5 Oceanography

In all regions, the oceanography of inshore waters is too site specific to be generalized, and so will not be discussed here in detail. This does not mean that oceanography at this scale is not important to crustaceans, though, as inshore oceanographic features seems to be the dominant factors in determining many, if not most, significant recruitment events with Dungeness crab at least.

Thomson (1981) summarized the prevailing surface currents in the North Pacific Ocean in Figure 29. Currents in the northwest Pacific (Fig. 30) are more complex and variable than in the northeast Pacific because of a more complex topography. The Kamchatka Peninsula, Japan, and the Korean Peninsula create the Okhotsk Sea, the Japan/East Sea and the Yellow Sea, while the Aleutian Islands create the Bering Sea. In contrast, the east-moving Subarctic Current divides when in encounters North America at about the latitude of British Columbia, creating the southern flowing California Current and the northern flowing Alaska Current. The lack of basin-sized water bodies in the north-eastern Pacific may mean that the ocean climate there is more affected by regime shifts in the North Pacific as a whole, although theses events are only now just beginning to be understood.

From British Columbia south, there is a wind-driven seasonal shift in dominant surface coastal current direction, with the Davidson Current flowing northwards in the winter and it being absorbed into the southward flowing, more offshore California Current during the summer (Fig. 31). This reversal in current direction in the spring in particular appears to have implications for at least Dungeness crab. This species has about a four month larval period, and with larval hatching in the southern waters prior to the current reversal, newly hatched larvae tend to be transported offshore and potentially hundreds, if not thousands, of kilometers northwards. The reversal of current direction around the middle of the larval period then tends to transport larvae onshore and southwards. While the actual dispersal fates of individual larvae are unknown, there seems to be extensive mixing of larvae from most of the nearshore coastal regions where adult Dungeness crab occur.

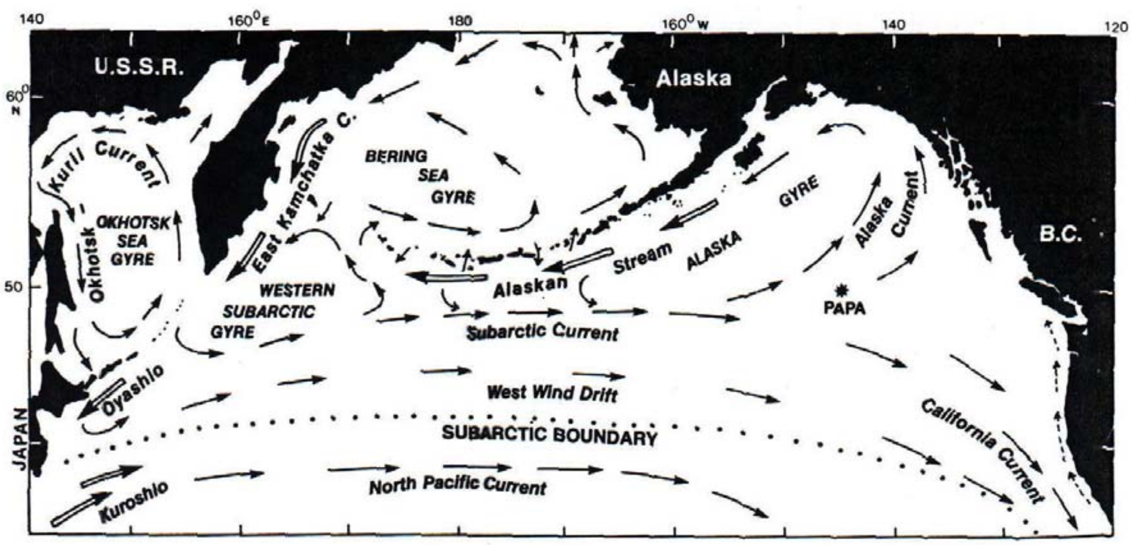

Fig. 29 Schematic diagram of prevailing surface currents in the North Pacific Ocean. Double arrows are intense boundary currents, typically 1-2 $m \cdot s^{-1}$; over most of the region, speeds are less than 0.24 $m \cdot s^{-1}$. Broken arrows correspond to the winter Davidson Current off the north California to southern British Columbia coast (Fig. 13.17 from Thomson 1981).

