AN OVERVIEW OF ICHTHYOPLANKTON RESEARCH IN THE NORTHERN CALIFORNIA CURRENT REGION: CONTRIBUTIONS TO ECOSYSTEM ASSESSMENTS AND MANAGEMENT

TOBY D. AUTH
Pacific States Marine Fisheries Commission
Hatfield Marine Science Center
2030 Marine Science Drive
Newport, OR 97365
tauth@psmfc.org
ph: 541-867-0350
fax: 541-867-0389

RICHARD D. BRODEUR
Northwest Fisheries Science Center
NOAA Fisheries
Hatfield Marine Science Center
2030 Marine Science Drive
Newport, OR 97365

ABSTRACT

We review the scientific literature based on ichthyoplankton research conducted in the northern California Current (NCC) north of Cape Mendocino, California to northern Washington. A total of 69 papers have been written on ichthyoplankton research in the NCC region from 1940 to 2012, with several more currently in the process of publication. Although there were some extended California Cooperative Fisheries Investigation (CalCOFI) cruises in the 1950s conducted as far north as northern California, the first dedicated larval fish survey in this region was made by Ken Waldron of the Bureau of Commercial Fisheries in 1967. Extensive cruises were conducted starting in 1969 and continuing through the 1970s by William Pearcy at Oregon State University (OSU) and the ichthyoplankton were analyzed by Sally Richardson and her colleagues. Much new information on larval taxonomy, spatial and temporal distributions, and relationships to environmental conditions was generated as part of these studies. Nearshore studies continued in the early 1980s by OSU focusing on the recruitment and connections of mainly flatfish species to the local estuaries. At the same time, there were a series of eight joint U.S.-Soviet large-scale cruises covering the entire region organized by Art Kendall of NMFS, with the data analyzed primarily by Miriam Doyle. After a hiatus in the early to mid-1990s, sampling began anew by NMFS and OSU focusing initially off the central Oregon coast, but by the mid-2000s was expanded over a broader area of the NCC over multiple years and seasons to provide information to managers on the outlook for future recruitment. We discuss current gaps in our knowledge, and give examples of applications of ichthyoplankton data to fisheries management and to improving our understanding of ecosystem processes and their relationships to environmental variability.

INTRODUCTION

Ichthyoplankton research is well-known to be an important tool in understanding trophic dynamics, recruitment processes, and associations between environmental fluctuations and productivity of recreationally, commercially, and ecologically important fish stocks (Hunter and Kimbrell 1980; Houde 1997; Miller and Kendall 2009). A notable example of a long-term (>60 yr) sampling program that has contributed greatly to our understanding of the physical and biological drivers of fish production has been the California Cooperative Fisheries Investigation (CalCOFI) program which has been sampling almost continuously since 1949 in the southern California Current (reviewed by McClatchie 2013). The success of this program inspired similar studies using similar sampling regimes further north into the northern California Current (NCC) region. For this reason, many studies have been conducted in the NCC over the past 70 years to examine the development, spatial and temporal distributions, size distributions, food habits, age and growth, community structure, environmental relationships, and production of fish eggs and larvae. This has resulted in an increasing abundance of information on ichthyoplankton dynamics in the NCC that is widely scattered among a variety of peer-reviewed publications, theses, dissertations, technical reports, and other gray literature that are often part of broader geographic or community studies, may be difficult to access, or are simply overlooked.

The present study is the first to provide a synopsis of the research that has been conducted to date on ichthyoplankton in the NCC. The objectives of this study are to (1) outline in tabular form the purpose, parameters, and implications of each study, (2) provide an historical background for ichthyoplankton research in the NCC, (3) examine temporal trends in this research, (4) identify applications of the research to management, and (5) discuss current and future research needs. In addition, we provide a list of all egg and larval fish taxa that have been collected in the region during recent years (i.e., 1996–2012). The results of this study are intended to provide fisheries researchers with an easily accessible, comprehensive, and tabular reference guide to ichthyoplankton research in the NCC to aid in ongoing research and guide the development of future studies.

METHODS

We used various library and internet search engines, historical and current literature references, and personal communication with leading scientists in the field of ichthyoplankton research in the California Current region to compile our list of studies to include in the present literature review. We only included studies on ichthyoplankton in the coastal and oceanic regions of the NCC from north of Cape Mendocino, California to northern Washington State, excluding estuaries and rivers. For each study that we examined, we provided the following information: author name(s), publication year; title, literature source, and annual and seasonal period; frequency, latitudinal, longitudinal, and depth ranges of sampling; number of transects and stations sampled; number of samples collected; gear types used; taxa examined; and the purpose and scientific, management, and sampling implications of the study. We did not include progress reports, theses, or gray literature that contained information subsequently published in peer-reviewed literature. In addition, we did not include references to ichthyoplankton updates contained in the State of the California Current articles published in the annual CalCOFI Reports, which can be accessed via their Web site (http://www.calcofi.org 2013). References for larval fish identification, distribution, habitat association, and seasonal parturition for the various taxa occurring in the NCC are found in Matarese et al. 1989, although several important or omitted references are also included in the present review. All dates (i.e., years) included in the figures refer to the periods of sampling and not the publication years of the reviewed studies.

RESULTS AND DISCUSSION

Historical background and recent studies

A total of 69 papers have been written on ichthyoplankton research in the NCC region from 1940 to 2012, encompassing sampling conducted as early as 1939 (tables 1, 2). From 1996 to 2012, 116 larval fish taxa representing 40 families and an additional two orders (one of which, Elopomorpha, is a superorder) have been collected in the NCC as part of the most recent pelagic sampling regime (table 3).

Although there were some extended CalCOFI cruises in the 1950s up to at least northern California (Ahlstrom 1956; Ahlstrom and Stevens 1976), the first dedicated larval fish survey in this region was made by Ken Waldron of the Bureau of Commercial Fisheries (predecessor to National Marine Fisheries Service [NMFS]) in 1967 (Waldron 1972). An extensive series of cruises were conducted starting in 1969 and continuing through the 1970s by William Pearcy at Oregon State University (OSU) and the ichthyoplankton were analyzed by Sally Richardson and her colleagues (Richardson 1973, 1981; Laroche 1976; Pearcy et al. 1977; Richardson and Pearcy 1977; Richardson et al. 1980a, b; Laroche et al. 1982). Much original information on larval taxonomy, spatial and temporal distributions, community structure, and relationships to environmental conditions were generated as part of these studies.

Nearshore larval studies continued in the 1980s by OSU focusing on the recruitment and connections of species to the local estuaries (Gadomski and Boehlert 1984; Boehlert et al. 1985; Brodeur et al. 1985; Shenker 1988). At the same time, there were a series of eight joint U.S.-Soviet large-scale surveys covering the entire NCC organized by Art Kendall of NMFS, that led to a series of papers looking mainly at distribution, community structure, and feeding ecology (Grover and Olla 1986, 1987; Dunn and Rugen 1989; Doyle 1992, 1995; Doyle et al. 1993, 2002). After a hiatus in the early to mid-1990s, sampling began anew by NMFS and OSU focusing initially off the central Oregon coast (Auth and Brodeur 2006; Auth et al. 2007; Brodeur et al. 2008), but by the mid-2000s was expanded over a broader area of the NCC over multiple years and seasons (Emmett et al. 1997; Auth 2008, 2009, 2011; Parnel et al. 2008; Takahashi et al. 2012; Auth et al. submitted). Several of these studies were able to provide information to managers on the outlook for future recruitment of commercially-important species in the NCC (Phillips et al. 2007; Brodeur et al. 2011; Daly et al. 2013).

Trends in research

We found disparity in the relative proportion of ichthyoplankton studies conducted in the NCC by decade, month, gear type, purpose, and spatial-temporal distribution. Relatively few studies were conducted prior to 1970 (<20%), with a sharp increase in the 1970s (24%) followed by a gradual decline in the 1980s (20%) and 1990s (14%), before reaching a maximum in the 2000s

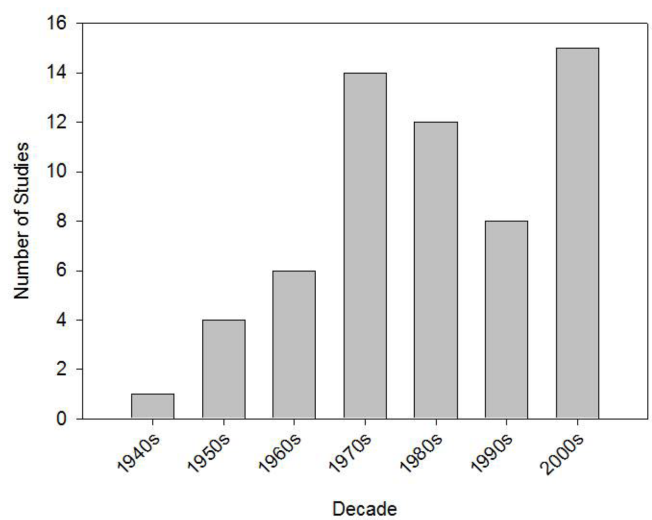

Figure 1. Studies conducted in the northern California Current from 1949 to 2012 by decade of sampling.

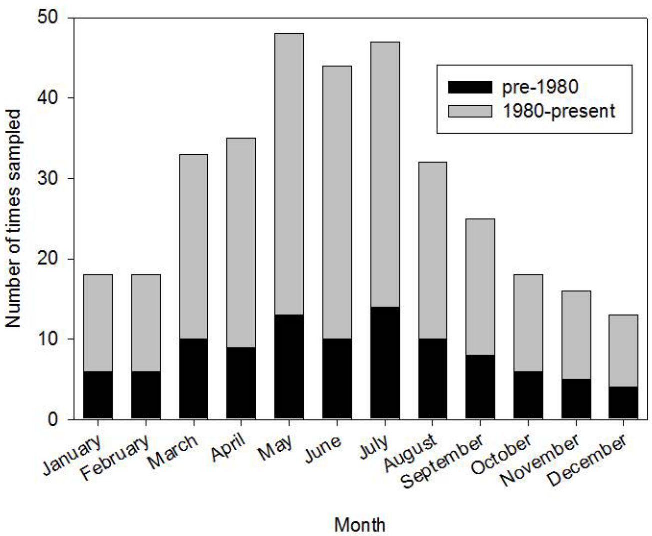

Figure 2. Studies conducted in the northern California Current from 1949 to 2012 by month displayed by sampling period (i.e., pre-1980 and post-1980).

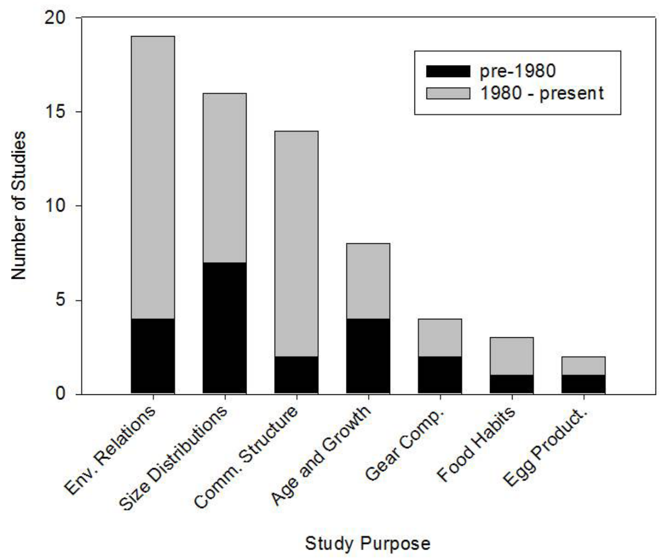

Figure 4. Studies conducted in the northern California Current from 1949 to 2012 by purpose displayed by sampling period (i.e., pre-1980 and post-1980).

