Summary

The hypothesized mechanisms reviewed in this chapter have been selected as having potential for generating low frequency variability in sardine (*Sardinops* spp.) and anchovy (*Engraulis* spp.) populations such as those experienced in the California Current, Humboldt Current, and the Benguela and Kuroshio Current systems. No generally accepted theory yet exists. An initial framework for such a theory is proposed, in which sardine productivity is linked to low frequency variability in boundary current flows, which is also related to the characteristic sea surface temperature anomalies associated with sardine productivity in these systems. During periods of weaker flow, planktonic sardine larvae are able to gain swimming capacity before being flushed from the system, allowing sardines to inhabit the main body of the boundary current. During periods of stronger flows, successful sardine reproduction is restricted to coastal waters, and productivity is relatively low. Anchovies are always restricted to coastal waters, and are more influenced by upwelling and coastal productivity; these characteristics tend to be correlated with boundary current fluctuations, giving rise to a tendency (but not requirement) of sardine and anchovy alternations. The Japanese system lacks coastal upwelling, but the cold, nutrient-rich Oyashio Current provides an analogous function.

A wide variety of mechanisms can be added to this framework as appropriate to individual systems. Physical process include patterns of boundary current flow, including current meandering and formation of cyclonic eddies. A latitudinal shift in the source water coming from the north Pacific has been identified in the California Current, and contributes to the characteristic temperature and nutrient anomalies. Important

biological mechanisms include indeterminate fecundity, strong age-dependent increases in fecundity, temperature preferences, and a regime-dependent plasticity in life history (sardines become longer lived during productive periods). Behavioral mechanisms include possible imprinting on regions or waters where a successful cohort is spawned, and possible learning of favorable migratory paths from older individuals in the population. Patterns of distribution may be abundance-dependent, due to density-dependent habitat selection, and during periods of low abundance, individuals may mix in schools of other species, whether this is to their advantage or to their disadvantage. Multispecies mechanisms include trophic dynamic influences from both higher and lower trophic levels, as well as competition from other species at similar levels. There is evidence of cyclic dominance of pelagic species in some systems, but it is unclear whether it is driven biologically by competition and predation, or by long-term cyclic properties of the physical environment. Fisheries on sardine and anchovy populations have tended to be intense, and have resulted in rapid declines in abundance when productivity rates decrease. Fisheries also affect demographics, including reduced average life span and net lifetime fecundity, as well as introducing geographic variability in survivorship. Fisheries may increase the contrast between favorable and unfavorable regimes.