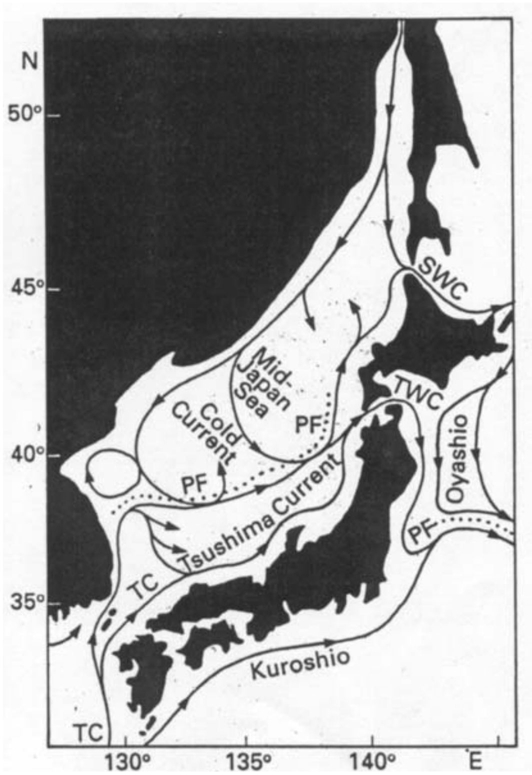

Fig. 30 Surface currents in the Japan/East Sea (Fig. 5.1.1-10 from http://mob.nfesc.navy.mil/documents/BNI/EnvSpec/report-pdfs/Sect5Figs1.PDF)

How regional currents disperse crustacean larvae of other species, and in other areas, is largely unknown, although there appears to be an upcurrent movement of maturing red king crab on the western side of the Kamchatka Peninsula, and subsequent downstream dispersal of larvae along that coast by the counter-clockwise Okhotsk-Kuril Current.

At the northern latitudes, there are a number of counter-clockwise gyres, notably within the GOA and Bering Sea (Fig. 29), of south-eastern Kamchatka, and in the Sea of Okhotsk. There is water exchange between the GOA and the Bering Sea between the Aleutian Islands, and a strong current (East Kamchatka Current) off the eastern Kamchatka Peninsula that becomes the Oyashio Current off northern Japan. This latter current turns eastward at the Subarctic Boundary, feeding the Subarctic Current and West Wind Drift, which both move across the Pacific towards North America.

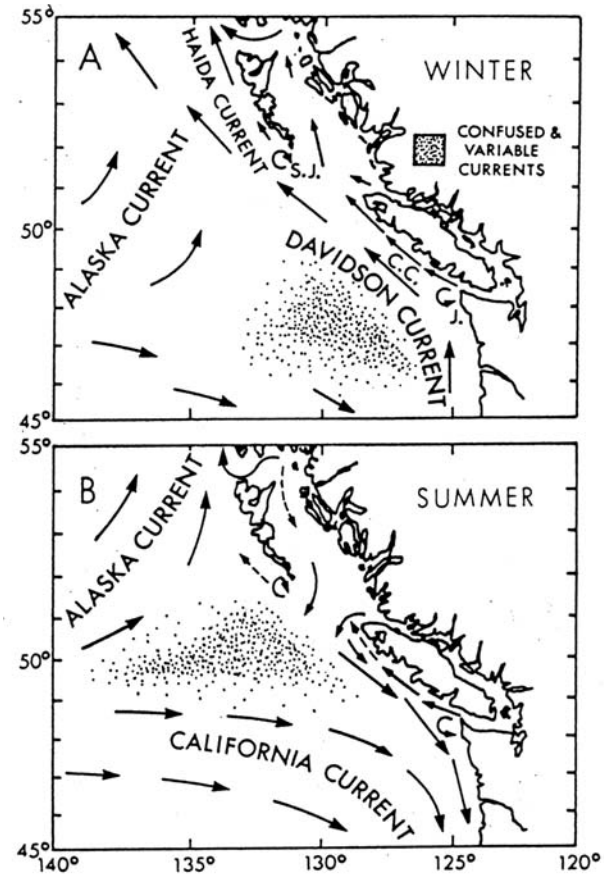

Fig. 31 Regional surface circulation pattern for the northeast Pacific Ocean for A. winter and B. summer based on water property surveys and ship drift information. J. = Juan de Fuca Eddy, C.C. = Vancouver Island Coastal Current, S.J. = Cape St. James Eddy (from Thomson *et al*. 1989).