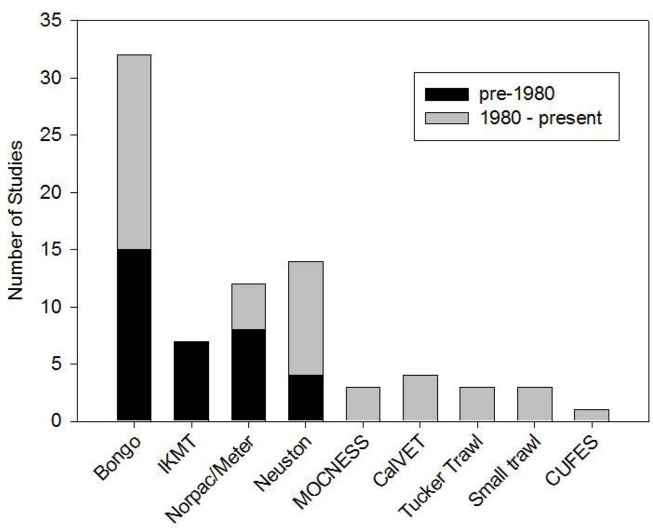

Figure 3. Studies conducted in the northern California Current from 1949 to 2012 by gear type displayed by sampling period (i.e., pre-1980 and post-1980).

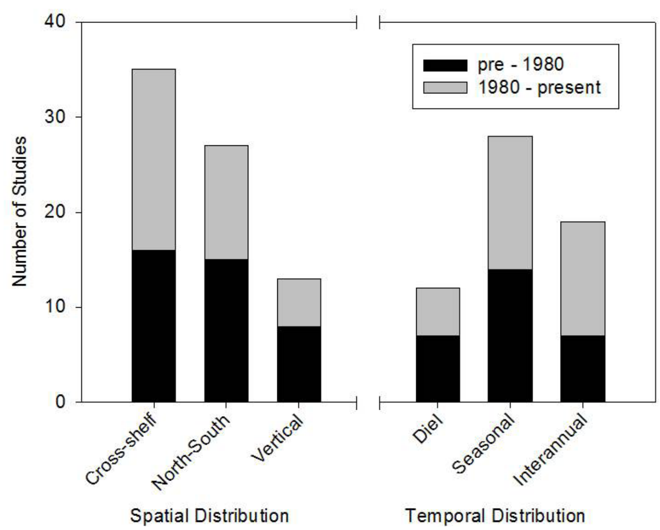

Figure 5. Studies conducted in the northern California Current from 1949 to 2012 by spatial and temporal scale of sampling displayed by sampling period (i.e., pre-1980 and post-1980).

(25%) (fig. 1). Most sampling was conducted from March to September, with peak sampling occurring in May–July, most likely due to the rough weather conditions prevalent in the NCC during fall and winter months that make consistent sampling difficult. The predominant type of gear used to collect samples consisted of bongo, neuston, and ring (North Pacific [NorPac]/meter) nets, with bongos being favored during all periods and employed in more than half of the studies overall (fig. 2). Relatively rarely used gear types included the Isaacs-Kidd midwater trawl (IKMT), which was seldom used after 1980, and the Multiple Opening/Closing Net and Environmental Sampling System (MOCNESS), Californian Vertical Egg Tow (CalVET), Tucker and smaller trawls, and the Continuous Underway Fish Egg Sampler (CUFES), which were used only since 1980 (fig. 2). The primary purposes of the ichthyoplankton studies were investigations of environmental relations to larval ecology and examinations of size distributions and community structure, while age and growth, gear comparison, food habits, and egg production were the focus of smaller proportions of the total number of studies (fig. 3). Interannual and seasonal were the dominant temporal scales examined while longitudinal (inshore–offshore) and latitudinal distributions were the primary spatial scales examined in the ichthyoplankton studies conducted to date, while vertical and diel studies were undertaken much less frequently (fig. 4).

In summary, many of the early studies focused on single species of interest to an investigator, and although there were some studies that attempted to describe the whole larval community (e.g., Waldron 1972; Richardson and Pearcy 1977), there were few that examined community structure in a quantitative sense (Richardson et al. 1980). Knowledge on the taxonomy of early-life stages of marine fishes in the Northeast Pacific was relatively scant in the early years (Kendall and Matarese 1994), but many descriptions done in the 1980s led to a more complete catalogue of egg and larval stages by the end of the decade (Matarese et al. 1989). A shift on a national scale towards informing resource assessments of important species in many of the U.S. Large Marine Ecosystems (Sherman et al. 1983) led to large-scale sampling of this region and shifted the emphasis to gaining a mechanistic understanding of recruitment processes for a variety of species. More recent studies attempted to look more holistically at the role of early-life stages in pelagic ecosystems with a view towards predicting recruitment in fish populations (e.g., Daly et al. 2013).

Applications to management and future studies

Ichthyoplankton research in the NCC has yielded much important information that can be used for fisheries and ecosystem management in the region (table 2), although many unanswered questions still remain which are the subjects of ongoing and future research. As mentioned earlier, the vast majority of studies have provided information on abundance and distribution patterns, early-life history traits, community structure, and environmental relationships, which can be incorporated into single-species and ecosystem-based models to regulate commercially and ecologically important fish stocks (e.g., Kendall and Matarese 1987; Shanks and Eckert 2005; Auth et al. 2011).

As an example of using larval fishes as an indicator of potential ocean changes, the marked variations in abundance and productivity of larval fishes observed during anomalous El Niño years (Brodeur et al. 1985; Doyle 1995; Auth et al. submitted) or other low production years (Brodeur et al. 2006; Takahashi et al. 2012) may be an indicator of future responses under projected climate changes in the California Current. A recent study by Roegner et al. (2013) examined finer-scale variations in the spatial and temporal surface distributions and concentrations of ichthyoplankton relative to the dynamics of the Columbia River plume during a delayed transition from downwelling to upwelling conditions to understand the fate of meroplanktonic organisms under strong advective forcing. Recent work by Thompson et al. (submitted) examines the large-scale and regional responses of ichthyoplankton assemblages to climate variability in the contrasting regions of the California Current of Oregon and southern California. Finally, Johnson et al. (in prep.) has completed a study examining the effects of recent hypoxia events in NCC coastal waters on the larval abundance and distribution of ecologically and commercially important fish taxa. Much of the information summarized in the current review will be the basis for a future study by us to utilize early-life history traits of important fish taxa in conjunction with changing environmental forcing factors in the development of ecosystem-based management policies in the California Current, similar to that proposed by Doyle and Mier 2012 for the Gulf of Alaska region.

Another critical informational gap that exists is the inability to identify to species or species groups samples of larval *Sebastes* spp. (rockfish). Currently, larval *Sebastes* spp., one of the most abundant and commercially important taxa in the ichthyoplankton community, are not identifiable below the generic level based on meristics and pigmentation patterns. However, Gray et al. (2006) have developed a technique to identify most *Sebastes* to species level based on mitochondrial markers, which has already been utilized for larval *Sebastes* in the southern California Current (Thompson et al. 2011) and juvenile *Sebastes* in the NCC (Johansson et al. in prep.). The implementation of this technique to identify *Sebastes* larvae in the NCC would vastly facilitate the utility of ichthyoplankton sampling to make species-specific inferences of larval *Sebastes* spp. survival, ecological and trophic significance, and recruitment in this region.

Although we presently have a good understanding about where and when the early-life stages of most fishes occur in the NCC, and some knowledge about the important physical and biological factors that affect their abundance patterns, there is a general dearth of knowledge about the ecological aspects of their early-life history in this region. For example, there are only a limited number of studies that have examine the diets of larval fish (Gadomski and Boehlert 1984; Grover and Olla 1986, 1987) and no attempts to examine feeding selectivity or food consumption in relation to available food sources. Similarly, although there is one estimate of egg mortality for sardines (Bentley et al. 1996), there have been no attempts to quantify sources of mortality for fish larvae similar to those made off southern California (Hewitt et al. 1985), or to identify important invertebrate and vertebrate predators on early-life stages in this region (Bailey and Houde 1989; Brodeur and Bailey 1996). Larval fish have been documented in the stomachs of at least some gelatinous zooplankton off Oregon (Auth and Brodeur 2006), although quantification of predation rates will require some dedicated process studies which have not been attempted to date.

The trophic interactions of fish larvae can also be important in developing fisheries management plans in the NCC. This is especially true for those involving piscivory by commercially and recreationally important salmonids on early-life stages of pelagic fish prey taxa. Although some previous work has been done to address this interaction (Brodeur 1989; Brodeur et al. 2011b), Daly et al. (2013) found that a significant relationship exists between the biomass of larval fish prey taxa in winter and subsequent *Oncorhynchus kisutch* (coho salmon) and spring and fall *O. tshawytscha* (Chinook salmon) survival. This relationship has been one of the most important among a long list of physical and biological indicators that have been used to explain and predict salmon survival in the ocean (Burke et al. 2013).

Other important applications of ichthyoplankton research to fisheries management are the estimation of spawning stock biomass (SSB), and perhaps above all, prediction of future recruitment success of commercially, recreationally, and ecologically important fish stocks. Several ichthyoplankton studies have been conducted in the NCC to examine the factors influencing SSB, year-class strength, and recruitment in general (Parrish et al. 1981), and for individual taxa such as *Engraulis mordax* (northern anchovy) (Richardson 1981), *Sardinops sagax* (Pacific sardine) (Bentley et al. 2006), *Isopsetta isolepis* (butter sole) and *Parophrys vetulus* (English sole) (Mundy 1984), *Merluccius productus* (Pacific hake) (Phillips et al. 2007), *Sebastes* spp. (Brodeur et al. 2011a), and *Anoplopoma fimbria* (sablefish) (Kendall and Matarese 1987; Sogard 2011). Although some recruitment models do exist which include physical factors and their effects on early-life stages (e.g., Kruse and Tyler 1989), the contribution of early-life ecology and survival to variation in recruitment of adults remains poorly understood among most fish species. Another study that is currently underway (Auth et al. in prep.) aims to utilize environmental and larval and juvenile fish data collected as part of the 2004–12 Stock Assessment Improvement Plan (SAIP, see Auth 2011 for sampling details) in conjunction with adult fish data from the Pacific West Coast bottom trawl survey of groundfish to determine if and to what degree a relationship exists between environmental factors, SSB, ichthyoplankton production, survival into the juvenile stage, and future adult recruitment. Studies such as this, in conjunction with continued research into areas of early-life fishery dynamics such as trophic interactions, mortality, growth, and environmental connectivity, could bring us closer to solving the recruitment problem, which has been referred to as "the holy grail of fisheries science" (Houde 2008).

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TABLE 1

Summary of sampling protocols, sampling effort, and taxa examined for all ichthyoplankton studies conducted in the northern California Current (NCC) region (1940–2012).

