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Introduction to the Symposium: Trends in Soft-Sediment Ecology During the Period 1970–1989[1]

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As we seek to discover promising avenues of inquiry into the ecology of marine soft-sediment communities, it is appropriate to examine where we have been. In this contribution, we will examine trends of soft-sediment research during the past 20 years. One's impression of the field is often belied by the data. We compiled a large sample of literature in soft-sediment ecology published since 1970, deciding *a priori* to examine trends over the past 20 years. We conclude that soft-sediment ecology, while still struggling to define itself, has grown and matured in ways that parallel the overall field of ecology.

To examine the directions of soft-sediment ecology, we surveyed the literature in seven major journals in which a preponderance of marine soft-sediment papers have appeared. These are: *Journal of Experimental Marine Biology and Ecology, Ecology, Ecological Monographs, Journal of Marine Research, Marine Biology, Marine Ecology Progress Series,* and *Marine Pollution Bulletin.* The first issue of *Marine Ecology Progress Series* appeared in 1979. All of the other journals were in existence at the beginning of this survey (1970). (We realize that some habitats for which there are specialized journals [e.g., *Deep-Sea Research, Estuaries*] may be incompletely represented.) For all issues of these journals in the period 1970–1989, we surveyed the table of contents and recorded all papers which pertained to the ecology of soft-sediment organisms. Some subjectivity was involved, for instance, in the exclusion of physiological papers whose intent was far removed from gaining an understanding of field patterns of soft-sediment organisms.

For each paper, we classified the primary focus at the "community" or "population" level. We also assigned keywords to indicate the major fields of inquiry. The ones we report here are: "competition," "predation," "meiofauna," "deposit-feeding," "pollution," "hydrodynamics," "population dynamics" and "community structure." "Population dynamics" papers involve at least two samplings of a population or community for the purposes of identifying changes in abundance. "Community structure" papers herein are those which involve a sampling of a given habitat with the subsequent description of the community using diversity measurements, species lists and animal-sediment relationships. Over 20 other keywords were entered, but the trends will not be discussed here. Most references had two or three keywords assigned. For the data analysis, we divided the 20-year span into four-year intervals.

An important pattern that quickly became evident is that the literature has grown tremendously (Fig. 1A) and shows no sign of becoming asymptotic. To determine how the soft-sediment literature has grown relative to marine ecology at large, we ran an analysis restricted to the *Journal of Marine Biology and Ecology* (hereafter, *JEMBE*). The editors of this journal have not changed over the period 1970–1989, thus reducing a possible bias in interpretation. We counted all papers appearing in that journal over the period (2,565 papers) and regressed the number of papers published during each interval against time (Fig. 1B). The slope of the soft-sediment regression is significantly lower than the slope for the regression for non-soft-sediment papers (ANCOVA, $P < 0.01$); the soft-sediment literature appears to be expanding at a slower rate than other marine ecological disciplines.

Because of the vast increase in pollution research in marine environments since the early 1970s, we also queried whether or not the proportion of pollution-related papers

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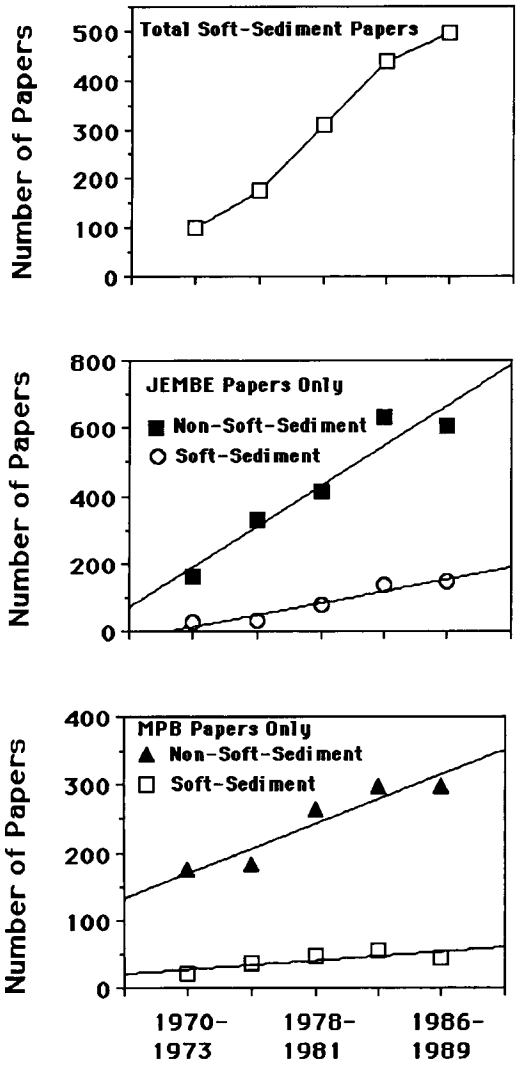