West of Japan, branches of the Kuroshio Current moves northwards into the Yellow Sea and through the Korea (Tsushima) Strait between South Korea and Japan into the Japan/East Sea. This creates a counter-clockwise gyre towards the head of the Yellow Sea, and the Yellow Sea Warm Current that sweeps around Korea into the eastern portion of the Japan/East Sea, joining the other branch of the Kuroshio Current, the Tsushima (Warm) Current (Fig. 31). There is a cold current (Korean Cold Current) that flows south from the Sea of Okhotsk along the coast in the western Japan/East Sea, creating a series of counter-clockwise gyres. Surface outflow from the Japan/East Sea is eastwards along the northern and southern shores of Hokkaido.

In summary, overall oceanography of the North Pacific is complex, and any variable that would affect many crustacean stocks simultaneously would have to be quite widespread and of considerable regional influence. It is generally accepted that such a widespread climate shift occurred in North Pacific marine ecosystems about 1977, and there is debate about whether additional ones also occurred in 1989 and around 1998 (McFarlane *et al.* 2000). The suggestion for these latter regime shifts has come from a composite climate index based on three aspects of ocean climate conditions (Aleutian Low Pressure Index, the Pacific Atmospheric Circulation Index and the Pacific Interdecadal Low Pressure Index) being linked to decadal changes in eastern Pacific fish population parameters (Beamish *et al.* 1999; King *et al.* 2000). To date, evidence of such regime shifts has not been shown from crustacean landings data, but this does not necessarily mean that large-scale oceanographic events are not affecting crustaceans. Rather, the short time series of credible data and unexplained population collapses form other causes may simply be masking potential signals in crustacean populations of regime shifts.

5.1 Oceanography and recruitment

Major stocks of crabs and shrimps considered by WG 12 inhabit or historically occurred in all of the PICES areas identified by the Climate Change and Carrying Capacity (CCCC) Program, but not in the deep waters underlying the Eastern and Western Subarctic Gyres. There appear to be few trans-boundary stocks with respect to regions or basins, although a given region may contain multiple stocks of a species. For example, the EBS Region contains three stocks of red king crab in Norton Sound, Bristol Bay and around the Pribilof Islands. PICES areas and identified ocean basins are hence often useful geographic units with respect to crab and shrimp stocks.

There appears to be no particular climatic or oceanographic patterns that are unique to crustaceans, as opposed to finfish. Further the same zoogeographic regions that have been differentiated for finfish seem to be largely applicable to macrobenthic crustaceans. These regions correspond well with the ten PICES-GLOBEC CCCC Program Components and seem to derive from large-scale oceanographic features. It is noted, however, that boundaries of zoogeographic provinces may change with increasing depths.

We noted that there were intraspecific as well as interspecific differences in life history mechanisms that related to these regions. These differences may provide natural clines or dichotomies that could be exploited for experiments. For example, in the Sea of Okhotsk (Rodin 1985) and in Bristol Bay (see above), red king crab populations appear to be located so that there is a classic (Jones 1968) denatant drift of larvae to nursery areas and a contranatant ontogenetic migration. By contrast, in the GOA, onshore migration of adults and spawning in semi-enclosed waters seem to be an important mechanism (Gray and Powell 1966, McMullen 1967, Powell 1964, Powell and Nickerson 1965, Powell *et al.* 1973, Powell *et al.* 1974) to ensure that larvae reach suitable nursery grounds. There may be very different climatic effects on these two strategies. Experimentation might deal with contrasting growth and mortality between such regions.