Study	Period	Frequency	Latitudinal range	Longitudinal range	Depth range (m)	Transects (no.)	Stations (no.)	Samples (no.)	Gear type (mouth diameter/ area and mesh size)	Taxon
Brock (1940)	1939 (May)	Annual	44.77–44.90°N	126.33–128.37°W	Surface	1	2	4 (individuals)	Dip net (unspecified mesh)	*Anoplopoma fimbria*
Ahlstrom (1956)	1949 and 1955 (July–September)	Unspecified	20–48°N	110–150°W	0–>123	Unspecified	Unspecified	Unspecified	Unspecified	*Trachurus symmetricus*
Aron (1959)	1957 (July–September)	Continuous	48–59°N	122°W–174°E	20–250	Unspecified	149	143	0.5 m Isaacs-Kidd midwater trawl (IKMT) (3.2 mm)	Community
Aron (1962)	1957 (summer) and 1958 (summer and fall)	Seasonal	32–56°N	122°W–174°E	0–400	Unspecified	90	564	0.5 m IKMT (3.2 mm)	Community
Pearcy (1962)	1961 (March–May) and 1962 (April)	Monthly	43.34–44.65°N	124.72–125.26°W	Surface	Unspecified	4	4	Dip net (unspecified mesh)	*Sebastolobus* spp.
LeBrasseur (1970)	1956–59 (unspecified months)	Unspecified	42–59°N	124–160°W	0–150	Unspecified	Unspecified	~3000	Norpac net (2 mm) and IKMT (unspecified mesh)	Community
Day (1971)	1963 (May and November)	Monthly	46.8–50.0°N	124.3–128.5°W	0–150	4 (May), 9 (November)	18 (May), 44 (November)	139	0.9 m IKMT (3 mm)	Community; featured taxa: Agonidae, Cottidae, Hexagrammidae, Liparidae, Pleuronectidae, and Scorpaenidae
Waldron (1972)	1967 (April and May)	Monthly	42–51°N	122.4–136.5°W	1–200	10	103	103	1 m ring (500–600 µm)	Community; featured taxa: Ammodytidae, Gadidae, Pleuronectidae, Myctophidae, and Scorpaenidae
Richardson (1973)	1969 (May–October)	Monthly	42.00–46.50°N	124.00–129.50°W	1–200	Unspecified	Unspecified	354	IKMT, 70 cm bongo, and 1 m ring (all 571 µm)	Community; featured taxa: Bothidae, *Engraulis mordax*, Osmeridae, Pleuronectidae, Myctophidae (esp. *Stenobrachius leucopsarus* and *Tarletonbeania crenularis*), and Scorpaenidae (esp. *Sebastes* spp.)
Ahlstrom and Stevens (1976)	1972 (May)	Monthly	20–48°N	107–148°W	Surface (neuston), 0–200 (ring)	24	148	148 (neuston), 148 (ring)	0.3 m^2 neuston and 1 m ring (505 µm)	Community; featured taxa: *Anoplopoma fimbria, Engraulis mordax, Cololabis saira, Macrorhamphosus gracilis,* Myctophidae, *Sebastes* spp., and *Trachurus symetricus*
Laroche (1976)	1975 (January–October)	Monthly	46.1°N	124.1°W	Entire water column	1	6 (January and March), 2 (July–October)	48 (January and March), 228 (July–October)	1 m ring (571 µm)	Community; featured taxon: Osmeridae
Pearcy et al. (1977)	January 1971–August 1972, 1972–73 (March and April), 1974–75 (March)	Monthly	42.0–46.2°N	124.0–128.2°W	1–200 (IKMT), 1–150 (bongo), 1–1000 (opening-closing midwater trawl)	36 (IKMT), 89 (bongo), unspecified number (opening-closing midwater trawl)	36 (IKMT), 89 (bongo), unspecified number (opening-closing midwater trawl)	>2200 (IKMT), 593 (bongo), unspecified number (opening-closing midwater trawl)	0.5 m IKMT (571 µm), opening-closing midwater trawl (unspecified mesh), and 70 cm bongo (571 µm)	*Eopsetta jordani, Glyptocephalus zachirus*, and *Microstomus pacificus*
Richardson and Pearcy (1977)	January 1971–August 1972	Biweekly	44.65°N	124.1–125.5°W	1–150	1	12	287	20 and 70 cm bongo (233–571 µm)	Community
Laroche and Richardson (1979)	1972–73 (March and April), 1974–75 (March)	Monthly	42.7–46.3°N	124.0–125.2°W	Surface (neuston), 0–200 (bongo)	12	84	16 (neuston), 320 (bongo)	0.35 m^2 neuston (505 µm) and 70 cm bongo (571 µm)	*Isopsetta isolepis, Parophrys vetulus* (primary), *Platichthys stellatus*, and *Psettichthys melanostictus*

[1]Additional live individuals for spawning and rearing were collected in fall–winter 1978 at 44.17°N, 124.30°W at 68–77 m water depth using a 12 m otter trawl.
[2]Only the west coast sampling protocal is listed.

(continued)

TABLE 1, cont'd.

Summary of sampling protocols, sampling effort, and taxa examined for all ichthyoplankton studies conducted in the northern California Current (NCC) region (1940–2012).

Study	Period	Frequency	Latitudinal range	Longitudinal range	Depth range (m)	Transects (no.)	Stations (no.)	Samples (no.)	Gear type (mouth diameter/ area and mesh size)	Taxon
Richardson and Laroche (1979)	1961–76 (unspecified months)	Unspecified	42.6–46.3°N	124–128°W	Unspecified	Unspecified	Unspecified	>12000 (individuals)	70 cm bongo, neuston, and 1 m ring, and IKMT, beam, and otter trawls (unspecified mesh)	*Sebastes crameri, S. helvomaculatus,* and *S. pinniger*
Laroche and Richardson (1980)	1961–76 (January–December)	Unspecified	42.6–46.3°N	124–128°W	Unspecified	Unspecified	Unspecified	556 (individual *Sebastes flavidus*), 365 (individual *S. melanops*)	70 cm bongo, neuston, 1 m ring, dip net, beach seines, and IKMT, beam, and otter trawls (unspecified mesh)	*S. flavidus* and *S. melanops*
Richardson et al. (1980a)	January 1971–August 1972	Biweekly	44.65°N	124.1–125.5°W	1–150	1	12	407 (individuals)	20 and 70 cm bongo (233–571 µm)	*Isopsetta isolepis*
Richardson et al. (1980b)	1972–73 (March and April), 1974–75 (March)	Monthly	42.7–46.3°N	124.0–125.2°W	0–150	12	84	306	70 cm bongo (571 µm)	Community
Kendall (1981)	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Community
Laroche and Richardson (1981)	1961–76 (unspecified months)	Unspecified	42.6–46.3°N	124–128°W	Unspecified	Unspecified	Unspecified	Unspecified	70 cm bongo, neuston, and 1 m ring, purse seines, and IKMT and commercial mid-water, beam, and otter trawls (unspecified mesh)	*Sebastes entomelas* and *S. zacentrus*
Methot (1981)	1977 (July)	Monthly	42.3–47.0°N	124.1–126.6°W	0–70	7	25	367 (individual *E. mordax*), 141 (individual *S. leucopsarus*)	60 cm bongo (333 µm)	*E.mordax* and *S. leucopsarus*
Parrish et al. (1981)	Unspecified	Unspecified	20–51°N	111–136°W	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Community
Richardson (1981)	1975–76 (July)	Annual	43–47°N	124.1–127.8°W	0–150	7	70	140	70 cm bongo (333 µm)	*Engraulis mordax*
Laroche et al. (1982)[1]	November 1977–June 1978	Monthly	44.62°N	124.08°W	Entire water column	1	1	331 (individuals)	70 cm bongo (505 µm)	*Parophrys vetulus*
Rosenberg and Laroche (1982)	November 1977–June 1978	Monthly	44.62°N	124.08°W	Entire water column	1	1	127 (individuals)	70 cm bongo (505 µm)	*Parophrys vetulus*
Gadomski and Boehlert (1984)	January 1971–August 1972, 1972–73 (March and April), 1974–75 (March)	Monthly	42.7–46.3°N	124.0–125.2°W	0–150	12	84	438 (individual *Isopsetta isolepis*), 563 (individual *Parophrys vetulus*)	70 cm bongo (571 µm)	*I. isolepis* and *P. vetulus*
Mundy (1984)	June 1969–August 1972	Biweekly	44.65°N	124.1–124.3°W	Entire water column	1	4	277	20 and 70 cm bongo (233–571 µm)	Community; featured taxa: *Ammodytes hexapterus, Artedius fenestralis, A. harringtoni, A. meanyi, Isopsetta isolepis, Liparis* spp., *Lyopsetta exilis, Microgadus proximus,* Osmeridae, *Parophrys vetulus, Psettichthys melanostictus, Platichthys stellatus,* and *Sebastes* spp.
Young (1984)	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Osmeridae
Boehlert et al. (1985)	1982 (May–July)	Biweekly	44.65°N	124.17–124.29°W	Entire water column	1	2	75 depth-stratified samples from 6 hauls (4 day, 2 night)	1 m^2 Tucker trawl (505 µm)	Community
Brodeur et al. (1985)	1983 (April–September)	Biweekly	44.65°N	124.07–124.29°W	Entire water column	2	4	38	70 cm gimballed, bridleless frame and bongo (333 µm)	Community; featured taxon: *Engraulis mordax*

[1]Additional live individuals for spawning and rearing were collected in fall–winter 1978 at 44.17°N, 124.30°W at 68–77 m water depth using a 12 m otter trawl.
[2]Only the west coast sampling protocal is listed.

(continued)

TABLE 1, cont'd.

Summary of sampling protocols, sampling effort, and taxa examined for all ichthyoplankton studies conducted in the northern California Current (NCC) region (1940–2012).