FIG. 1. A. Number of soft-sediment papers published in four-year intervals between 1970 and 1989 in seven marine journals. B. The number of soft-sediment papers and non-soft-sediment papers published in *Journal of Experimental Marine Biology and Ecology* in each four-year interval. Regression lines are drawn for each set of points. The slopes of the two lines are significantly different ($P < 0.01$). C. The number of soft-sediment papers and non-soft-sediment papers published in *Marine Pollution Bulletin* in each four-year interval. Regression lines are drawn for each set of points. The slopes of the two lines are significantly different ($P < 0.001$).

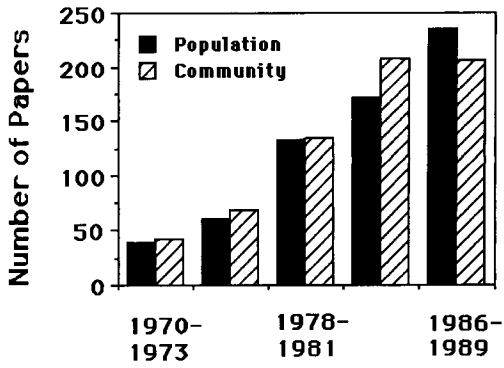

FIG. 2. Number of papers published in each four-year interval dealing with a single species (population) or many species (community).

had changed during the study period. To answer this query, we ran an analysis restricted to the *Marine Pollution Bulletin* (hereafter, *MPB*) whose first issue was in the year 1970. We counted all the papers appearing from 1970 until 1989 and regressed the number of papers against time, using the same four-year intervals, as we did for *JEMBE* (Fig. 1C). We found that the slope of the non-soft-sediment papers was significantly ($P < 0.001$) higher than for the soft-sediment papers (using ANCOVA). Thus, while the number of soft-sediment papers was increasing, their relative proportion was decreasing.

An analysis of the broad-scale, changing focus of soft-sediment ecology over time is shown in Figure 2; all papers were classified as either focusing primarily on a single species (population) or on several species (community). As with subsequent figures, all data refer to the database obtained from the survey of the seven journals listed above rather than simply *JEMBE* or *MPB*. For the period of 1970–1981, population- and community-level papers were roughly equal. Contributions in community ecology outnumbered population ecology contributions in 1982–1985 but decreased in the following four-year interval.

Figure 3 provides data on the number of papers classified according to eight keywords. All of the analyses refer to the proportion of soft-sediment papers published in the interval which were assigned the keyword. It should be remembered that keyword categories were not always mutually exclusive of each other. The absolute number of papers published steadily increases over the 20-year interval (Fig. 1A). The

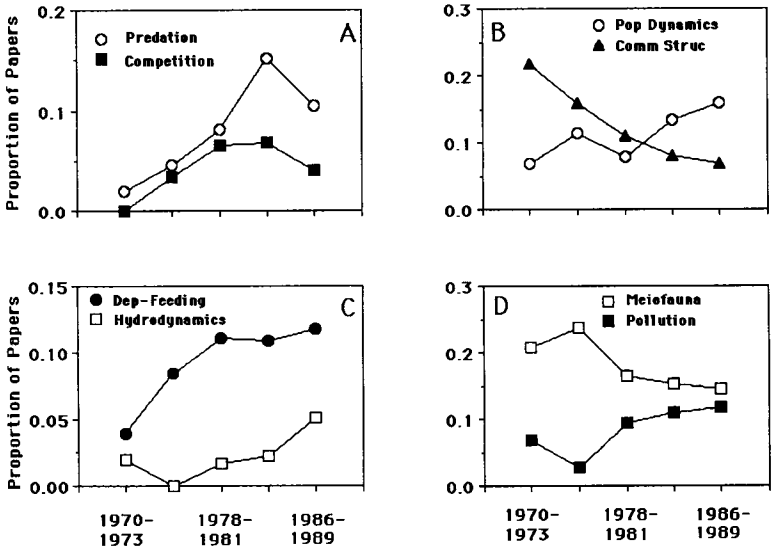

FIG. 3. Trends of subjects of marine soft-sediment papers. For each four-year interval, the proportion of all soft-sediment papers pertaining to each subject is plotted.

number of papers assessing predation increased linearly until the period 1986–1989 when a drop was seen (Fig. 3A). Papers examining competition are consistently less numerous than those related to predation, rising from nearly none in 1970–1973 to peak in 1978–1981 (Fig. 3A). The proportion of papers pertaining to population dynamics (multiple-period sampling) and to community structure (one-time sampling) have increased and declined respectively (Fig. 3B). We regard both of these trends as positive advances of the field. A thorough understanding of community organization will be aided greatly by long-term data sets on changes of benthic populations. Static or snapshot community structure papers, as we have defined them, offer little insight into the processes affecting populations and communities; the decline in these studies implies that our opinion is shared by other researchers.

