ZOOPLANKTON

Zooplankton ("animal" plankton) are the links in the food web between phytoplankton and higher animals such as fishes and whales. Many species are herbivorous grazers, although there are also numerous carnivorous predators. Zooplankton are generally small, with little ability to swim against ocean currents. They are often divided by size, such that meso-zooplankton are 0.2 -200 mm in size and macro-zooplankton are 2-20 cm in size. Many species of fish and commercially-important invertebrates have larval stages which are members of the zooplankton for at least part of their lives. The biology and taxonomy of zooplankton in the North Pacific tend to be better known than for phytoplankton, because of their larger size. However, the inability to survey them quickly and remotely, as is possible using chlorophyll as an index for phytoplankton biomass, means that information on zooplankton is limited in time and in spatial detail.

YELLOW SEA / EAST CHINA SEA

Bimonthly zooplankton samples have been taken in Korean waters over the past decades. Beginning in the late 1980s, the zooplankton biomass on the Korean side of the Yellow Sea has been increasing, with an annual average biomass of 129.2 mg m^{-3} (Figure 1). The causes of the change are not yet understood.

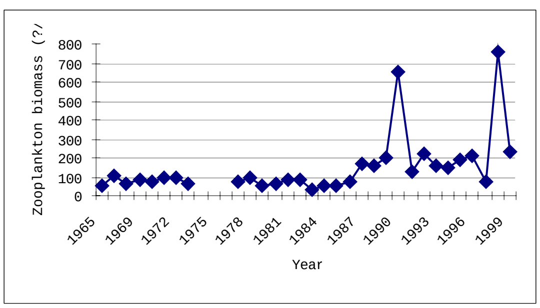

FIGURE 1 ZOOPLANKTON BIOMASS IN THE CENTRAL AREA OF THE YELLOW SEA SINCE THE MID-1960S.

A detailed analysis of bimonthly samples during the 1997-1999 period showed that copepods were the major group comprising 70.1% of the total zooplankton biomass, on average.[1] The remainder was comprised of dinoflagellates (5.78%, mostly N*octiluca*), Cladocera (5.42%), Chordata (5.26%) and Chaetognatha (5.19%). The proportion of copepods was highest during late autumn through early spring because the biomass of other groups increased from late spring and remained high until late autumn. Among the copepods, *Calanus sinicus*, *Paracalanus* sp., *Oithona atlantica*, *Corycaeus affinis* were dominant through all seasons and occurred in most areas, comprising 75.6% of the total copepod biomass. The total zooplankton biomass was highest in June and October. A conspicuous feature of the zooplankton in recent years are blooms of the large scyphomedusa, *Nemopilema nomuri*, in the East China Sea.[2] An unusual bloom was first observed in 2000, and the largest bloom occurred in 2003. Ocean currents carried the jellyfish to Region 3 and Yellow Sea causing serious problems for fishing activities.

Sea of Okhotsk

Regular sampling of zooplankton has been conducted by SakhNIRO in the southwestern Okhotsk Sea (east and south coasts of Sakhalin Island) for many years. Generally, cold-water species (*Thysanoessa raschii, Parasagitta elegans, Metridia okhotensis,* and *Pseudocalanus minutus*) account for the majority of the biomass, but in the southernmost stations warmer water species are found in small numbers. The seasonal and year-to-year changes in zooplankton biomass are similar in magnitude. During the period 1987 to 1996, zooplankton biomass had an absolute minimum in 1991. Preliminary investigations indicated a strong impact of the environment on species structure and distribution of net zooplankton in the southwestern part of the Okhotsk Sea; in cold years, zooplankton biomass is greater than in warm years.

According to a series of complex macro-surveys conducted in the area of the Okhotsk Sea during the 1980s, the average zooplankton biomass is 223 g m^{-2} in the upper level in summer, but in fall this declines to 180 g/m^2. The total zooplankton biomass is about 590 million t, and in fall it is 424 million t.[3] The majority of zooplankton biomass consists of macroplankton irrespective of season. Among them are euphausiids, copepods, hyperiids, chaetognaths (Figure 2).