Primary and secondary production in planktonic communities are translated to meroplanktonic larval stages of macrobenthic crustaceans and may be related to year-class strength through match-mismatch mechanisms relating to the timing of phytoplankton blooms relative to larval release. Detritus from upper levels feeds into the secondary production of benthic infauna that serve as primary food sources for crabs and shrimps, as well as other epibenthic fauna. Also, many shrimps make nocturnal vertical migrations in order to feed on zooplankton (Barr 1970, Barr and McBride 1967, Percy 1970).

Physical properties of the bottom and ecological relationships within the benthos have probably not been considered very heavily in CCCC Program deliberations, but are inescapably important relative to crabs and shrimps and other benthic crustaceans.

Crabs and shrimps are much less mobile than finfish and hypothetically less able to adjust their times and places of spawning relative to productivity or other conditions in the euphotic zone that might affect larval survival. Benthic crustaceans may have to cope with ambient, but suboptimal, conditions during egg hatching and early life history while many finfish can move with water masses to better optimize conditions. It is also noteworthy that many northern species of benthic crustaceans carry eggs for about a year prior to hatching and that their larval life span is long (week-months) relative to most fishes (days to weeks). These consequences of relative immobility and long embryonic-larval periods could lead to greater variability in recruitment for crabs and shrimps as opposed to finfishes of the same regions.

Climatic variability may affect crustacean populations directly through recruitment processes as noted above. In much of the GOA and EBS, effects may also have been mediated through predation. For example the regime shift that occurred in the late 1970s produced strong year classes of several ground fishes that in turn may have resulted in decreased shrimp abundance through predation and or competition (Albers and Anderson 1985).

Because many of the region's groundfish are long lived, there is an inertia re change in species dominance within a region. A regime shift that resulted from short-term climatic or oceanographic phenomena could potentially produce long-term ecological effects due to the persistence of strong year classes. This may also be relevant with respect to longer-lived crustaceans such as king and snow crabs.

Top down versus bottom up control of species composition and relative abundance is likely very different between pelagic and benthic crustacean habitats. Most crabs and shrimps in the region have relatively long larval periods (as much as 90 days) during which they are meroplanktonic. It is not clear how meroplankton might be controlled or influenced by the holoplankton community through competition or predation. Interactions between the two groups certainly provide a broad topic of research and experimentation.

Hypothetically, if both meroplankton and phytoplankton abundance were controlled by the dynamics of primary productivity, then there may be a way to use information on primary productivity to model year-class success through the larval phases.

Bottom up control may involve the rate of transfer of primary production to the bottom as detritus. One hypothesis is that warmer conditions are conducive to greater zooplankton abundance or diversity and greater respiration in the upper water column. Since more energy would be consumed in upper layers, less might become available to lower layers or the bottom where detritus may be consumed by filter feeders, that in turn become food for macrobenthic crustaceans. Wind patterns affecting surface water currents appear to be important in some cases.

Top down control through predation may occur when changes in finfish biomasses result in increases or decreases in crab and shrimp biomasses. Albers and Anderson (1985) were able to largely account for declines in shrimp biomass in Pavlof Bay, Alaska, by using conservative estimates of Pacific cod (*Gadus macrocephalus*) predation. The same might be said of certain marine mammals. For example, bay populations of Dungeness crab may be being controlled through sea otter predation (Kimker 1985, Shirley *et al.* 1995).

Some crustacean populations may, in part, be achieving longer-term stability in abundance because of either the coincidental presence of favorable oceanographic regimes or the possible selection over time of unique larval behaviors. An example of the former is the sustained availability of Dungeness crab in McIntyre Bay in Dixon Entrance. This area is the site of continuous counter-clockwise current gyre just to the left of the northern part of Hecate Strait, which separates the Queen Charlotte Islands from mainland BC. Dungeness crab have a relatively long planktonic larval period (3-4 months) in late winter and spring. While the source of larvae may either be local or from some more remote location, sufficient larvae seem to always be retained in this gyre so as to support a substantial fishery in the extensive shallow sand substrate along the southern boundary of the gyre. Crawford and Jamieson (1996) modeled the region's oceanographic features, and have demonstrated that the gyre retains larvae that might otherwise be advected to a less favorable habitat.