Research into deposit-feeding increased greatly from the 1970–1973 interval through the 1978–1981 interval and then leveled off (Fig. 3C). This period has been an exciting period during which our understanding of deposit-feeding has grown tremendously. Deposit-feeding research touched on and enhanced many areas including animal-sediment interactions, biogeochemistry, nutrition, selectivity (*e.g.*, on the basis of grain size, angularity, smoothness, nutritional value), hydrodynamics, detritus cycling, and more. Sedimentary deposits are difficult to characterize nutritionally and new approaches are being taken to examine this poorly understood resource. The long-standing need in the area of deposit-feeding research for combined ecological, biogeochemical, microbial, and biochemical skills largely remains.

An emerging trend is the consideration of hydrodynamics in the interpretation of infaunal behavior, feeding and dispersion (Fig. 3C). We expect that the trend from the low in 1974–1977 to the present high will continue. Papers dealing with meiofauna have slightly increased from 1970 after a low during the period of 1974–1977 (Fig. 3D). This rise can be attributed in large part to ecological principles previously applied to marine macrofauna being applied to meiofaunal populations and communities.

Soft-sediment papers examining the effect of pollution show a variable pattern, but have decreased in proportion (though not in number) since 1974–1977 (Figs. 1C, 3D). In our opinion, this result merely indicates proportionally fewer pollution-related, soft-

sediment papers are being submitted to the seven journals studied here. Many such papers have appeared in numerous other journals, some of which are comparatively new (*e.g., Bulletin of Environmental Contamination and Toxicology, Journal of Coastal Research, Marine Environmental Research*). While the comparison has not been done, we expect that the authorship of the newer pollution-related journals is substantially different from that of the seven journals under review in this paper. Of those pollution-related papers that have appeared in the seven journals, some trends did appear. Initially, much of the pollution-related research pertained to oil spills as they affected field population and to toxicity studies on the impacts of hydrocarbons on marine organisms. Since that time, more types of pollutants (*e.g.,* polychlorinated biphenyls, volatile organics, pesticides, herbicides, dioxins and furans) have been investigated using increasingly improved methods. The analytical technology has improved tremendously over the past 20 years and now allows detailed analyses on the individual chemical basis at a reasonable cost. While toxicity studies were prevalent during the early part of the study period, an increasing number of papers on the uptake, accumulation, and elimination of pollutants in soft-sediment organisms have appeared. Some of this work was conducted in field studies. Field surveys continue to be conducted, but experimental manipulations in the field have increased in number and sophistication.

A simple compilation of studies can be misleading because some studies involve the interaction of two processes or patterns (*e.g.,* competition for resources among deposit-feeders, the influence of physical oceanography/hydrodynamics on benthic community distribution patterns). A more subjective, qualitative assessment is useful in elucidating points not apparent from the data alone. A first glance at the trends in the eight areas examined (Fig. 3) might indicate that there have been no major shifts in emphasis over the past 20 years. Despite the fact that soft-sediment systems are difficult to study, advances have been made and new directions have been taken.

Several major trends are evident from a qualitative assessment of changes in the field. There has been a switch from the study of functional groups of organisms to the study of organisms at the species level. There is increasing appreciation for the importance of planktonic events, affecting larval mortality and dispersal, in explaining benthic dynamics. Over the past 20 years, there has been a generalized trend in soft-sediment research from a lack of hypothesis testing to strict adherence to null hypothesis testing and statistics to relaxation of such testing, accompanied by renewed emphasis on natural history.

There has been an obvious increase in interdisciplinary approaches as new technologies are developed. We view the application of technological advances to the study of deposit-feeding as exciting and groundbreaking. There is a trend from an emphasis in the 1970s on biological interactions to emphasis on disturbance-mediated interactions and, more recently, on physical and chemical processes acting on small scales (hydrodynamics, biogeochemistry). Certainly, an increasingly broad range of research topics has been pursued indicating that the field is maturing and diversifying at a rapid rate. As with many maturing sciences, the history of the field of soft-sediment ecology has built on the past and grown with available technology, the rate of which is dependent on the fiscal resources available. We regard the area of soft-sediment ecology to be dynamic, intriguing, and healthy with ample room for new areas of research and inquiry.

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