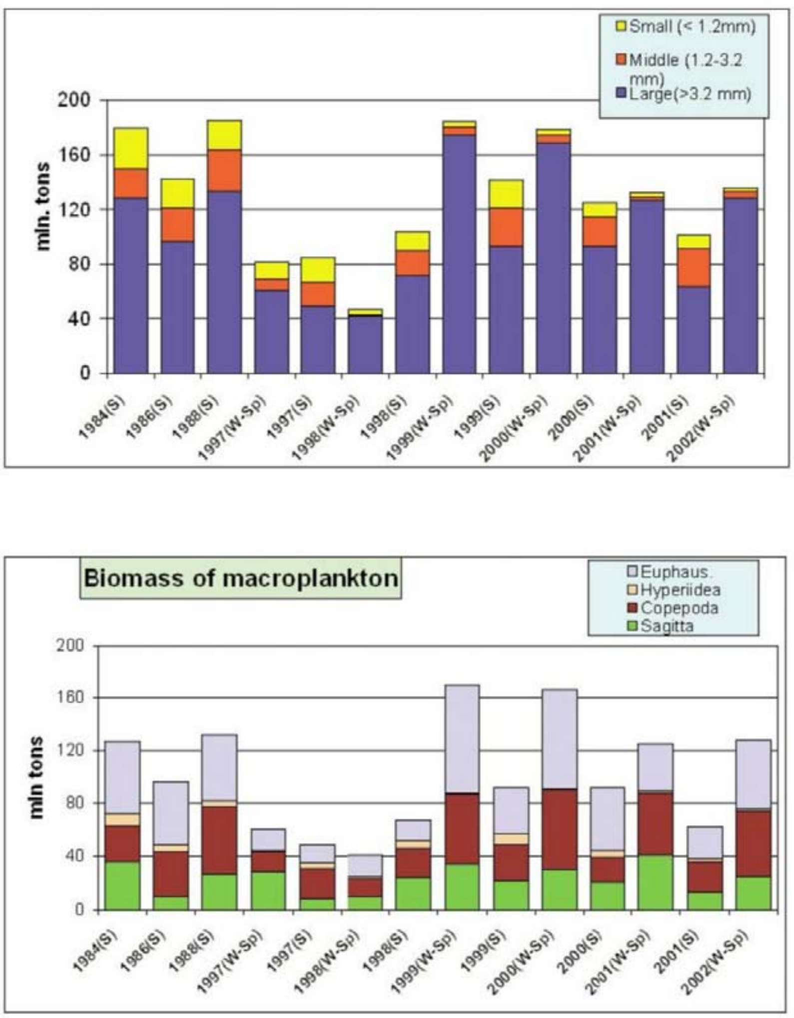

FIGURE 2 DYNAMICS OF SIZE AND TAXONOMIC GROUP BIOMASS IN THE NORTHERN PART OF THE OKHOTSK SEA. W-WINTER, SP-SPRING, S-SUMMER.[4]

A literature survey of zooplankton feeding in the Okhotsk Sea indicated that the biomass of phyto- and euryphagous zooplankton was 171 g m^{-2} in summer, 125 g/m^{-2} in fall. As for predatory zooplankton, the number is 51 g m^{-2} in summer, 56 g m^{-2} in fall. On the whole the share of the predatory zooplankton in 1990s was higher than in 1980s. Obviously this is connected with ecosystem reorganizations,[5] which are known to take place in the Far Eastern Seas. These are caused by a considerable reduction in the number of the most plentiful planktivorous fishes – walleye pollock and Pacific sardine. At the end of the 1990s, the state of plankton communities became stable and thus, the share of predatory zooplankton decreased. Copepods of different sizes form the basis of phyto- and euryphagous species production (70%), while the small copepods take the main part (up to 50%) in this formation. One of the main sources of the predatory zooplankton production is chaetognaths. Converting to units of area, and taking into account the plankton of depth level average, annual non- predatory and predatory zooplankton production is 1672 and 320 g/m^2. For the Okhotsk Sea average annual non-predatory production is 2507 million t, predatory zooplankton production is 542 million t.

Zooplankton biomass sampled by Japanese scientists with a NORPAC zooplankton net from 150 m depth to the surface indicates variability from year to year. Some of this variability is related to the abundance of juvenile pink and chum salmon. In years when juvenile salmon are abundant in the autumn in the Okhotsk Sea, zooplankton biomass tends to be low, at least during the small number of years of sampling. The tables below give an indication of the variability among years.