Study	Period	Frequency	Latitudinal range	Longitudinal range	Depth range (m)	Transects (no.)	Stations (no.)	Samples (no.)	Gear type (mouth diameter/ area and mesh size)	Taxon
Grover and Olla (1986)	1980 (April–May)	Annual	43.6–47.0°N	124–129°W	Surface	6	9	143 (individuals)	0.5 m neuston (505 μm)	*Anoplopoma fimbria*
Grover and Olla (1987)	1980 and 1983 (April–May)	Annual	43.3–47.3°N	124–129°W	Surface	8	10 (1980), 6 (1983)	267 (individuals, 1980), 136 (individuals, 1983)	0.5 m neuston (505 μm)	*Anoplopoma fimbria*
Kendall and Matarese (1987)	1939–1985	Unspecified	40–60°N	124°W–170°E	0–400	Unspecified	Unspecified	Unspecified	50–70 cm bongo, neuston, and dipnet (unspecified mesh)	*Anoplopoma fimbria*
Shenker (1988)	1984 (April–July)	Biweekly	44.65°N	124.08–125.25°W	Surface	1	12	107	0.7 m^2 Manta neuston (333 μm)	Community
Brodeur (1989)	1985 (June, July, and September)	Monthly	41–59°N	124–139°W	Surface	35	106	228	0.35 m^2 neuston (505 μm)	Community
Dunn and Rugen (1989)	1965–88 (unspecified months)	Unspecified	32–61°N	118–179°W	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Community
Matarese et al. (1989)	1966–86 (January–December)	Unspecified	38–66°N	120–180°W	Unspecified	Unspecified	Unspecified	Unspecified	60 and 70 cm bongo, neuston, 1.2 m^2 MOCNESS, 1 m ring, and 1 m^2 Tucker trawl, and midwater trawls (unspecified mesh)	Community
Brodeur (1990)	1981 (May–August)	Monthly	43.2–46.6°N	124–125°W	0–150	12	48	Unspecified	70 cm bongo (571 μm)	Community
Ureña (1990)	1980–83 (April–November)	Semiannual–annual	40–48°N	124–129°W	Surface (neuston), 0–200 (bongo)	25	125	825 (neuston), 749 (bongo)	0.15 m^2 neuston and 60 cm bongo (505 μm)	*Citharichthys sordidus, C. stigmaeus, Glyptocephalus zachirus, Isopsetta isolepis, Lyopsetta exilis, Microstomus pacificus, Parophrys vetulus,* and *Psettichthys melanostictus*
Doyle (1992)	1980–87 (April–November)	Semiannual–annual	40–48°N	124–129°W	Surface (neuston), 0–200 (bongo)	25	125	1161 (neuston), 1086 (bongo)	0.15 m^2 neuston and 60 cm bongo (505 μm)	Community; featured taxa: *Ammodytes hexapterus, Anoplopoma fimbria, Cololabis saira, Cryptacanthodes aleutensis, Engraulis mordax, Hemilepidotus hemilepidotus, H. spinosus, Hexagrammos decagrammus, H. lagocephalus, Ophiodon elongatus, Ronquilus jordani, Scorpaenichthys marmoratus, Sebastes* spp., and *Tarletonbeania crenularis*
Markle et al. (1992)	1961–82 (unspecified months)	Unspecified	32–61°N	118–179°W	0–600	Unspecified	425	796 (individuals)	IKMT, Cobb, rectangular, and commercial midwater trawls, Tucker trawl, and 1 m^2 multiple plankton sampler (unspecified mesh)	*Microstomus pacificus*
Doyle et al. (1993)[2]	1980–87 (April–November)	Semiannual–annual	40–48°N	124–129°W	Surface (neuston), 0–200 (bongo)	25	125	1161 (neuston), 1086 (bongo)	0.15 m^2 neuston and 60 cm bongo (505 μm)	Community
Doyle (1995)	1980–87 (April–November)	Semiannual–annual	40–48°N	124–129°W	Surface (neuston), 0–200 (bongo)	25	125	1161 (neuston), 1086 (bongo)	0.15 m^2 neuston and 60 cm bongo (505 μm)	Community
Bentley et al. (1996)	1994 (July)	Monthly	43.2–46.3°N	124.1–126.8°W	0–70	12	234	234	0.05 m^2 CalVET (150 μm)	*Sardinops sagax*
Emmett et al. (1997)	1994–95 (July)	Annual	43–47°N	124–127°W	0–70	12	234	355	0.05 m^2 CalVET (150 μm)	*Engraulis mordax*

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[2]Only the west coast sampling protocal is listed.

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Study	Period	Frequency	Latitudinal range	Longitudinal range	Depth range (m)	Transects (no.)	Stations (no.)	Samples (no.)	Gear type (mouth diameter/area and mesh size)	Taxon
Doyle et al. (2002)	1980–81, 1984–85, and 1994–95 (April–June)	Annual	40–57°N	124–168°W	0–200	Unspecified	Unspecified	950	60 cm bongo (333–505 µm)	Community
Matarese et al. (2003)	1972–96 (January–December)	Unspecified	38–66°N	120–180°W	Unspecified	Unspecified	Unspecified	11,379	60 and 70 cm bongo, neuston, 1.2 m² MOCNESS, 1 m ring, 1 m² Tucker trawl, and midwater trawls (unspecified mesh)	Community
Emmett et al. (2005)	1994–98 (July; June in 1996)	Annual	42.6–47.0°N	124.1–126.8°W	0–70	17	340	1086	0.05 m² CalVET (150 µm)	*Sardinops sagax*
Shanks and Eckert (2005)	Unspecified	Unspecified	30–47°N	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Community
Auth and Brodeur (2006)	2000 and 2002 (April–September)	Monthly	44.65°N	124.17–125.12°W	0–350	1	5	281 depth-stratified samples from 43 hauls	1.2 m² MOCNESS (333 µm)	Community; featured taxa: *Engraulis mordax, Lyopsetta exilis, Sebastes* spp., *Stenobrachius leucopsarus,* and *Tarletonbeania crenularis*
Brodeur et al. (2006)	2000, 02, 04, and 05 (April–September)	Monthly	44.00–46.67°N	124.22–125.36°W	0–350	4	20	195	60 cm bongo and 1.2 m² MOCNESS (333 µm)	Community; featured taxa: *Engraulis mordax, Merluccius productus,* and *Trachurus symmetricus*
Charter et al. (2006)	2001 (August–December)	Annual	30–48°N	118–131°W	0–200	Unspecified	71	71	70 cm bongo (505 µm)	Community
Pool and Brodeur (2006)	2000 and 2002 (June and August)	Monthly	41.9–44.7°N	124.1–126.0°W	Surface	6	98	347	0.3 m² neuston (333 µm)	Community
Auth et al. (2007)	2000 and 2002 (August)	Diel	44.00°N	125.00°W	0–350	1	1	74 depth-stratified samples from 9 hauls (5 day, 4 night)	1.2 m² MOCNESS (333 µm)	Community; featured taxa: *Lyopsetta exilis, Sebastes* spp., *Stenobrachius leucopsarus,* and *Tarletonbeania crenularis*
Phillips et al. (2007)	1996–2004 (January–December), 2004–06 (May–November)	Biweekly (1996–2004), monthly (2004–06)	44.65°N (1996–2004), 38.48–47.00°N (2004–06)	124.17–124.29°W (1996–2004), 123.35–126.00°W (2004–06)	0–20 (1996–2004), 0–100 (2004–06)	1 (1996–2004), 16 (2004–06)	2 (1996–2004), 75 (2004–06)	85 (1996–2004), 320 (2004–06)	60 cm bongo and 1 m ring (1996–2004), 60 and 70 cm bongo (333 µm) and 1 m² Tucker trawl (2004–06) (335 µm)	*Merluccius productus*
Auth (2008)	2004–06 (May)	Annual	38.48–47.00°N	123.35–126.00°W	0–100	15	60	170 depth-stratified samples from 106 hauls	1 m² Tucker trawl (335 µm)	Community; featured taxa: *Citharichthys* spp., *Engraulis mordax, Sebastes* spp., and *Stenobrachius leucopsarus*
Brodeur et al. (2008)	1996–2005 (January–December)	Biweekly	44.65°N	124.17–124.29°W	0–20	1	2	258	60 cm bongo and 1 m ring (200 and 333 µm)	Community; featured taxa: *Ammodytes hexapterus, Artedius harringtoni, Citharichthys* spp., *Engraulis mordax, Isopsetta isolepis, Liparis* spp., Osmeridae, *Parophrys vetulus, Psettichthys melanostictus,* and *Sebastes* spp.
Parnel et al. (2008)	1999–2004 (April–July), 1999–2001 (sporadically other months)	Biweekly	46.05°N	124.05–124.25°W	0–40	1	2	85	1 m ring (335 µm)	Community; featured taxon: *Engraulis mordax*

[1]Additional live individuals for spawning and rearing were collected in fall–winter 1978 at 44.17°N, 124.30°W at 68–77 m water depth using a 12 m otter trawl.

[2]Only the west coast sampling protocal is listed.

(continued)

TABLE 1, cont'd.

Summary of sampling protocols, sampling effort, and taxa examined for all ichthyoplankton studies conducted in the northern California Current (NCC) region (1940–2012).

Study	Period	Frequency	Latitudinal range	Longitudinal range	Depth range (m)	Transects (no.)	Stations (no.)	Samples (no.)	Gear type (mouth diameter/ area and mesh size)	Taxon
Auth (2009)	2007 (March, April, and October) and 2008 (March, June, and July)	Monthly	41.90–44.65°N	124.10–128.73°W	0–45 (0–100 in June and July 2008)	2	30	72	70 cm bongo (60 cm in June and July 2008) (335 µm)	Community; featured taxa: *Engraulis mordax, Sebastes* spp., *Stenobrachius leucopsarus*, and *Tarletonbeania crenularis*
McClatchie (2009)	2008 (April and July/August)	Monthly	30–49°N	118–128°W	3	Unspecified	Continuous	Continuous	CUFES	*Engraulis mordax* and *Sardinops sagax*
Bystydzieńska et al. (2010)	2009 (June–July)	Monthly	44.00–46.16°N	125.12–125.28°W	0–100	3	5	13 (individuals)	60 cm bongo (333 µm)	*Tarletonbeania crenularis*
Lo et al. (2010)	2003 (July), 2004 (March and July), and 2005 (March)	Annual	42–48°N	124.5–128.0°W	18–20 (surface trawl), unspecified (CalVET), 3 (CUFES)	7	42	214 (surface trawl), 151 (CalVET), continuous (CUFES)	Surface trawl (7 mm), 0.05–m^2 CalVET (150 µm), and CUFES (July only)	*Sardinops sagax*
Auth (2011)	2004–09 (May–October/ November)	Monthly	44.00–46.67°N	124.18–127.14°W	0–100	4	30	489	60 and 70 cm bongo and 1 m^2 Tucker trawl (June 2004) (335 µm)	Community; featured taxa: *Engraulis mordax, Lyopsetta exilis, Sebastes* spp., *Stenobrachius leucopsarus*, and *Tarletonbeania crenularis*
Auth et al. (2011)	January 1971–August 1972, November 1977–June 1978, April–September 1983, and December 1996–December 2005	Biweekly–monthly	44.65°N	124.17–124.29°W	Entire water column (0–20 in 1996–2005)	1	2	350	60 and 70 cm bongo and 1 m ring (200–571 µm)	Community; featured taxa: *Ammodytes hexapterus, Citharichthys* spp., *Engraulis mordax, Isopsetta isolepis*, Osmeridae, *Parophrys vetulus, Psettichthys melanostictus*, and *Sebastes* spp.
Brodeur et al. (2011a)	1998–2010 (January–March)	Biweekly	44.65°N	124.10–124.65°W	0–20	1	6	179	60 cm bongo (200–333 µm) and 1 m ring (333-µm)	*Sebastes* spp.
Brodeur et al. (2011b)	2008 (May–June)	Monthly	46–47°N	124.2–124.5°W	0–10 (herring and Marinovich trawls), 0–20 (Methot trawl), 0–30 (bongo)	Unspecified	Unspecified	21 (each gear type)	37.2 m^2 herring (10 mm), 27.0 m^2 Marinovich (6 mm), and 5 m^2 Methot (1 mm) trawls, and 60 cm bongo (335 µm)	Community
Sogard (2011)	1993–2001 (April–May); too few samples in 1996 for analysis	Annual	44.8°N	124.6°W	Surface	1	1	295 (individuals)	0.7 m^2 Manta (1 mm) and 3.7 m^2 neuston (4.8 mm)	*Anoplopoma fimbria*
Watson and Manion (2011)	2008 (April and July/August)	Monthly	34.1–48.4°N	121–128°W	Surface (Manta), 0–212 (bongo)	20	99	186 (Manta), 188 (bongo)	0.13 m^2 Manta and 70 cm bongo (both 505 µm)	Community
Takahashi et al. (2012)	2005 (August–October) and 2006 (August–September)	Monthly	44.0–48.3°N	124.17–124.29°W	0–40 (2005), 0–12 (2006)	13	113 (2005), 101 (2006)	175 (individuals, 2005), 203 (individuals, 2006)	Midwater (3 mm, 2005) and surface trawls (8 mm, 2006)	*Engraulis mordax*

[1]Additional live individuals for spawning and rearing were collected in fall–winter 1978 at 44.17°N, 124.30°W at 68–77 m water depth using a 12 m otter trawl.
[2]Only the west coast sampling protocal is listed.

