanabe, Y., Yatsu, A., and Nishida, H. 2009. Contrasting responses in larval and juvenile growth to a climate–ocean regime shift between anchovy and sardine. Can. J. Fish. Aquat. Sci. 66: 972–982.

Takahashi, M. and Chekley. D.M. Growth and Survival of Pacific sardine (*Sardinops sagax*) in the California Current Region. 2008. J. Northw. Atl. Fish. Sci., Vol. 41: 129–136.

Tang, F., and Chen, W. 2021. The complete mitochondrial genome of *Sardinops sagax* (Jenyns, 1842) (Clupeiformes: Clupeidae) and phylogenetic analyses of sardines. 6(3): 1080–1081. https://doi.org/10.1080/23802359.2021.1899867

Tanasichuk R.W. 2002. Implications of interannual variability in euphausiid population biology for fish production along the south-west coast of Vancouver Island: A synthesis. Fish Oceanogr., 11(1):18-30.

Tanasichuk R.W. 2002. Implications of interannual variability in euphausiid population biology for fish production along the south-west coast of Vancouver Island: A synthesis. Fish Oceanogr., 11(1):18-30.

Tanasichuk R.W. 1998a. Interannual variations in the population biology and productivity of Thysanoessa spinifera in barkley sound, Canada, with special reference to the 1992 and 1993 warm ocean years. Marine Ecology Progress Series., 173:181-195.

Tanasichuk, R.W., 1998b. Interannual variations in the population biology and productivity of *Thysanoessa spinifera* in Barkley Sound, Canada, with special reference to the 1992 and 1993 warm ocean years. Marine Ecology Progress Series 173, 163–180.

Thayer, J.A., Field, J.C., and Sydeman, W.J. 2014. Changes in California chinook salmon diet over the past 50 years: Relevance to the recent population crash. *Mar Ecol Prog Ser*. 2014;498:249-261. doi: http://dx.doi.org/10.3354/meps10608.

Theilacker, G.H., Lo, N.C.H., and Townsend, A.W. 1993. An immunochemical approach to quantifying predation by euphausiids on the early stages of anchovy. Mar. Ecol. Prog. Ser. 92, 35–50.

Thompson A.R., Auth, T.D., Brodeur, R.D.., Bowlin, NM., and Watson, W. 2014. Dynamics of larval fish assemblages in the California current system: A comparative study between Oregon and southern Valifornia. *Mar Ecol Prog Ser*., 506:193-212. doi: http://dx.doi.org/10.3354/meps10801

Thompson, A.R., Schroeder, I.D., Bograd, S.J., Hazen, E.L., Jacox, M.G., Leising, A., Wells, B.K., Largier, J.L., Fisher, J.L., Jacobson, K., Zeman, S., Bjorkstedt, E.P., Robertson, R.R., Kahru, M., Goericke, R., Peabody, C.E., Baumgartner, T.R., Lavaniegos, B.E., Miranda, L.E., Gomez-Ocampo, E., Gomez-Valdes, J., Auth, T.D., Daly, E.A., Morgan, C.A., Burke, B.J., Field, J.C., Sakuma, K.M., Weber, E.D., Watson, W., Porquez, J.M., Dolliver, J., Lyons, D.E., Orben, R.A., Zamon, J.E., Warzybok, P., Jahncke, J., Santora, J.A., Thompson, S.A., Hoover, B., Sydeman, W., and Melin, S.R.. 2019. State of the California Current 2018–19: A novel anchovy regime and a new marine heat wave? California Cooperative Oceanic Fisheries Investigative Reports 60:1–65.

Turley, B.D., and Rykaczewski, R.R. 2019. Influence of wind events on larval fish mortality rates in the southern California Current Ecosystem. Can. J. Fish. Aquat. Sci., 76: 2418–2432. dx.doi.org/10.1139/cjfas-2018-0458

Turner, C.H., and Sexsmith, J.C. 1967. Marine baits of California. First revision. Calif. Dept. Fish Game, Sacramento, CA. 70 p.

Tynan, C.T., Ainley, D. G., Barth, J.A., and Cowles, T. J., Pierce, S.D., and Spear, L.B. 2005. Cetacean distributions relative to ocean processes in the northern California Current System. Deep-sea Research II 52: 145-167.

Valencia-Gasti, J., Baumgartner, T., and Durazo, R. 2015. Effects of ocean climate on life cycles and distribution of small pelagic fishes in the California current system off Baja California. Cienc Mar., 41(4):315-348.