TABLE 1 ZOOPLANKTON BIOMASS COLLECTED BY JAPANESE RESEARCH VESSELS IN THE OPEN WATERS OF THE OKHOTSK SEA SOUTH OF 51°N.[6]

Year	N	mg m^{-3}
1993	20	122.9
1996	15	75.8
2000	5	257
2002	18	65.6

TABLE 2 DYNAMICS OF AVERAGE BIOMASS IN THE NORTHERN PART OF THE OKHOTSK SEA IN 1997-2002, MG/M³

Seasons, size and taxonomic dimensional groups	1997	1998	1999	2000	2001	2002
Spring						
Small dimensional groups	108	35	38	41	26	18
Middle dimensional groups	73	11	55	49	24	45
Large dimensional groups	547	373	1561	1510	1136	1150
Including:						
Euphausiids	144	145	731	670	326	459
Hyperiids	8	13	9	10	12	17
Copepods	135	124	466	541	417	444
Sagittas	258	91	313	269	370	222
All zooplankton	**729**	**418**	**1654**	**1600**	**1186**	**1213**
Summer-fall						
Small dimensional groups	190	119	142	105	88	-
Middle dimensional groups	155	125	220	195	251	-
Large dimensional groups	460	567	859	845	563	-
Including:						
Euphausiids	131	125	314	417	206	-
Hyperiids	33	51	99	50	29	-
Copepods	214	185	238	170	201	-
Sagittas	78	186	184	194	121	-
All zooplankton	**805**	**811**	**1220**	**1119**	**903**	**-**

Oyashio / Kuroshio

Kuroshio The zooplankton fauna of this region is well known biogeographically, but knowledge of species composition or distribution is limited. The Copepod fauna is dominated by *Neocalanus cristatus, N. plumchrus, E. bungii, M. pacific, Pseudocalanus spp. Oithona spp. Euchaeta/Paraeuchaeta*. Trends in long-term changes of biomass and size composition of copepods from winter to early spring are well known from the egg census survey (Figure 3). In a recent study, the biomass of large copepods in the Kuroshio was shown to be higher in the period before 1977 and in 1999 to 2000 than that in 1977-88, which could be related to the climatic regime shift in the North Pacific.[7]

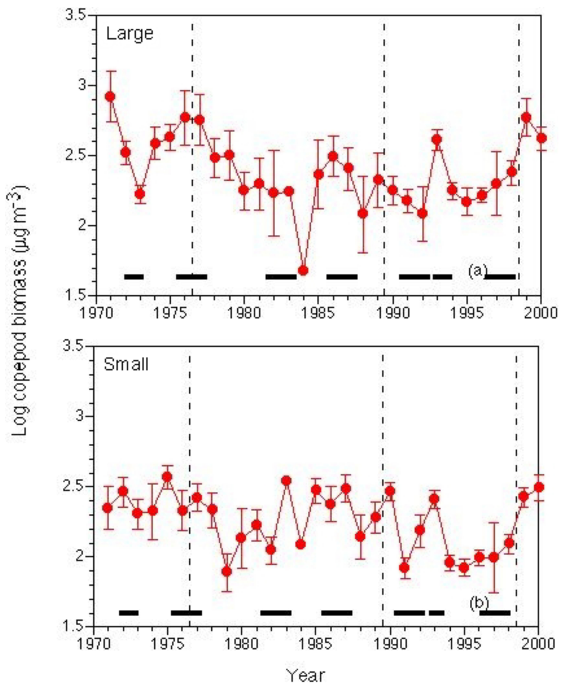

Figure 3 Interannual variations in the log-transformed biomass of large (>1mmPL) and small (<1mmPL) copepods in the Kuroshio in winter. Vertical line and solid bars denotes the climate regime shifts and the periods of El Nino, respectively.

Information about seasonal changes of zooplankton biomass and/or composition are scarce and the result of the 2002-03 survey (Figure 4) suggest that the general pattern will require further observations.[8]