TABLE 2
Study purpose and primary results and management implications of studies listed in Table 1.

Study	Purpose	Scientific, management, and sampling implications
Brock (1940)	Examine development and longitudinal distributions.	Development and spatial distribution of early-life stages of a commercially important species.
Ahlstrom (1956)	Examine development and latitudinal, longitudinal, and vertical distributions.	Development and spatial distribution of early-life stages of a commercially important species.
Aron (1959)	Examine seasonal, latitudinal, longitudinal, vertical, and diel distributions and relative abundances of late-larval taxa and their relation to environmental factors (i.e., temperature and bathymetry).	Variability in the seasonal, spatial, and diel distributions and relative abundances of early-life stages of important commercial and forage taxa. Study is limited to larger, late-larval stage individuals due to the large mesh size employed in sampling, and no flow data are provided to calculate actual abundances.
Aron (1962)	Examine seasonal, latitudinal, longitudinal, vertical, and diel distributions and relative abundances of late-larval taxa and their relation to environmental factors (i.e., temperature, salinity, and bathymetry).	Variability in the seasonal, spatial, and diel distributions and abundances of early-life stages of important commercial and forage taxa, and their relation to environmental factors. Study is limited to larger, late-larval stage individuals due to the large mesh size employed in sampling.
Pearcy (1962)	Examine development and seasonal, latitudinal, and longitudinal distributions.	Development and spatial and temporal distribution of early-life stages of a commercially important species.
LeBrasseur (1970)	Examine annual, seasonal, latitudinal, and longitudinal occurrences and distributions.	Qualitative early description of the temporal and spatial occurrences of larvae in the northeastern Pacific Ocean. Concludes that, in view of the low incidence of larvae, both in terms of numbers and species in the oceanic waters off western Canada, it is unlikely that any major stocks of unexploited or unknown fish species are resident in the mid-ocean area. Gear comparison.
Day (1971)	Examine seasonal, latitudinal, longitudinal, and vertical distributions and abundances of late-larval taxa.	Variability in the seasonal and spatial distributions and abundances of early-life stages of important commercial and forage taxa. Study is limited to larger, late-larval stage individuals due to the large mesh size employed in sampling.
Waldron (1972)	Examine latitudinal and longitudinal distributions and abundances of larvae in the northeastern Pacific Ocean and Puget Sound.	Variability in the spatial distributions and abundances of larvae of important commercial and ecological taxa.
Richardson (1973)	Examine seasonal, latitudinal, longitudinal, and vertical distributions, abundances, and length frequencies of larvae. Compare gear types.	Variability in the seasonal and spatial distributions, abundances, and length frequencies of larvae of commercially and ecologically important taxa. Larval *Engraulis mordax* were concentrated in Columbia River plume waters from June to August. Isaacs-Kidd midwater trawl (IKMT) caught the greatest number and had the greatest frequency of occurrence of major taxa, whereas the bongo caught the most larvae per volume filtered.
Ahlstrom and Stevens (1976)	Examine latitudinal and longitudinal distributions, abundances, and length frequencies. Compare gear types.	Identification and spatial distribution of early-life stages of all taxa with pelagic larvae. Discern the advantages and disadvantages of sampling with different gear types.
Laroche (1976)	Examine taxonomic composition, relative abundance, seasonal occurrence, and diel depth distribution of early-life stages of fish collected off the mouth of the Columbia River.	No conclusive diel or tidal depth differences in abundance. The important forage taxon Osmeridae was dominant, followed by *Engraulis mordax*. Most early-life stage taxa were collected in January-June.
Pearcy et al. (1977)	Examine annual, seasonal, latitudinal, longitudinal, vertical, and diel distributions, abundances, length frequencies, and stage duration of larvae. Estimate age and duration of pelagic life.	Variability in the annual, seasonal, spatial, and diel distributions, abundances, and length-frequencies of early-life stages of important commercial taxa. Duration of the pelagic larval stage for *Glyptocephalus zachirus* and *Microstomus pacificus* estimated to be 1 year, while that for *Eopsetta jordani* is estimated at 6 months.
Richardson and Pearcy (1977)	Examine annual, seasonal, latitudinal, longitudinal, vertical, and diel distributions, abundances, and assemblages of larvae. Compare distribution patterns of larvae off the mid-Oregon coast with those found in nearby Yaquina Bay, elsewhere in the northeast Pacific Ocean, and with other planktonic components.	Variability in the annual, seasonal, spatial, and diel distributions, abundances, and assemblages of larvae of commercially and ecologically important taxa. Coastal and offshore assemblages were identified. Peak abundance in both assemblages occurred between February and July. The larval taxa present in the coastal assemblage were similar to those in Yaquina Bay, but dominant taxa were very different. The coastal zone is an important spawning area for the commercially important species *Parophrys vetulus*, which utilizes Yaquina Bay estuary during part of its early life. Larval fish and zooplankton trends do not always correspond with each other.
Laroche and Richardson (1979)	Examine annual, seasonal, latitudinal, longitudinal, vertical, and diel distributions, abundances, and length frequencies of larvae and their relation to environmental factors (i.e., coastal winds, surface water transport, upwelling, coastal precipitation, temperature, and salinity). Compare gear and tow types. Estimate age and duration of pelagic life.	Variability in the annual, seasonal, spatial, and diel distributions, abundances, and length-frequencies of early-life stages of important commercial taxa, and their relation to environmental factors. Development of an indirect method to obtain rough estimates of age from size composition for *Parophrys vetulus* larvae. Duration of the pelagic larval stage for *P. vetulus* estimated to be 18–22 weeks.
Richardson and Laroche (1979)	Document developmental characteristics to aid in taxonomic identification, and seasonal, latitudinal, and longitudinal distributions and length frequencies.	Identification and seasonal and spatial distribution of early-life stages of commercially important taxa.

(continued)

TABLE 2, cont'd.
Study purpose and primary results and management implications of studies listed in Table 1.

Study	Purpose	Scientific, management, and sampling implications
Laroche and Richardson (1980)	Document developmental characteristics to aid in taxonomic identification, and seasonal, latitudinal, and longitudinal distributions and length frequencies.	Identification and seasonal and spatial distribution of early-life stages of commercially important taxa.
Richardson et al. (1980a)	Document developmental characteristics to from egg through benthic juvenile to aid in taxonomic identification, and seasonal, latitudinal, and longitudinal distributions and length frequencies.	Identification and seasonal and spatial distribution of early-life stages of commercially important taxa.
Richardson et al. (1980b)	Examine annual, seasonal, latitudinal, longitudinal, and diel distributions, abundances, length frequencies, and assemblages of larvae and their relation to environmental factors (i.e., coastal winds, surface water transport, upwelling, coastal precipitation, temperature, and salinity).	Variability in the annual, seasonal, spatial, and diel distributions, abundances, length-frequencies, and assemblages of larvae of important commercial and ecological taxa, and their relation to environmental factors. Coastal, transitional, and offshore assemblages persisted along the coast and from year to year. Differences in the extent off offshore distribution of the coastal assemblages among years reflected differences in local coastal wind patterns. These consistencies suggests that transport may not be a major cause of larval mortality and recruitment failure in the northern California Current (NCC).
Kendall (1981)	Describe the life-history patterns of North Pacific fishes, the constraints on fisheries investigations imposed by these patterns, and offer some suggestions for further studies.	Broad, theoretical discussion of the importance of early-life history stages and studies to fisheries research in the northeastern Pacific Ocean.
Laroche and Richardson (1981)	Document developmental characteristics to aid in taxonomic identification, and seasonal, latitudinal, and longitudinal distributions and length frequencies.	Identification and seasonal and spatial distribution of early-life stages of commercially important taxa.
Methot (1981)	Determine and compare the larval growth rates of two co-occurring, dominant species. Examine covariance in growth rate between the species among samples for clues to relationships between larval fish and their environment.	Larval growth of important forage species. No correlation found between *Engraulis mordax* and *Stenobrachius leucopsarus* growth rates. Based on ambient water temperatures, growth of *E. mordax* larvae appears to be similar in the laboratory and in the sea.
Parrish et al. (1981)	Present a simplified, but unified and consistent, description of broad time and space scale characteristics of ocean surface flow in the California Current region (CCR), and point out a gross pattern of correspondence to these features among the reproductive strategies of the most successful coastal fish stocks.	Insights into the factors regulating recruitment. Anomalies in surface drift patterns could be a major cause of the observed wide variation in spawning success of the major fishery species of the CCR. In the northwest Pacific, coastal fish taxa having pelagic larvae tend to spawn during winter when surface wind drift is generally directed toward the coast, rather than during the more productive upwelling season.
Richardson (1981)	Examine annual, latitudinal, and longitudinal distributions of eggs and larvae of an ecologically important species, and their relation to environmental factors (i.e., temperature, salinity, chlorophyll *a*, and surface currents). Define spawning centers and provide estimates of spawning stock biomass (SSB). Examine ecological data on the early-life stages of *Engraulis mordax*.	Variability in the annual and spatial distributions and abundances of eggs and larvae of an ecologically important species, and their relation to environmental factors. A major spawning center for the northern subpopulation of *E. mordax* is documented off the Oregon-Washington coast beyond the continental shelf, associated with waters of the Columbia River plume. Biomass, SSB, and potential yield estimates are provided.
Laroche et al. (1982)	Examine stage duration, age, and growth.	Spawning season and early-life stage growth of an important commercial species. Duration of the pelagic larval stage for *Parophrys vetulus* estimated to be 8–10 weeks.
Rosenberg and Laroche (1982)	Document developmental characteristics to aid in taxonomic identification, and examine stage duration, age, and growth.	Early-life stage growth of an important commercial species. Duration of the pelagic larval stage for *Parophrys vetulus* estimated to be 120 d (17 weeks).
Gadomski and Boehlert (1984)	Describe annual differences in the feeding ecology of larvae of the commercially important species *Isopsetta isolepis* and *Parophrys vetulus* in order to improve understanding of the causes of variability in year-class strength.	Larval *I. isolepis* have a varied diet. Larval *P. vetulus* are dependent upon a specific prey (i.e., the appendicularian *Oikopleura* spp.). A mismatch of *P. vetulus* and appendicularian abundance peaks may result in significant food-related mortality.
Mundy (1984)	Examine annual, seasonal, and longitudinal distributions, abundances, length frequencies, and community structure of larvae and their relation to environmental factors (i.e., temperature, salinity, wind speed and direction, wind stress curl, upwelling intensity, percipitation, zooplankton, and relative year-class strength estimates for *Isopsetta isolepis* and *Parophrys vetulus*). Determine spawning seasons, transport mechanisms, and early-life histories of coastal northeastern Pacific fishes.	Variability in the annual, seasonal, and spatial distributions, abundances, and length frequencies of early-life stages of commercially and ecologically important taxa, and their relation to environmental factors. Identification of spawning seasons and mechanisms of larval retention. Identified three seasonal spawning groups: winter, spring-summer, and continuous. Abundances of *I. isolepis* and *P. vetulus* larvae are not good predictors of year-class strength in the fishery. Gear comparison.
Young (1984)	Document developmental characteristics to aid in taxonomic identification.	Identification of early-life stages of commercially, recreationally, and ecologically important taxa.