An example of selection for unique larval behaviors within a population, and the subsequent independence of some populations from wide-scale oceanographic events that may affect other populations of the species, is that of Strait of Georgia/Puget Sound (Salish Sea) Dungeness crab. Jamieson and Phillips (1993) reported that megalopae of these crab have a vertical diel migration of about 140 m, whereas outer coast megalopae have a vertical diel migration of only about 25 m. The inner waters of the Salish Sea are connected to outer coast waters primarily through the Strait of Juan de Fuca, which is about 200 m deep, 161 km long and 18–27 km wide. Because of the large freshwater discharge of the Fraser River into the Strait of Georgia, Juan de Fuca Strait has an estuarine flow, with outflowing surface water (generally above 100 m depth) and deeper inflowing outer coast water. During the spring and summer, daylight is 14-16 hr and night is about 8-10 hr. As a result, Salish Sea megalopae are mostly in deeper inflowing waters while outer coast megalopae are always in outflowing surface waters. This difference in behavior is suggested to prevent Salish Sea larvae from being flushed out of the Salish Sea during this crab's long larval period, and by separating the crab populations, may allow for the continued genetic selection that was required to achieve this difference in behavior.

Dungeness crab (*Cancer magister*) have cyclic populations from Central California to Washington State, but Alaskan and British Columbia landings are more consistent from year to year and do not display the cyclic patterns observed southwards. Alaskan landings are not in synchrony with that of the contiguous 48 states of the U.S. or with Canada, and landings may instead be market driven over some portion of the historical landings time-series. Since patterns differ between zoogeographic provinces, comparative studies may provide insight into mechanisms of population control.

The reason for the lack of a cyclic fluctuation in abundance not being observed in British Columbia appears to be because of local oceanography (Thomson *et al.* 1998). The brackish water outflow from Juan de Fuca Strait arising from Fraser River discharge into the inner Strait of Georgia moves to the right because of the Coriolis force arising from the Earth's spin. This outflow thus hugs the west coast of Vancouver Island to about its northern tip, where it tends to jet offshore, and is known as the Vancouver Island Coastal Current. During the summer, when outer coast waters from the northern tip of Vancouver Island southwards mostly move southwards, this inner water coastal current, which averages about 30 km in width, continues to move northwards. A boundary zone thus exists off the outer coast of Vancouver Island between the two counter currents, and this seems to operate as a barrier to the shoreward movement of Dungeness crab megalopae that occur in abundance seaward of the Vancouver Island Coastal Current. As explained above, the surface outflow of Juan de Fuca Strait contains virtually no Dungeness crab larvae.

Observations (Jamieson *et al.* 1989) indicated that during substantial storm events, which have southern winds, water piles up against Vancouver Island, which extends to the northwest. This hydraulic head, even though measured in only centimeters, can stop the outflow of Juan de Fuca Strait waters, thereby removing the countercurrent barrier boundary and allowing the Dungeness crab larvae concentrated there to move shorewards, movement which can be rapid because of the storm winds. To survive after settlement, Dungeness crab must settle in waters less than about 50 m depth. Such storm events typically last for 5-7 days, and sufficiently strong ones only seem to occur infrequently in the spring when megalopae are present in abundance. During the past 15 years, substantial crab settlements on the West Coast of Vancouver Island only occurred 2-3 times. This, coupled with the relative lack of suitable sandy substrate off the mostly fjord-like, west coast of Vancouver Island, has meant that the substantial cycling in abundance of crab populations that has characterized California to Washington State waters in recent decades has not occurred in Canada.

The list of factors used to explain changes in Dungeness crab populations is a fair sampling of factors that are thought to control crab populations in general. Additionally, predation on adults (Livingston *et al.* 1993), parasitism and epizootic diseases (Sparks 1985, Sparks and Hibbits 1979, Sparks and Morado 1985) are documented in a number of king and Tanner crab populations. Tanner and snow crabs have broad distributions across several zoogeographic provinces and provide opportunities similar to those for king crabs.