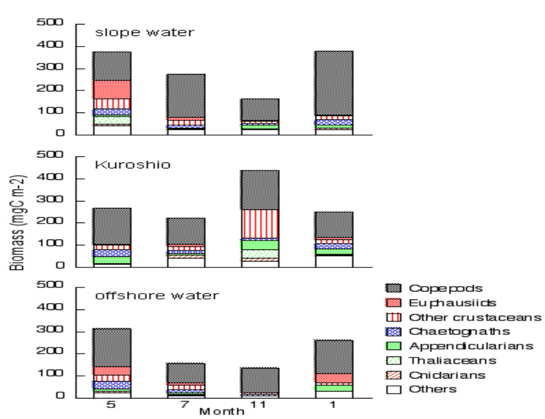

Figure 4 Zooplankton composition along 138°E in 2002-2003

Oyashio Meso-zooplankton biomass in the Oyashio is at the same level as in the western Subarctic Pacific, slightly higher than in the eastern Subarctic Pacific, but lower than in the Bering Sea and Okhotsk Sea. The species composition of meso-zooplankton is similar to other areas of the Subarctic Pacific. Copepods of the genus *Neocalanus* are the main composition in the mesozooplankton community in terms of biomass.[9] In the Oyashio, meso-zooplankton biomass was low from the early 1950s to the mid-1960s, increased in the late 1960s and sustained high values until the late 1970s, decreasing in the early 1980s and thereafter sustained low values through the decade.[10] The variation is similar to that observed in the eastern Bering Sea, and the western and central Subarctic Pacific.[11]

A recent study looked at the interannual variation of meso-zooplankton biomass in Oyashio water using data and samples collected from 1972 to 1999.[12] In spring, meso-zooplankton biomass, presumably composed mainly of *N. flemingeri*, was high in the mid-1970s and decreased considerably in the late 1970s and sustained low values until the late 1990s (Figure 5). The biomass of mesozooplankton in any year was positively related ($r=0.486$, $p<0.05$) to the abundance of diatom cells the previous year. *N. flemingeri* normally has a one year life cycle except for some populations in the western Subarctic Pacific. It has been suggested that copepod egg production is affected by diatom availability the preceding year, such that it affects the number of nauplii surviving the following year. In summer, meso-zooplankton biomass presumably was dominated by *N. plumchrus.* Its biomass was high in the mid 1970s and decreased in the late 1970s, sustaining low values until the late 1980s, whereupon, it increased during the 1990s (Figure 5).

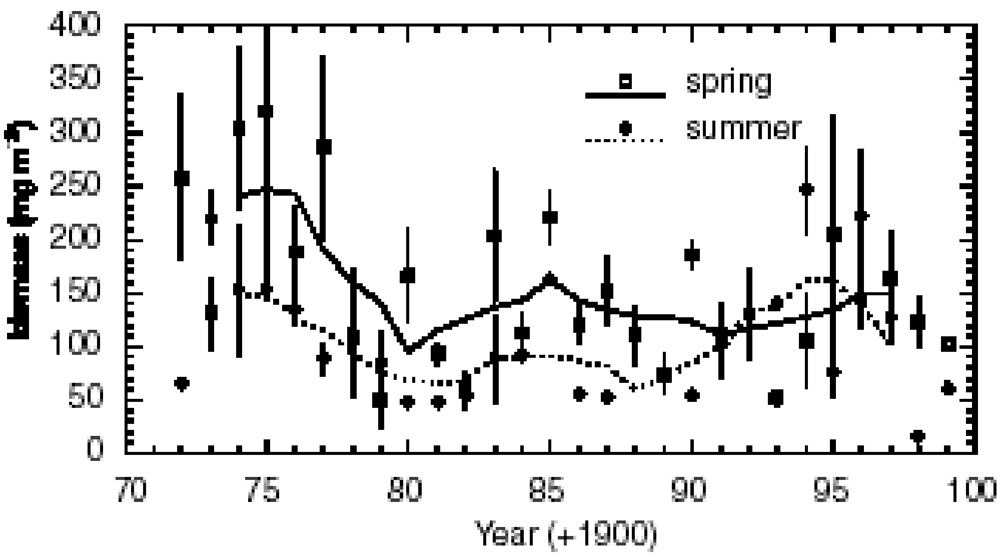

Figure 5 Interannual variation in total zooplankton biomass (mg m^{-3}) in spring (squares) and in summer (diamonds) from 1972 to 1999. Lines show five-year running mean in spring (solid) and summer (broken). Bars denote ± 1 standard deviation.