(continued)

TABLE 2, cont'd.
Study purpose and primary results and management implications of studies listed in Table 1.

Study	Purpose	Scientific, management, and sampling implications
Boehlert et al. (1985)	Examine seasonal, longitudinal, diel, and vertical distributions, abundances, and community structure of fish larvae.	Variability in the seasonal, longitudinal, diel, and vertical distributions, abundances, and community structure of early-life stages of important commercial and forage taxa. Identification of longitudinal assemblages. Highest abundances near seasonal thermocline. Evidence for type I and II diel vertical migration.
Brodeur et al. (1985)	Examine seasonal and longitudinal distributions, abundances, length frequencies, and community structure, and their relation to environmental factors, of a nearshore assemblage during anomalous El Niño conditions.	Shoreward displacement and increased abundance of offshore taxa, especially the commercially ecologically important species *Engraulis mordax*, and reduced abundance of nearshore taxa during El Niño conditions.
Grover and Olla (1986)	Detect the possible occurrence of starvation in larval *Anoplopoma fimbria* in the NCC using selected morphological measurements to determine variability in larval condition. Analyze prey size-selection and diet to examine the relationship between larval condition and feeding requirements.	Occurrence of starving larvae at a single station appears to reflect a paucity of copepod nauplii. Definitive shifts in prey size occur at ~12.5 and 20.5 mm standard length (SL). The diet of larger larvae is more diverse than that of smaller larvae. Smaller larvae appear limited in the size of prey they can exploit. This limitation, combined with larvae ≤12.5 mm SL being associated with an unsuitable prey patch, may have been responsible for the high incidence of empty guts and starvation at a single station.
Grover and Olla (1987)	Examine the effect of an El Niño event on the feeding habits of larval *Anoplopoma fimbria*, through a comparison of their diet in the NCC during the 1983 El Niño event and 1980, a year in which oceanographic conditions were not anomalous. Examine ontogenetic differences in diet.	Differential utilization of appendicularians, pteropods, and amphipods was seen in the two years. Small copepods contributed significantly more to the diet in the El Niño year of 1983 than in 1980. Dietary data for 1983 were generally supported by independent plankton observations, especially with respect to the predominance of *Paracalanus parvus,* a small calanoid copepod species. Because adult *A. fimbria* live and spawn in deep water, changes in the food habits of neustonic larvae may represent one of the principal effects of the El Niño conditions on this species.
Kendall and Matarese (1987)	Review studies to describe spawning season, egg and larval morphology, developmental rates, and annual, seasonal, latitudinal, longitudinal, and vertical distributions, larval feeding, and determination of year-class size.	Determination of spawning season and early-life stage morphology, developmental rates, distribution, feeding, and year-class size of an important commercial species. *Anoplopoma fimbria* spawn pelagic eggs in winter near the continental shelf. The eggs float deeper than 200 m and probably require 2–3 weeks to develop. Shortly after hatching, larvae appear to swim to the surface and grow quickly (up to 2 mm per day) as part of the neuston during the spring. There is no transition from larvae to juvenile, but by summer the young-of-the-year fish are found at the surface in inshore waters. Evaluation of how early-life history information might be used to improve fisheries management.
Shenker (1988)	Examine seasonal, longitudinal, and diel distributions, abundances, length-frequencies, and assemblages of larvae and their relation to environmental factors (i.e., upwelling, temperature, salinity, and chlorophyll *a*).	Variability in the seasonal, spatial, and diel distributions, abundances, length-frequencies, and assemblages of larvae of important commercial and ecological taxa, and their relation to environmental factors. Identification of pre-upwelling (i.e., *Anoplopoma fimbria*, *Hemilepidotus spinosus*, *Hexagrammos* spp., *Parophrys vetulus*, and *Scorpaenichthys marmoratus*) and post-upwelling (i.e., *Engraulis mordax* and *Sebastes* spp.) assemblages. These taxa had distinct zonal (east-west) distribution patterns and were generally associated with, or affected by, hydrographic characteristics such as convergences, upwelling, and the Columbia River plume.
Brodeur (1989)	Examine the seasonal, latitudinal, and longitudinal distributions and abundances of all neustonic organisms >5 mm, and compare the taxonomic composition and relative abundance with those found in the stomachs of juvenile salmon collected from the same stations at approximately the same times.	Variability in the seasonal and spatial distributions and abundances of early-life stages of important forage taxa. Study assesses the importance of the neustonic fauna to the diets of juvenile coho and Chinook salmon.
Dunn and Rugen (1989)	Document all ichthyoplankton cruises conducted by the Northwest and Alaska Fisheries Center (NWAFC) during 1965–88.	For each cruise, the report explains areas of sampling, cruise purposes, number of stations sampled, sampling methodology, and associated measurements made, along with a brief assessment of catch composition. Provides a good overview/reference for NWAFC sampling during 1965-88.
Matarese et al. (1989)	Document developmental characteristics to aid in taxonomic identification, and seasonal, latitudinal, and longitudinal distributions.	Identification and seasonal and spatial distribution of early-life stages of all taxa with pelagic, coastal larvae.
Brodeur (1990)	Examine seasonal, latitudinal, longitudinal, and diel occurrence of early-life stage taxa.	Variability in the seasonal and spatial occurrences of early-life stages of important commercial and forage taxa. Study is mostly qualitative.
Ureña (1990)	Examine annual, seasonal, latitudinal, and longitudinal distributions, abundances, and length frequencies of eggs and larvae and their relation to environmental factors (i.e., temperature, salinity, density, and upwelling intensity). Develop standard criteria to stage larval specimens of the eight pleuronectiformes and use that classification with standard length as an indicator of a chronological order of development.	Variability in the annual, seasonal, and spatial distributions, abundances, and length frequencies of early-life stages of eight important commercial flatfish taxa, and their relation to environmental factors. Identification of spawning seasons and mechanisms of larval retention. Increased poleward advection of eggs and larvae from regions south of the study area during the 1983 El Niño event. Gear (depth) comparison.
Doyle (1992)	Examine annual, seasonal, latitudinal, longitudinal, diel, and vertical distributions, abundances, and community structure of eggs and larvae. Gear comparison.	Variability in the temporal and spatial distributions, abundances, and community structure of early-life stages of important commercial and forage taxa, and their relationship to variable environmental factors and seasonal currents. The ecological significance of a neustonic existence. Gear (depth) comparison.

(continued)

TABLE 2, cont'd.
Study purpose and primary results and management implications of studies listed in Table 1.

Study	Purpose	Scientific, management, and sampling implications
Markle et al. (1992)	Document developmental characteristics to aid in taxonomic and stage identification, and examine stage duration, age, and growth.	Spawning season and early-life stage growth of an important commercial species. Duration of the pelagic larval stage for *Microstomus pacificus* estimated to be 18–24 months. Metamorphosis is protracted, seasonally-triggered, and may involve a significant period during which larvae switch between midwater and bottom habitats.
Doyle et al. (1993)	Examine broad-scale spatial patterns in the ichthyoplankton off the west and east coasts of the U.S.	Multispecies spatial patterns imply the existence of persistant and geographically distinct larval fish assemblages, possibly related to specific hydrographic features, off both coasts. On the West Coast, four assemblages were identified: coastal/shelf, slope/transition, Columbia River plume, and oceanic, for which northern and southern components were apparent during winter and spring. Gear (depth) comparison.
Doyle (1995)	Identify anomalies in the seasonal, latitudinal, and longitudinal distribution and abundance patterns of larval taxa during the El Niño event in 1983 with those in other years during the 1980s.	Provides insight into the effects of El Niño events on the spawning patterns and early-life history of ecologically and commercially important fish in the NCC region. Anomalies observed during the El Niño event in 1983 include temporal shifts in peak abundance of some ichthyoplankton, reduced abundance of others, the occurrence of rare southern species, and changes in distribution patterns. These anomalies are attributed to changes in spawning patterns and advection of ichthyoplankton in response to the physical oceanographic anomalies (i.e., water temperature and transport) resulting from El Niño. A high level of stability in the spawning and early-life history patterns of taxa is implied, since only a small portion of the dominant taxa were affected by the sttrong 1983 El Niño event. Gear (depth) comparison.
Bentley et al. (1996)	Examine latitudinal and longitudinal distributions of eggs and larvae, and estimates of egg production and mortality and SSB.	First documented occurrence of early-life stages of *Sardinops sagax* north of California since the 1940s. Early-life stage spatial distribution, egg production and mortality, and SSB estimates for a commercially important taxa. Identification of an association between geographic distribution of *S. sagax* eggs and the 14°C isotherm derived from the 1–10 m depth zone. The isotherm of 14°C may form a distinct boundary for spawning *S. sagax* off Oregon and may prove useful for determining boundaries for future spawning surveys.
Emmett et al. (1997)	Examine annual, latitudinal, and longitudinal distributions of eggs and larvae of an ecologically important species.	Abundance and distribution of *Engraulis mordax* eggs and larvae were extremely limited when compared to those observed in the mid-1970s. Eggs, and thus spawning, occurred nearshore on the continental slope. Larvae occurred offshore in the Columbia River plume.
Doyle et al. (2002)	Identify dominant taxa and taxonomic assemblages in the ichthyoplankton of the Gulf of Alaska, eastern Bering Sea, and U.S. West Coast. Describe latitudinal and longitudinal distributions of these assemblages, and relate them to the prevailing oceanographic conditions in the three regions.	Occurrence of geographically distinct assemblages of larvae in each region. For all three regions, assemblage structure is primarily related to bathymetry, and shelf, slope, and deep-water assemblages are described. This shallow to deep-water gradient in taxon occurrence and abundance reflects the habitat preference and spawning location of the adult fish. Another degree of complexity is superimposed on this primary assemblage structure and appears to be related to local topography and the prevailing current patterns.
Matarese et al. (2003)	Create a regional atlas to summarize and illustrate the annual, seasonal, latitudinal, and longitudinal distribution, abundance, and length-frequency patterns of fish eggs and larvae of 102 taxa within 34 families found in the northeast Pacific Ocean.	Summary of general life-history data for each taxon. Variability in the annual, seasonal, and spatial distributions, abundances, and length frequencies of egg and larval stages of numerically dominant taxa. Framework for future studies to define assemblages of larvae and how their occurrences reflect spatial and temporal patterns.
Emmett et al. (2005)	Examine annual, latitudinal, and longitudinal distributions and abundances of eggs and larvae, and relate them to ecological factors.	Variability in the annual, seasonal, and spatial distributions and abundances of early-life stages of an important commercial and forage species, and their relationship to environmental variables. Identification of an association between geographic distribution of *Sardinops sagax* eggs and surface temperatures between 14° and 15°C.
Shanks and Eckert (2005)	Investigate the effects of life-history traits on alongshore larval transport in the CCR, specifically whether combinations of life-history traits (timing of propagule release, planktonic duration, etc.) might "move" larvae against the dominant southward flow of the California Current. Because oceanographic variables controlling flow change dramatically between nearshore (<30 m deep) and deeper waters, the study compares life-history traits of nearshore fishes to taxa from the continental slope.	Pelagic larval durations of shelf/slope taxa (as are found in the NCC) are long (~136 d). Offspring are pelagic winter through summer and are found at depth below the mixed layer offshore. Offspring experience northward flow in winter and southward flow in spring/summer, perhaps minimizing alongshore drift. Adults are both long-lived and highly fecund. The pelagic phase, rather than being dispersive, may be selected to achieve a migration between larval pelagic and adult benthic habitats. Summaries of data on life-history traits and cross-shelf and vertical distributions of fish larvae.
Auth and Brodeur (2006)	Identify, quantify, and compare distributions, abundances, diversity, evenness, and assemblages across annual, seasonal, longitudinal, and vertical scales, and relate them to temperature and salinity.	Variability in the annual, seasonal, and spatial distributions, abundances, and community structure of early-life stages of important commercial and forage taxa, and their relationship to environmental variables. Community is similar to that reported in previous studies. Trophic interaction between fish larvae and ctenophores and salps. Occurrence of *Sardinops sagax* larvae in the NCC. Identification of longitudinal (coastal, offshore, and Columbia River plume [consisting of *Engraulis mordax* and *S. sagax* larvae]) and seasonal (spring, summer, and fall) assemblages. Cross-shelf location most important factor to community structure. Sampling in the upper 100 m of the water column is sufficient to characterize the larval community. Larvae generally possitivelty correlated with in situ temperature, and negatively correlated with salinity.