Valencia-Gasti, J., Weber, E.D., Baumgartner T., Durazo, R., Mcclatchie, S., and Lennert-Cody, C. 2018. Spring spawning distribution of Pacific sardine in US and Mexican waters. *California Cooperative Oceanic Fisheries Investigations, Reports*. 79-85.

Van Noord J.E. 2020. Dynamic spawning patterns in the California market squid (*Doryteuthis opalescens*) inferred through paralarval observation in the southern California bight, 2012–2019. Mar Ecol., 41(4). doi: http://dx.doi.org/10.1111/maec.12598

Van Noord J.E., and Dorval, E. 2017. Oceanographic influences on the distribution and relative abundance of market squid paralarvae (*Doryteuthis opalescens*) off the Southern and Central California coast. Marine Ecology 38, e12433.

Velarde, E., Excurra, E., and Anderson, D.W. 2015. Seabird diet predicts following-season commercial catch of Gulf of California Pacific sardine and Northern anchovy. Journal of Marine Systems, 146: 82-88. http://dx.doi.org/10.1016/j.jmarsys.2014.08.014

Vergara-Solana, F., Garcia-Rodriguez, F., and De La Cruz-Aguero, J. 2013. Comparing body and otolith shape for stock discrimination of Pacific sardine, *Sardinops sagax* jenyns, 1842. *J Appl Ichthyol*.;29(6):1241-1246. doi: http://dx.doi.org/10.1111/jai.12300

Wainwright T.C., Emmett, R.L., Weitkamp, L.A., Hayes, S.A., Bentley P.J., and Hardin, J.A. 2019. Effect of a mammal excluder device on trawl catches of salmon and other pelagic animals. *Marine and Coastal Fisheries*. 2019;11(1):17-31. doi: http://dx.doi.org/10.1002/mcf2.10057.

Webb, L. 2013. Spatiotemporal Variability in the Diet of Nonbreeding Brandt's Cormorant (*Phalacrocorax penicillatus*) in the Monterey Bay region. Master's theses. 4405. DOI: https://doi.org/10.31979/etd.pgn5-rs4j

Webb L.A., Harvey J.T. 2015. Diet of a piscivorous seabird reveals spatiotemporal variation in abundance of forage fishes in the Monterey bay region. *J Mar Syst*.,146:59-71. doi: 10.1016/j.jmarsys.2014.08.011

Weber, E.D., Auth, T.D., Baumann-Pickering, S., Baumgartner, T.R., Bjorkstedt, E.P., Bograd, S.J., Burke, B.J., Cadena-Ramírez, J.L., Daly, E.A., de la Cruz, H. Dewar, J.C. Field, J.L. Fisher, A. Giddings, R. Goericke, E. Gomez-Ocampo, J. Gomez-Valdes, M., Hazen, E.L., Hildebrand, J., Horton, C.A., Jacobson, K.C, Jacox, M.G., Jahncke, J., Kahru, M., Kudela, R.M., Lavaniegos, B.E., Leising, A., Melin, S.R., Miranda-Bojorquez, L.E., Morgan, C.A., Nickels, C.F., Orben, R.A., Porquez, J.M., Portner, E.J., Robertson, R.R., Rudnick, D.L., Sakuma, K.M., Santora, J.A., Schroeder, I.D., Snodgrass, O.E., Sydeman, W.J., Thompson, A.R., Thompson, S.A., Trickey, J.S., Villegas-Mendoza, J., Warzybok, P., Watson, W., and Zeman, S.M. 2021. State of the California Current 2019–2020: Back to the future with Marine Heatwaves? Frontiers in Marine Science 8:709454.

Weber E.D., Chao, Y., and Chai, F., McClatchie, S. 2015. Transport patterns of Pacific sardine *Sardinops sagax* eggs and larvae in the California current system. *Deep Sea Research (Part I, Oceanographic Research Papers)*,100:127-139. https://search.proquest.com/docview/1732822399?accountid=28257. doi: http://dx.doi.org/10.1016/j.dsr.2015.02.012.

Weber E.D., and McClatchie, S. 2012. Effect of environmental conditions on the distribution of Pacific mackerel (*Scomber japonicus*) larvae in the California current system. Fish Bull., 110(1):85-97.