Western Subarctic Gyre

Mesozooplankton biomass is slightly higher in the western than in the eastern Subarctic Pacific, and is lower than in the Bering Sea.[13] Species composition of the mesozooplankton community is similar to that of other Subarctic North Pacific areas. The large copepods *Neocalanus plumchrus, N. cristatus, Euchaeta bungii* dominate in the western Subarctic Pacific, and can make up 80-95% of total mesozooplankton biomass. Other important non-copepod zooplankton include the chaetognath *Sagitta elegans*, euphausiids *Thysanoessa longipes, Euphausia pacifica,* and the mollusks *Limicina helicina, Clio polita, and Clione limacina*. Studies of long term variation in the zooplankton are few in the western Subarctic Pacific because the sampling frequency is low. Mesozooplankton biomass was relatively high in the 1970s but decreased in the 1980s (Figure 6).

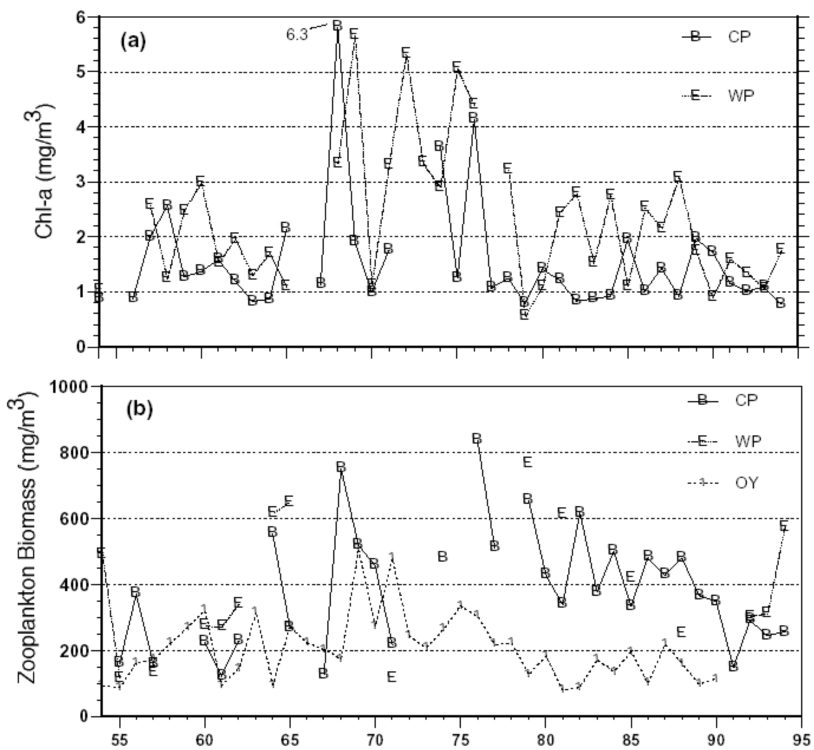

FIGURE 6 CHLOROPHYLL-A AND ZOOPLANKTON BIOMASS TIME SERIES FOR THE CENTRAL PACIFIC, WESTERN PACIFIC AND OYASHIO REGIONS.[13]

Eastern Bering Sea

Zooplankton of the shelf regions of the Eastern Bering Sea are mostly the smaller continental shelf copepods such as *Calanus pacificus*, Pseudocalanus *spp.* and *Acartia longiremus*. The euphausiid *Thysanoessa raschii* is also abundant. Zooplankton composition in the deeper waters of the Bering Sea is dominated by the same large open water species of the eastern and western subarctic North Pacific: *Neocalanus plumchrus, N. cristatus, Eucalanus bungii, Metridia pacifica* (comprising 70-90% of the copepod biomass in the Bering Sea), and other species such as *Pseudocalanus* spp., *Thysanoessa* spp., and *Sagitta elegans* (Longhurst, 1998). Zooplankton biomass in the eastern Bering Sea varies depending on the particular region (Figure 7).