(continued)

TABLE 2, cont'd.
Study purpose and primary results and management implications of studies listed in Table 1.

Study	Purpose	Scientific, management, and sampling implications
Brodeur et al. (2006)	Examine changes in the ichthyoplankton community resulting from the aomalous late upwelling in 2005, which was unrelated to ENSO.	Early-life stages of the commercially important species *Merluccius productus* and *Trachurus symmetricus* were collected in unprecedented numbers during 2004–05, suggesting that their spawning area had shifted north by ~1000 km. *E. mordax* larvae were found at many stations outside of their normal Columbia River plume habitat. These anomalous occurrences were related to the unusual ocean conditions in 2004–05, similar to El Niño conditions.
Charter et al. (2006)	Document latitudinal and longitudinal abundances and distributions of ichthyoplankton and paralarval cephalopods throughout the CCR in 2006.	This report provides ichthyoplankton and associated station and tow data from the Oregon, California, and Washington Line-Transect Expedition (ORCAWALE) survey during 2006 and makes these data available to all investigators.
Pool and Brodeur (2006)	Examine annual, seasonal, latitudinal, longitudinal, and diel distributions, abundances, and community structure of early-life stages and their relation to environmental factors.	Variability in the annual, seasonal, diel, and spatial distributions and abundances of early-life stages of important salmonid forage taxa, and their relationship to environmental variables.
Auth et al. (2007)	Examine diel and vertical distributions, abundances, diversity, evenness, and community structure of fish eggs and larvae, and their relation to temperature and salinity.	Variability in the diel and vertical distributions, abundances, and community structure of early-life stages of important commercial and forage taxa, and their relationship to environmental variables. Community is similar to that reported in previous studies. Occurrence of *Sardinops sagax* and *Trachurus symmetricus* larvae and eggs in the NCC. Identification of depth-stratified (<100 m and >100 m) assemblages. Depth most important factor to community structure. Sampling in the upper 100 m of the water column is sufficient to characterize the ichthyoplankton community. More larvae collected at night than during the day, so sampling should be conducted at night to minimize effects of net avoidance. Evidence for type I and II diel vertical migration. Eggs and larvae generally possitivelty correlated with in situ temperature, and negatively correlated with salinity.
Phillips et al. (2007)	Document relatively high occurrence of early-life stage *Merluccius productus* in the NCC in 2003–06.	Spawning and recruitment of commercially important *M. productus* has expanded northward from its historical spawning region off southern California, which will likely have major economic and ecological consequences in the NCC.
Auth (2008)	Analyze distribution, abundance, and community structure from the central and NCC region to investigate interannual, latitudinal, longitudinal, and vertical variability during the transitional month (with respect to larval community structure) of May in three consecutive years, each representing periods of highly variable climate-induced oceanic conditions.	The ichthyoplankton community changed swiftly and dramatically in response to the variable environmental conditions of 2004–06. Larvae were found in higher abundances in norther (>43°N) than southern (<43°N) stations. Latitude, station depth, and sea-surface temperature were the most important factors explaining variability in larval abundances of important commercial and forage taxa. Occurrence of commercially important *Merluccius productus* and *Sardinops sagax* larvae throughout the study area. Taxa clustered into two latitudinal and three longitudinal groups suggesting that limited, but representative, sampling within each group could adequately describe the community structure of each region.
Brodeur et al. (2008)	Identify and compare abundance, diversity, and community structure from two nearshore stations off the central Oregon coast to test for annual, seasonal, and monthly differences. Relate the larval communities to fluctuating marine environmental conditions in this dynamic upwelling region using a long time-series of data.	Identified two seasonal assemblages: winter/spring (January–May) and summer/fall (June–December), with the winter/spring assemblage having the highest diversity and abundance. Diversity and abundance of important commercial and forage taxa were positively related to the Pacific Decadal Oscillation (PDO). During cool years (1999–2002; negative PDO), the assemblage was dominated by northern or coastal taxa such as *Ammodytes hexapterus, Citharichthys* spp., and Osmeridae, whereas in warm years (2003–05; possitive PDO), southern or offshore taxa such as *Parophrys vetulus*, *Engraulis mordax*, and *Sebastes* spp. were more important. These changes were related to concurrent shifts in the zooplankton biomass and composition off Oregon during cold and warm environmental regimes. Identified a small subset of fish whose larvae can be monitored as indicators of warm and cold phases in the NCC. Occurrence of commercially important *Merluccius productus* and *Sardinops sagax* larvae collected in the study area.
Parnel et al. (2008)	Examine annual, seasonal, and longitudinal distributions, abundances, and community structure of eggs and larvae, and their relation to environmental factors (i.e., temperature, salinity, chlorophyll *a*, Columbia River flow, and day of spring upwelling transition), near the mouth of the Columbia River.	Variability in the annual and seasonal distributions, abundances, and community structure of early-life stages of commercially and ecologically important taxa, and their relation to environmental factors. Identified strong taxonomic associations based primarily on season (before or after the spring upwelling transition date). Egg and larval abundances were most correlated with temperature. Occurrence of *Trachurus symetricus* eggs denotes spawning of this normally southern commercially important taxa in northern waters.
Auth (2009)	Compare the ichthyoplankton in the heavily-sampled coastal and shelf region to those in the under-sampled far-offshore region in the NCC. Relate these abundance data to local and basin-scale environmental variables and indices.	Abundances of all dominant commercially and ecologically important larvae were significantly greater in the normally unsampled, far-offshore (>2000 m depth) region than in the normally sampled, coastal and shelf (<2000 m depth) region. *Engraulis mordax* were exclusively found in the warmer Columbia River plume waters in the far-offshore region in June and July 2008. *Sardinops sagax* eggs and larvae were exclusively found at the furthest offshore stations. Abundances were generally positively correlated with temperature and negatively correlated with salinity. Sampling designs should incorporate far-offshore stations at least 100 km beyond the continental slope if they are to truely capture the entire community structure of the important commercial and forage species in the NCC.
McClatchie (2009)	Document seasonal, latitudinal, and longitudinal abundances and distributions of *Engraulis mordax* and *Sardinops sagax* eggs throughout the CCR in 2008.	This report provides *E. mordax* and *S. sagax* egg data from the California Current Ecosystem Survey (CCES) cruises during 2008 to aid in estimation of spawning locations, success, and SSB.

(continued)

TABLE 2, cont'd.
Study purpose and primary results and management implications of studies listed in Table 1.

Study	Purpose	Scientific, management, and sampling implications
Bystydzieńska et al. (2010)	Examine stage duration, age, and growth.	Spawning season and early-life stage growth of an important forage species. Back-calculated hatch dates suggest a prolonged spawning season without any distinct peak.
Lo et al. (2010)	Examine annual, seasonal, latitudinal, and longitudinal distributions of eggs and early-life stages, estimate egg production and SSB, and identify spawning habitat of a commercially and ecologically important species.	Spawning habitat in 2003–04 was located in the southeastern area of the Pacific northwest coast (PNC), a shift from the northwest area off the PNC in the 1990s. Egg production off the PNC for 2003–04 was lower than that off California and that in the 1990s. Because the biomass of *Sardinops sagax* off the PNC appears to be supported heavily by migratory fish from California, the sustainability of the local PNC population relies on the stability of the population off California, and on local oceanographic conditions for local residence.
Auth (2011)	Investigate annual, seasonal, latitudinal, and longitudinal distributions, abundances, diversity, and community structure. Identify and describe the variability within taxonomic, annual, seasonal, latitudinal, and longitudinal ichthyoplankton assemblages within the NCC. Identify taxa indicative of each temporal and spatial assemblage. Identify the local and larger-scale environmental factors that influence variability in ichthyoplankton abundance and diversity.	Several seasonal and cross-shelf assemblages were identified, and annual, seasonal, latitudinal, and longitudinal gradients of taxonomic associations with significant indicator taxa were found. Community is similar to that reported in previous studies. Sampling can be reduced to four seasonal collections and fewer stations within each of three cross-shelf regions, and still adequately describe the spring-fall larval community. The larval community is influenced by variable local and larger-scale environmental conditions. Distance from shore, salinity, and temperature were the local environmental factors explaining the most variability in larval abundance. Indices such as Columbia River outflow and SST can help predict the spawning success of several dominant ecologically and commercially important taxa 2–4 months in advance. Researchers and managers may be able to incorporate the temporal and spatial distributions and abundances, along with in situ environmental statistics, into fisheries models.
Auth et al. (2011)	Examine seasonal and pseudo-decadal changes in abundance, community structure, diversity, and evenness using a long time-series of data from several studies. Incorporate readily available regional and basin-scale environmental data into generalized additive models (GAMs) to determine the most important environmental factors relating to the trends in larval fish data. Support informing fisheries management of the influence of climate on stock structure by affecting recruitment success of larval life-history stages.	The most abundant taxa from 1996–2005 differ from those of earlier decades. Abundances were generally greater in winter/spring (January-May) than summer/fall (June–December). Using GAMs, variations in taxa presence-absence and abundance were compared to climate indices such as the PDO, Northern Oscillation Index (NOI), and the Multivariate ENSO Index (MEI) and local environmental factors, such as upwelling, Ekman transport, and wind stress curl. Significant relationships were found for various combinations of environmental variables with lag periods ranging from zero to seven months. Large-scale climate indices explained more of the variance in abundance and diversity than did the more local factors. Readily-available oceanographic and climate indices can explain and possibly predict variations in the dominant, commercially and ecologically important ichthyoplankton taxa in the NCC. Different indices explain more variability in abundances of different taxa possibly due to variability in life-history strategies.
Brodeur et al. (2011a)	Identify the early-life stage at which recruitment may be set and provide indicators of year-class strength. Relate environmental indices to larval abundance, predation by salmonids, and future recruitment of *Sebastes* spp.	Multiple indicators used to identify upcoming strong year classes in *Sebastes* spp. suggest that 2004 and 2010 were above average for their recruitment. Continued monitoring of larval abundance may be used to predict future strong and weak year classes of this commercially important taxon.
Brodeur et al. (2011b)	Examine seasonal, latitudinal, and longitudinal abundances, distributions, length frequencies, and community structure of early-life stages of important salmonid prey taxa. Compare the taxonomic and size composition of potential salmonid prey organisms caught in a range of plankton/micronekton sampling gears with those found in juvenile *Oncorhynchus kisutch* and *O. tshawytscha* stomachs collected concurrently in the same locations in coastal marine waters, with a goal of evaluating factors related to prey estimation using different gears.	Gear comparison. Overlap between prey fields and salmonid diets was moderate for samples from the larger gear types but low for those from bongo nets towed in the same area.
Sogard (2011)	Examine variability in interannual growth rates and their relation to environmental factors and recruitment.	Growth rates were related to fish size and water temperature. Interannual differences in growth corresponded to large scale (e.g., PDO) oceanographic indices of productivity and transport in the NCC. Growth during the early neustonic stage was generally correlated with subsequent recruitment to the adult stock. The results are consistent with longer-term observations of strong environmental drivers of recruitment in West Coast *Anoplopoma fimbria* and suggest that bottom-up processes during the early-life stages are important determinants of year class success.
Watson and Manion (2011)	Document seasonal, latitudinal, longitudinal, and depth-stratified (surface versus entire water column) abundances and distributions of ichthyoplankton and paralarval cephalopods throughout the CCR in 2008.	This report provides ichthyoplankton and associated station and tow data from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) and CCES cruises during 2008, makes these data available to all investigators, and serves as a guide to the computer data base.
Takahashi et al. (2012)	Examine seasonal variability in growth rate of early-life stages of *Engraulis mordax* in response to physical and biological factors (i.e., upwelling intensity, temperature, chlorophyll *a*, and copepod community) in the anomalously late upwelling year of 2005, and compare these results to the more normal upwelling year of 2006.	Identification of variable spawning timing, location, and success. Delayed upwelling in 2005 resulted in low food availability and consequently reduced *E. mordax* growth rate in early summer, but once upwelling began in July, high food availability enhanced larval growth rate to that typical of a normal upwelling year (e.g., 2006) in the NCC.