Weber, E.D., and McClatchie, S. Predictive models of northern anchovy Engraulis mordax and Pacific sardine *Sardinops sagax* spawning habitat in the California Current. Mar. Ecol. Prog. Ser., 406: 251–263, 2010 doi: 10.3354/meps08544

Wells, B.K., Santora, J.A., Field, J.C., MacFarlane, R.B., Marinovic, B.B., and Sydeman, W.J. 2012. Population dynamics of chinook salmon Oncorhynchus tshawytscha relative to prey availability in the central California coastal region. Mar Ecol Prog Ser., 457:125-137.

Wilson, S., Anderson, E.M., Wilson, A.S.G., Bertram D.F., and Arcese, P. 2013. Citizen science reveals an extensive shift in the winter distribution of migratory western grebes. *PLoS One*. 8(6). http://dx.doi.org/10.1371/journal.pone.0065408.

Wing, B.L., Murphy, J.M., and Rutecki, T.L. 2000. Occurrence of Pacific sardine, Sardinops sagax off southeastern Alaska. Fish. Bull., 98: 881-883.

Yatsu A., and Kawabata, A. 2017. Reconsidering trans-Pacific 'synchrony' in population fluctuations of sardines. *Bulletin of the Japanese Society of Fisheries Oceanography*, 81(4):271-283.

Young M.A., Kvitek R.G., Iampietro P.J., Garza C.D., Maillet R., and Hanlon R.T. 2011. Seafloor mapping and landscape ecology analyses used to monitor variations in spawning site preference and benthic egg mop abundance for the California market squid (*Doryteuthis opalescens*). J Exp Mar Biol Ecol., 407(2):226-233. doi: http://dx.doi.org/10.1016/j.jembe.2011.06.017.

Youngbluth, M.J. 1976. Vertical distribution and diel migration of euphausiids in the central region of the California Current. Fish. Bull. U.S. 74(4): 925-936.

Zamon J.E., Phillips, E.M., and Guy, T.J. Marine bird aggregations associated with the tidally-driven plume and plume fronts of the columbia river. *Deep Sea Research (Part II, Topical Studies in Oceanography)*. 2014; 107:85-95. doi: http://dx.doi.org/10.1016/j.dsr2.2013.03.031

Zeidberg, L.D., Butler, J.L., Ramon, D., Cossio, A., Stierhoff, K., and Henry, A. 2012. Estimation of spawning habitats of market squid (*Doryteuthis opalescens*) from field surveys of eggs off central and southern California. Mar. Ecol. (Berl.) 33:326–336.

Zeidberg, L. D., and Hammer, W.M. 2002. Distribution of squid paralarvae*, Loligo opalescen* (Cephalopoda: Myopsida) in the southern California Bight in the three years following the 1997-1998 EL Niño. Marine Biology, 141: 111-122.

Zeidberg, L. D., Hamner, W. M., Nezlin, N., and Henry, A. (2006). The fishery for California market squid (*Loligo opalescens*) (Cephalopoda: Myopsid), from 1981 through 2003. *Fishery Bulletin*, *104*, 46–59

Zeidberg, L. D., Isaac, G., Widmer, C. L., Neumeister, H., and Gilly, W. F. 2011. Egg capsule hatch rate and incubation duration of the California market squid, *Doryteuthis* (=*Loligo*) *opalescens*: Insights from laboratory manipulations. *Marine Ecology*, *32*, 468–479.

Zwolinski, J. P., Stierhof, K. L., and Demer, D. A. 2019. Distribution, biomass, and demography of coastal pelagic fishes in the California Current Ecosystem during summer 2017 based on acoustic-trawl sampling. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-610: 76 pp.

Zwolinski J.P., and Demer, D.A. 2014. Environmental and parental control of Pacific sardine (*Sardinops sagax*) recruitment. *ICES J Mar Sci*. 71(8):2198-2207. doi: dx.doi.org/10.1093/icesjms/fst173.

Zwolinski J.P., and Demer, D.A. 2012. A cold oceanographic regime with high exploitation rates in the northeast Pacific forecasts a collapse of the sardine stock. *Proc Natl Acad Sci USA*. https://doi.org/10.1073/pnas.1113806109

Zwolinski J.P., Demer D.A., Byers K.A, Cutter, G.R., Renfree, J.S., Sessions, T.S., and Macewicz, B.J. 2012. Distributions and abundances of Pacific sardine (*Sardinops sagax*) and other pelagic fishes in the California current ecosystem during spring 2006, 2008, and 2010, estimated from acoustic-trawl surveys. *Fish Bull*., 110(1):110-122.

Zwolinski, J.P., Emmett, R.L., and Demer, D.A. 2011. Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). ICES Journal of Marine Science, 68(5), 867 –879. doi:10.1093/icesjms/fsr038