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Lecture Notes

Part 1

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MARINE PHENOLOGY AND ITS RESPONSE TO CLIMATE CHANGE

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Introduction

Phenology is defined as the study of the timing of recurring biological phases, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species. In other words it is the study of plant and animal life cycle events, which are triggered by environmental changes, especially temperature. The word “phenology” is derived from the Greek *Phainomai,* which means “to appear” or “come into view”, and indicates that phenology has been principally concerned with the dates of first occurrence of natural events in their annual cycle. Examples include the date of emergence of leaves and flowers, the first flight of butterflies and the first appearance of migratory birds, the date of leaf colouring and fall in deciduous trees, the dates of egg-laying of birds and amphibia, or the timing of the developmental cycles of temperate-zone honey bee colonies. In the scientific literature on ecology, the term is used more generally to indicate the time frame for any seasonal phenomena, including the dates of last appearance (e.g., the seasonal phenology of a species may be from April through September). Common changes in the timing of spring activities include earlier breeding or first singing of birds, earlier arrival of migrant birds, earlier appearance of butterflies, earlier choruses and spawning in amphibians and earlier shooting and flowering of plants.

Phenology and climate change

In the past century, the average global temperature has risen by about 0.6°C. That sounds like a small amount, but research on a wide variety of organisms shows that it is enough to drive major biological changes. Keeping track of cyclical events like these from year to year and how they relate to the weather patterns is in a large part what phenology is all about. As ocean temperatures in the North Sea have warmed in recent decades, the life cycles of some species low in the food chain have accelerated significantly, sometimes wreaking ecological havoc (Perkins, 2003). If a species responds to warming, it usually does so in one of several ways. Or the timing of major events in the life cycle of the species—migration, flowering, or egg lying, for example—can accelerate or lag. Other changes, such as in body size or genetic variability within a species, might occur over longer periods. Global warming has led to the expansion of the study of phenology. Phenological patterns are most diverse and least understood.

Phenology offers evidence of climate change and helps in assessment of the significant effects on plants and animals in future. Erratic weather patterns will have long-term effects on life-cycle stages and phenological patterns of almost all plant species and most of the animals. Life cycle events of both animals and plants depend upon several environmental parameters such as temperature, day light, rainfall, wind, snowfall etc. The annually recurring life cycle events such as the timing of migrations and flowering can provide particularly sensitive indicators of climate change. Changes in phenology may be important to ecosystem function because the level of response to climate change may vary across functional groups and multiple trophic levels. The decoupling of phenological relationships will have important ramifications for trophic interactions, altering food-web structures and leading to eventual ecosystem-level changes. Temperate marine environments may be particularly vulnerable to these changes because the recruitment success of higher trophic levels is dependent on synchronization with pulsed planktonic production.

Most examples of phenology are drawn from terrestrial systems, even though marine biota deserve equal attention (Marshall *et al*., 2001), if for no other reason than the commercial importance of fish. The year-class size of marine fish is greatly influenced by the timing of spawning and the resulting match–mismatch with their prey and predators. This was confirmed recently on the basis of satellite remote sensing and a long-term data set of haddock recruitment (Platt *et al*., 2003).

It is believed that global warming will change the latitudinal, altitudinal, and temporal distribution of populations (Parmesan and Johe, 2003). Though generally sparsely investigated, a northward displacement of marine organisms has been observed (Southward *et al*., 1995), and a seasonal shift to earlier appearance of fish larvae has been described (Greve *et al*., 1996). Predictions of the seasonal timing of zooplankton populations on the species level can be made from temperature (Greve *et al*., 2001), and inter-decadal phenological trends for North Atlantic phytoplankton and zooplankton have been found (Edwards and Richardson, 2004). A common obstacle limiting marine phenological studies is the requirement of long time-series of high frequency (at least weekly) observations, of which there are few in the ocean because of the considerable effort required. One such zooplankton time-series, including ichthyoplankton, has been collected near the only offshore island in the North Sea, Helgoland (Greve *et al*., 2005) and the study explored the changes in phenology of the ichthyoplankton using the Helgoland data set.

There is now ample evidence of the effects of climate change on various biota over the last decades, but the literature on the effects of climate on the phonological aspects in aquatic systems is meager. Many marine organisms have life histories adapted to seasonal events in the environment. Changes in the amplitude or phase of seasonal events can therefore significantly affect the productivity and community structure of marine ecosystems, from primary producers to fish stocks to apex predators. Such phenological effects are potentially more disruptive than those associated with interannual climate events and decadal climate shifts. Thus, any set of indicators of ecosystem state would need to include those that quantify changes in the seasonal cycle of dominant physical processes.

For example, Edwards and Richardson (2004) have studied the changes in marine pelagic phenology in the North Sea using long-term data of 66 plankton taxa during the period from 1958 to 2002. They have shown that not only is the marine pelagic community responding to climate changes, but also that the level of response differs throughout the community and the seasonal cycle, leading to a mismatch between trophic levels and functional groups. Planktonic phenological shifts of the magnitude reported in their study, coupled with large-scale shifts in plankton biogeography, will undoubtedly have a considerable effect on ecosystem function in the North Sea. In addition to the effects of overfishing, the decline in abundance of key planktonic prey, and shifts in their seasonality, has recently been implicated in exacerbating the decline in North Sea cod stocks.

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