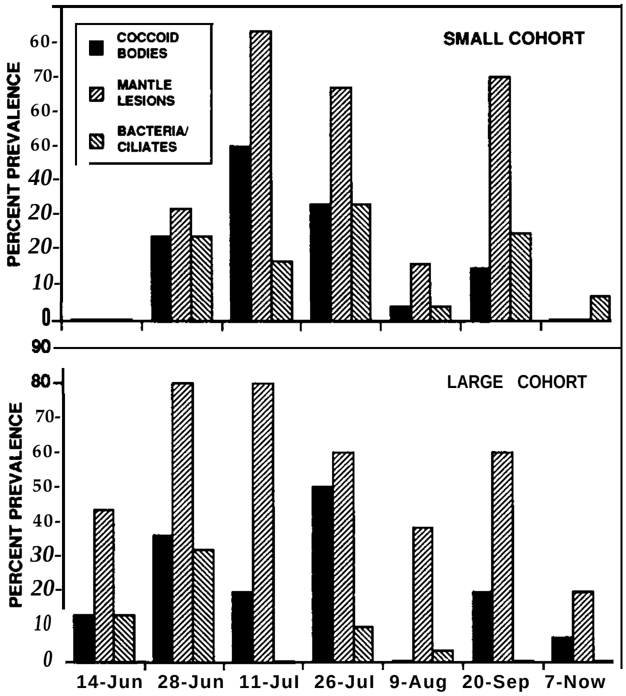

Figure 13. Percent prevalence of 3 pathological conditions observed by light microscopy in tissue sections of Juvenile oysters collected at Oyster Bay.

lesions in the digestive gland were observed only in oysters collected in late September and thereafter.

Although G. *sanguineum* has not been previously reported to be toxic to marine fauna, other dinoflagellate species comon to east coast estuaries in the summer, are toxic to and cause mortalities of bivalves, including oysters (reviewed by Shumway 1990 and Shumway et al. 1990). The eastern oyster, *Crassostrea virginica,* is particularly susceptible toxic dinoflagellates. For example, one week's exposure to bloom concentrations of the unarmored dinoflagelate *Gyrodinium aureolum,* (a species closely related to *G. sanguineum,* and associated with fish and shellfish kills [reviewed by Mahoney et al. 1990]), caused 68% mortalities in juvenile *C. virginica* 10°C, 6 weeks after exposure (Shumway, unpubl. results). Similarly exposed hard clams, *M. mercenaria,* experienced no mortalities. Oysters were able to filter this alga from suspension and were the most affected of 8 bivalve species tested. *Gyrodinium aureolum* was also implicated in mortalities of softshell clams and mussels in Maquoit Bay, Maine, in 1988 (Heinig and Campbell 1992). A bloom of the closely related toxic species *Gymnodinium breve (Ptychodischus brevis)* in North Carolina in 1987 resulted in recruitment failure of bay scallops (Summerson and Peterson 1990) and brevetoxin accumulation in oysters and hard clams (Tester and Fowler 1990). The dinoflagellate *Prorocentrum minimum,* which occurs in Long Island Sound, appears to be toxic to some bivalve species, such as the bay scallop, *Argopecten irradians* (Wikfors and Smolowitz, in press).

Early life history stages of bivalves are generally more susceptible to the detrimental effects of toxic algae. Thus, a summer bloom of *Gyrodinium* cf. *aureolum (= Gymnodinium nagasakiense)* in the Bay of Brest, France, caused heavy mortalities of postset scallops, *Pecten maximus (0.25–3 mm),* but only cessation of growth and shell abnormalities of juveniles (5–30 mm) held in a shore-based nursery, and growth disturbance rings in wild adults on the bay bottom (Erard-Le Denn et al. 1990). In conclusion, the large biomass contribution of *Gymnodinium sanguineum* at the time of oyster mortalities in Oyster Bay, and the fact that no information is available on this species' toxicity to *C. virginica,* raises the possibility that mortalities could have been caused by noxious/toxic phytoplankton. If so, it is not yet clear why no oyster mortalities were associated with the second bloom of G. *sanguineum.*

Roles of Physical Environmental Factors

Environmental factors such as temperature, salinity, and low levels of oxygen can interact synergistically with other stressors. In the present study, however, salinities and temperatures remained within normal levels for this site, although earlier spring warming occurred in 1991 relative to the 4 previous years. The water column is relatively shallow and well mixed, thus precluding oxygen limitation, except in an anoxic microzone that developed within the trays around dead animals. Dense algal blooms could, however, cause transient hypoxia during night hours, when the oxygen demand may exceed supply (see discussion in Heinig and Campbell 1992). Oyster mortalities of three experimental cohorts cultured at this site were restricted to the months of July and August. However, the "late cohort" was the last produced at this study site in 1991; there is no way of determining whether abnormal mortalities would also have affected later cohorts held in the system during the early fall period of decreasing temperatures. Earlier oyster cohorts held in the same growout system, but not tracked by our study, suffered heavy mortalities as early as July 4, when the water temperature was about 22°C. However, the earliest cohort, originating from a spawning in late February, which was deployed in the trays in the first week of April, first reached commercial bottom planting size (20-30 mm) on June 17 without experiencing anomalous mortalities (D. Relyea, Flower Co., pers. comm.).

Dinoflagellate blooms tend to occur during the warmer months of the year. Chang and Carpenter (1985) found that temperature was the principal factor controlling the appearance of summer blooms of *Gyrodinium aureolum* in the Carmans River estuary, Long Island. The rapid decline in *G. sanguineum* cell densities in Oyster Bay in late September, once temperatures dropped below ca. 18°C, may also be temperature related. Thus, while the exact role of elevated summer temperatures in relation to the oyster mortality events cannot be ascertained from our data, we suggest that they may have played an indirect role (e.g. through control of phytoplankton species composition and abundance or microbial activity) in the development and/or progression of mortalities, since these were not documented until temperatures exceeded about 22°C.

Comparative Response of Large and Small Cohorts

The two main cohorts available for comparison at this site, differed by only about 10 mm in mean shell height at the time of deployment. Thus size-dependent mortality can only be assessed over a relatively narrow size range.

In both experimental cohorts deployed on June 14, mortalities coincided with: a) reduction in shell and soft tissue growth (Table 2), b) reduction in gravimetric condition index (Fig. 4), and c) increased prevalence of a distinct ring of conchiolin deposited on the inner shell surface (Fig. 6) and of mantle lesions (Fig. 13).