TABLE 3
Summary of ichthyoplankton taxa collected in the northern California Current (NCC) region during recent years (1996–2012). Occurrence = rare (frequency occurrence <0.05), common (frequency occurrence >0.05), abundant (mean concentration >5 1000 m^{-3}) as defined by Brodeur et al. 2008 and Auth 2011.

Taxa	Common Name	Occurrence
Elopomorpha		
Undetermined spp.	Leptocephalus larval eels	Rare
Clupeiformes		
Undetermined spp.	Herrings, Anchovies	Rare
Clupeidae		
Sardinops sagax	Pacific sardine	Rare
Engraulidae		
Engraulis mordax	Northern anchovy	Abundant
Bathylagidae		
Bathylagus pacificus	Pacific blacksmelt	Rare
Leuroglossus schmidti	Northern smoothtongue	Rare
Lipolagus ochotensis	Eared blacksmelt	Common
Pseudobathylagus milleri	Stout blacksmelt	Rare
Undetermined spp.	Blacksmelts	Rare
Microstomatidae		
Microstoma microstoma	Slender argentine	Rare
Nansenia candida	Bluethroat argentine	Rare
Osmeridae		
Undetermined spp.	Smelts	Abundant
Phosichthyidae		
Cyclothone signata	Showy bristlemouth	Rare
Sternoptychidae		
Undetermined spp.	Hatchetfishes	Rare
Stomiidae		
Chauliodus macouni	Pacific viperfish	Rare
Tactostoma macropus	Longfin dragonfish	Rare
Aristostomias scintillans	Shiny loosejaw	Rare
Notosudidae		
Scopelosaurus spp.	Paperbones/Waryfish	Rare
Paralepididae		
Lestidiops ringens	Slender barracudina	Rare
Myctophidae		
Electrona rissoi	Chubby flashlightfish	Rare
Protomyctophum crockeri	California flashlightfish	Rare
Protomyctophum thompsoni	Bigeye lanternfish	Common
Tarletonbeania crenularis	Blue lanternfish	Abundant
Nannobrachium regale	Pinpoint lampfish	Common
Nannobrachium ritteri	Broadfin lampfish	Rare
Stenobrachius leucopsarus	Northern lampfish	Abundant
Diaphus theta	California headlightfish	Rare
Notoscopelus resplendens	Patchwork lampfish	Rare
Merlucciidae		
Merluccius productus	Pacific hake	Rare
Gadidae		
Microgadus proximus	Pacific tomcod	Common
Theragra chalcogramma	Walleye pollock	Rare
Ophidiidae		
Spectrunculus grandis	Pudgy cuskeel	Rare
Bythitidae		
Brosmophycis marginata	Red brotula	Rare
Cataetyx rubrirostris	Rubynose brotula	Rare
Gobiesocidae		
Gobiesox maeandricus	Northern clingfish	Rare
Lampridae		
Lampris guttatus	Opah	Rare
Trachipteridae		
Trachipterus altivelis	King-of-the-salmon	Rare
Melamphaidae		
Melamphaes lugubris	Highsnout bigscale	Rare
Scorpaenidae		
Sebastes spp.	Rockfishes	Abundant
Sebastolobus spp.	Thornyheads	Common
Anoplopomatidae		
Anoplopoma fimbria	Sablefish	Rare
Hexagrammidae		
Oxylebius pictus	Painted greenling	Rare
Ophiodon elongatus	Lingcod	Rare
Hexagrammos decagrammus	Kelp greenling	Rare
Hexagrammos lagocephalus	Rock greenling	Rare
Hexagrammos octogrammus	Masked greenling	Rare
Cottidae		
Hemilepidotus hemilepidotus	Red Irish lord	Rare
Hemilepidotus jordani	Yellow Irish lord	Rare
Hemilepidotus spinosus	Brown Irish lord	Rare
Hemilepidotus spp.	Irish lords	Rare
Scorpaenichthys marmoratus	Cabezon	Rare
Myoxocephalus polyacanthocephalus	Great sculpin	Rare
Ascelichthys rhodorus	Rosylip sculpin	Rare
Chitonotus pugetensis	Roughback sculpin	Rare
Enophrys bison	Buffalo sculpin	Rare
Paricelinus hopliticus	Thornback sculpin	Rare
Radulinus asprellus	Slim sculpin	Rare
Radulinus boleoides	Darter sculpin	Rare
Synchirus gilli	Manacled sculpin	Rare
Ruscarius meanyi	Puget Sound sculpin	Rare
Artedius fenestralis	Padded sculpin	Rare
Artedius harringtoni	Scalyhead sculpin	Common
Artedius lateralis	Smoothhead sculpin	Rare
Artedius corallinus or *notospilotus*	Coralline or Bonyhead sculpin	Rare
Clinocottus acuticeps	Sharpnose sculpin	Rare
Clinocottus embryum	Calico sculpin	Rare
Clinocottus globiceps	Mosshead sculpin	Rare
Oligocottus maculosus	Tidepool sculpin	Rare
Oligocottus snyderi	Fluffy sculpin	Rare
Cottus asper	Prickly sculpin	Rare
Leptocottus armatus	Pacific staghorn sculpin	Common
Hemitripteridae		
Blepsias cirrhosus	Silverspotted sculpin	Rare
Agonidae		
Stellerina xyosterna	Pricklebreast poacher	Rare
Bothragonus swani	Rockhead	Rare
Xeneretmus latifrons	Blacktip poacher	Rare
Bathyagonus pentacanthus	Bigeye poacher	Rare
Psychrolutidae		
Malacocottus zonurus	Darkfin sculpin	Rare
Undetermined spp.	Fathead sculpins	Rare
Liparidae		
Liparis fucensis	Slipskin snailfish	Common
Liparis gibbus	Variegated snailfish	Rare
Liparis mucosus	Slimy snailfish	Rare
Liparis pulchellus	Showy snailfish	Rare
Liparis spp.	Snailfishes	Abundant
Carangidae		
Trachurus symmetricus	Jack mackerel	Rare
Bathymasteridae		
Ronquilus jordani	Northern ronquil	Rare
Stichaeidae		
Poroclinus rothrocki	Whitebarred prickleback	Rare
Plectobranchus evides	Bluebarred prickleback	Rare
Anoplarchus purpurescens	High cockscomb	Rare
Xiphister atropurpureus	Black prickleback	Rare
Cryptacanthodidae		
Cryptacanthodes aleutensis	Dwarf wrymouth	Rare
Pholidae		
Pholis spp.	Gunnels	Rare
Ptilichthyidae		

(continued)

TABLE 3, cont'd.

Summary of ichthyoplankton taxa collected in the northern California Current (NCC) region during recent years (1996–2012). Occurrence = rare (frequency occurrence <0.05), common (frequency occurrence >0.05), abundant (mean concentration >5 1000 m^{-3}) as defined by Brodeur et al. 2008 and Auth 2011.

Taxa	Common Name	Occurrence
Ptilichthys goodei	Quillfish	Rare
Ammodytidae		
Ammodytes hexapterus or *personatus*	Pacific sand lance	Abundant
Icosteidae		
Icosteus aenigmaticus	Ragfish	Rare
Gobiidae		
Clevelandia ios	Arrow goby	Rare
Lepidogobius lepidus	Bay goby	Rare
Rhinogobiops nicholsii	Blackeye goby	Rare
Centrolophidae		
Icichthys lockingtoni	Medusafish	Rare
Tetragonuridae		
Tetragonurus cuvieri	Smalleye squaretail	Rare
Paralichthyidae		
Citharichthys sordidus	Pacific sanddab	Abundant
Citharichthys stigmaeus	Speckled sanddab	Rare
Pleuronectidae		
Atheresthes stomias	Arrowtooth flounder	Rare
Embassichthys bathybius	Deepsea sole	Rare
Eopsetta jordani	Petrale sole	Rare
Glyptocephalus zachirus	Rex sole	Common
Hippoglossoides elassodon	Flathead sole	Rare
Isopsetta isolepis	Butter sole	Abundant
Lepidopsetta bilineata	Rock sole	Rare
Lepidopsetta 2	Sole	Rare
Lyopsetta exilis	Slender sole	Abundant
Microstomus pacificus	Dover sole	Common
Parophrys vetulus	English sole	Abundant
Platichthys stellatus	Starry flounder	Rare
Pleuronichthys coenosus	C-O turbot	Rare
Pleuronichthys decurrens	Curlfin sole	Rare
Psettichthys melanostictus	Sand sole	Abundant