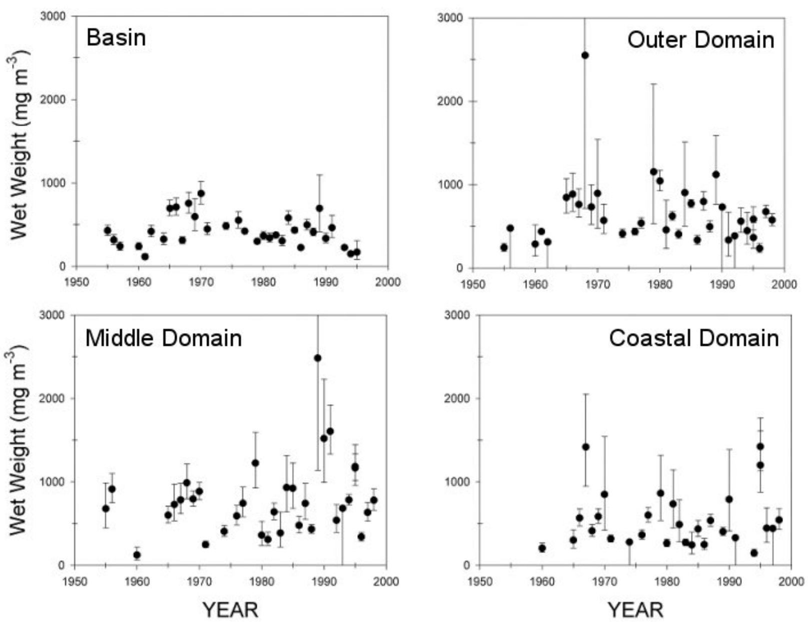

FIGURE 7 CHANGES IN SUMMER ZOOPLANKTON BIOMASS (MEANS WITH STANDARD ERRORS) IN THE SOUTHEASTERN BERING SEA. [14]

The most striking changes in zooplankton in the eastern Bering Sea have been associated with huge increases and sudden declines in the biomass of gelatinous zooplankton (jellyfish) since 1989 (Figure 8). Most of this increase was due to the large scyphomedusa, *Chrysaora melanaster*[15]. The catch of jellyfish during the summer survey in 2000 was the highest recorded, with an estimate for the area surveyed of 336,673 t, although the densities were highly variable on local spatial scales. Abundance has dropped dramatically in the most recent years.

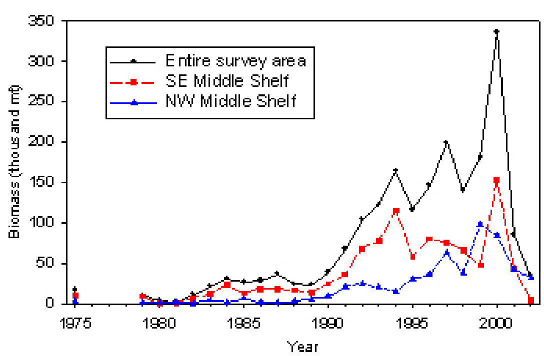

FIGURE 8 BIOMASS INDEX (THOUSAND METRIC TONS) OF JELLYFISH CAUGHT IN BOTTOM-TRAWL SURVEYS ON THE EASTERN BERING SEA SHELF DURING 1975 AND FROM 1979 TO 2002. ALSO SHOWN ARE THE TOTALS FOR THE SE MIDDLE SHELF AND NW MIDDLE SHELF ONLY.

Gulf of Alaska

Zooplankton dynamics have been relatively well-examined in the central and southern part of the Alaska Gyre, particularly at Ocean Station Papa, however relatively little information is available for the continental shelf areas of this region. At least 290 species of zooplankton have been reported from the oceanic, shelf, and coastal waters of the northern Gulf of Alaska, but like elsewhere in the oceanic subarctic North Pacific, three species of *Neocalanus* dominate the mesozooplankton in spring and summer. Zooplankton standing stocks are typically low in the central gyre, ranging from 1.5 g m^{-2} in winter to 30 g m^{-2} in the summer, while nearshore waters can have a high standing stock of up to 1,600 g m^{-2} in the summer and fall.[16] Estimates of annual production are scarce and questionable, but suggest that zooplankton production is about 30-50 gC m^{-2} yr^{-1} on the shelf and in nearshore areas and approximately 13 gC m^{-2} yr^{-1} at Ocean Staion Papa[16]. Zooplankton species composition on the shelf is characterized by a strong cross-shelf gradient in at least some years, although considerable cross-shelf exchanges can occur.[16] The zooplankton community on the inner shelf and within coastal embayments typically consists of a mix of oceanic (primarily *Neocalanus*) and neritic (e.g. *Pseudocalanus*) species. Recently, mesozooplankton biomass has been estimated periodically on the shelf and in the Alaska Gyre using the Continuous Plankton Recorder on commercial shipping vessels of opportunity. Results suggest high variability in the timing and magnitude of the zooplankton bloom on the shelf and a possible increase in biomass in the Alaska Gyre from 2000-2002 (Figure 9), consistent with increases in nutrient levels at Ocean Station Papa.

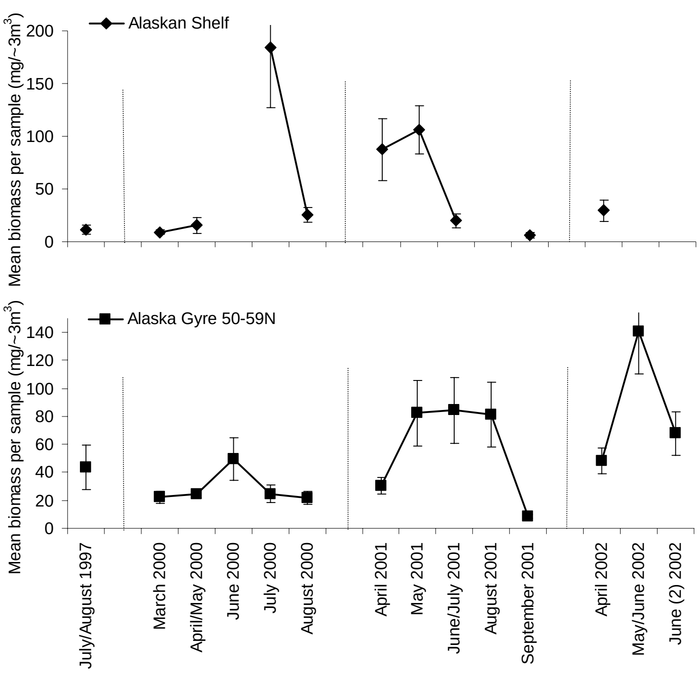

FIGURE 9 MEAN MESOZOOPLANKTON BIOMASS (ESTIMATED FROM ABUNDANCE) FOR CONTINUOUS PLANKTON RECORDER TRANSECTS SAMPLED IN 1997 AND BETWEEN MARCH 2000 AND SUMMER 2002.[17] ERROR BARS ARE ONE STANDARD ERROR.

California Current

Shifts in zooplankton composition in the northern areas of the California Current region, from British Columbia to Oregon, were dramatic during the 1990s and particularly strong at the end of the 1980s and between 1998-1999 (Figure 10). Through most of the 1990s, there was a strong shift toward a more "southerly" copepod community. This reversed abruptly in 1999 and since then, the biomass of most zooplankton taxa has been similar to the period before the 1990s. The California Current region oscillates between warm and cold regimes. A warm regime in the California Current system corresponds with unusually high biomass of warm water zooplankton off Oregon to British Columbia, whereas the reverse is true when cold water predominates. During the warm regime of the 1990s, the spring-summer biomass of subarctic species was unusually low, whereas the biomass of subtropical species was unusually high. This situation reversed in early 1999, as cool temperatures and boreal subarctic zooplankton species became dominant off the Oregon coast, a pattern that persisted through the late summer of 2002. Since then, subarctic species have returned to normal levels. Recent average levels of macrozooplankton biomass in the southern California and Baja California regions are shown in Figure 11. Copepod composition is dominated by the relatively large continental shelf species *Calanus pacificus*; *Acartia clausii* and *A. longiremis* are abundant smaller copepods, as are *Pseudocalanus* spp.and *Oithona similas*. An unusual and important component of upwelling cells is the bright red swimming galatheid crab *Pleuoncodes planipes*, which can comprise 90% of total zooplankton biomass at these locations (Longhurst, 1998).

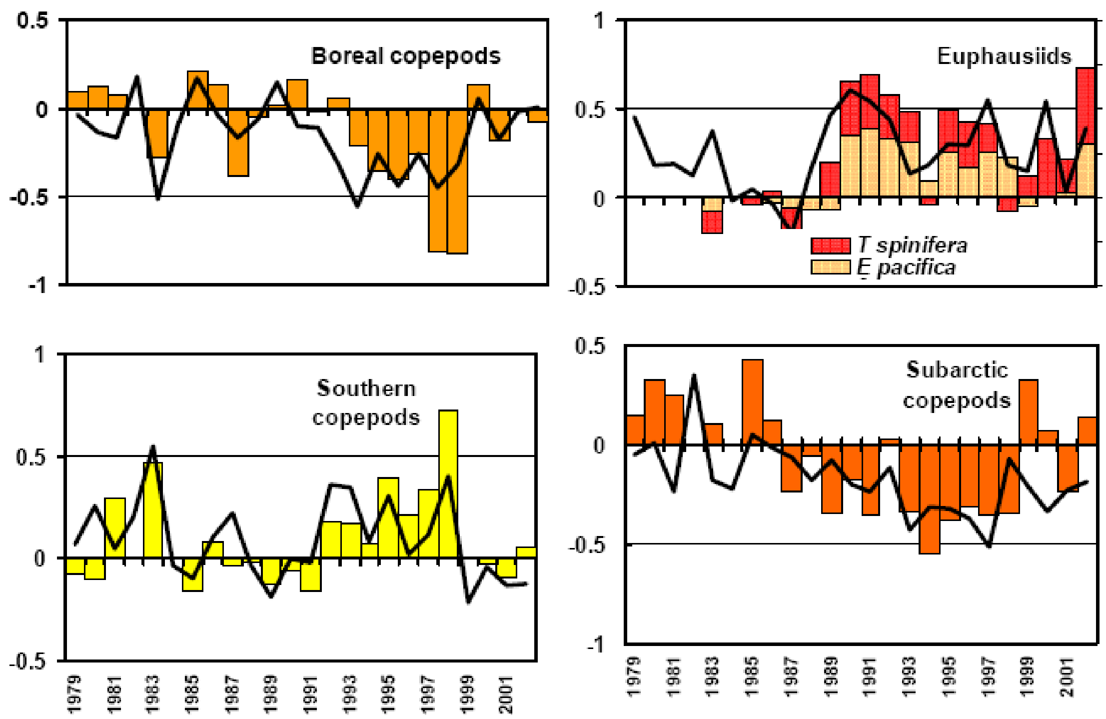

FIGURE 10 ANNUAL ZOOPLANKTON ANOMALIES (1979–2002) AVERAGED ACROSS SOUTHERN VANCOUVER ISLAND STATISTICAL AREAS AND WITHIN GROUPS OF ECOLOGICALLY SIMILAR SPECIES (COLOURED COLUMNS). LINES SHOW FITS TO THE ZOOPLANKTON ANOMALY TIME SERIES FROM STEPWISE REGRESSIONS ON 1985–1998 TIME SERIES OF ENVIRONMENTAL INDICES: LARGE-SCALE (SOLID LINES). NOTE THE CONTINUING "PREDICTIVE" FIT 1979–2002.

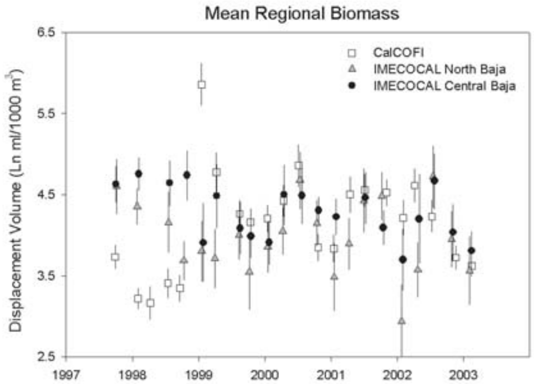

FIGURE 11 MEAN MACROZOOPLANKTON BIOMASS IN THREE REGIONS OF THE SOUTHERN CALIFORNIA CURRENT SYSTEM: SOUTHERN CALIFORNIA (CALCOFI LINES 80-93), NORTHERN BAJA CALIFORNIA (IMECOCAL LINES 100-110), AND CENTRAL BAJA CALIFORNIA (IMECOCAL LINES 113-133).

Gulf of California

Zooplankton biomass during ENSO events appears to remain largely unchanged. Several studies have found no differences between the period of the 1982-1983 ENSO and "normal" years in the central gulf. Increased biomass was observed in the southern gulf during the spring of 1984 and during other surveys.[18] This differs from the strong biomass reductions documented for nearby regions such as the west coast of the Baja Peninsula.[19]

Central North Pacific Transition Zone

Very limited information is available regarding the status of macro-zooplankton or micronekton (which includes juvenile forms of Subarctic and Transitional nektonic and micronektonic species that undergo extensive latitudinal/longitudinal migrations to preferred feeding and reproductive habitats as well as adult and young mesopelagic animals that compose the sonic scattering layer (SSL) in the region).

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