COMMUNITY STRUCTURE AND FISH AND INVERTEBRATE BIODIVERSITY IN MARINE ECOSYSTEMS: THE CONSEQUENCES OF OUR ACTIONS

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With 6 tables and 2 plates

ABSTRACT. Changes in biodiversity and species composition in marine ecosystems, induced by anthropogenic stresses and xenobiotics, are causing great concern in the scientific community. This article, however, reports first on a positive aspect, of man-induced change in which the opening of the Suez Canal enabled the impoverished East Mediterranean Sea to become enriched by almost 400 species of fish and invertebrates of Red Sea origin. The second, and negative impact, is of anthropogenic pollution, which has led to unpredictable changes, in both magnitude and duration. This has differentially affected the various biological taxa, eliminating the most sensitive ones and leaving the more resistant and opportunistic. Because the stress related effect are initially cryptic, a novel ecological approach is suggested here, making use of specific markers for DNA, RNA, mitochondria and fluorescence contact microscopy, in order to reveal the state of health of key species. This method offers a powerful tool in planing sustainable management and protection of biodiversity.

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RESUMO. As mudanças na biodiversidade e composição específica dos ecossistemas marinhos, induzidas por pressão humana e por substâncias poluentes, estão a causar grande preocupação na comunidade científica. Neste artigo, é reportada, de forma positiva, a mudança induzida pelo homem, na qual a abertura do Canal do Suez permitiu o enriquecimento, em mais de 400 espécies, dum Mediterrâneo Oriental empobrecido e, de uma forma negativa, o impacto resultante de poluição, que levou a mudanças imprevisíveis, tanto em magnitude como em duração. Isto afectou de forma diferencial os vários taxa, eliminando os mais sensíveis e deixando os mais resistentes e oportunistas. Uma vez que os efeitos destes estresses são inicialmente crípticos, é sugerida uma abordagem ecológica nova, fazendo uso de marcadores de ADN e ARN, mitocôndrias e microscopia de fluorescência de contacto, de forma a avaliar o estado de saúde de espécies-chave. Este método constitui uma ferramenta poderosa na planificação de uma gestão sustentável e na protecção da biodiversidade.

INTRODUCTION

This paper summarizes some data and thoughts on the increasingly important subject of changes in biodiversity and the disappearance of species in marine ecosystems. I refer not to premeditated and careful intervention, but to foolish and reckless acts, particularly the overuse of marine resources and increasing industrial pollution in the provision of goods to the growing human population.

In recognizing the impact of such phenomena, ecology, as a discipline also dealing with population dynamics, today stands at a crossroads in its analytic and developmental practices. Ecology is currently expected to provide scientific answers to practical problems connected with preserving animal communities. The challenge facing ecology is particularly critical in aquatic littoral ecosystems, which are frequently located close to human industry and its by-products, but are also subject to increasing pressure from tourism (BELL *et al*., 1989; KAY & LIDDLE, 1989; LIDDLE, 1991; RINKEVICH, 1995). It would be unthinkable for environmental ecologists to ignore such development in local communities, while instead blaming only global changes, such as global warming or the results of El Niño. It has also long been recognized that the opening of new waterways and the increase in marine transport routes, paralleled by increasing discard of ballast waters by ships, have enabled the active redistribution of various animal species from their original sites to new ones. Striking examples of this nature are the invasion of North American waters by the zebra mussel, *Dreissenia polymorpha*, which has led to severe damage to various installations; the flourishing of the tropical medusa, *Rhopiloma nomadica* (GALIL *et al*., 1990) along the East Mediterranean, endangering bathers' on the Israeli shores; and the expanded distribution of the algae, *Caulerpa taxifolia*, which is destroing marine formations along the West Mediterranean shores. Parallel to this, thousands of new man-made chemicals and xenobiotics are being released into the environment, either directly eliminating many of the sensitive taxa, or acting cryptically on the organisms vital defense systems, on their *DNA* - structure and membrane functions, inducing deviations that adversely affect the survival and stability of biota (FISHELSON *et al*., 1994). Such subtle changes are not visible at the organismal level, and are able to generate novel selective processes (BRESLER *et al*., 2001). The time is ripe for this problem to be dealt with by environmentally-oriented ecologists. In order to tackle specific, local anomalies, there is a need to acquire sufficient temporal and quantitative data on actual situations and changes in marine biological communities, and to suggest some ideas on how to deal with this increasingly disturbing problem.

METHODS

This report is based on data collected during many years of observations in the Red and Mediterranean Seas, and repeated ecological observations on various biota. Data were collected by skin-diving and scuba, along marked transects of the habitats, or within 1 m^2 quadrants. Data are also presented from various published studies.

RESULTS AND DISCUSSION

The Suez Canal phenomenon

The Red and Mediterranean Seas have long been separated; during the Miocene, in particular, the Mediterranean was almost totally dry (HSU *et al*., 1973). At that time the Red Sea, as an extension of the Indian Ocean, swarmed with diverse life forms, particularly along the coral reefs. With the rise in water levels, the Mediterranean was flooded by Atlantic waters, and during the Pliocene links were established between the northern end of the Red Sea and the Mediterranean waters. This enabled Red Sea biota to penetrate into the Mediterranean, *e. g*., the fish genera *Thalassoma* and *Coris* now found throughout the Mediterranean.

At the end of the Pliocene, eustatic changes in plate levels and a drop in water levels finally permanently separated the northern end of the Red Sea from the Mediterranean, and the bitter lakes that evolved at this site of the Gulf of Suez reinforced this physical barrier. During this period, the Red Sea, behind the southern straits of Bab el Mandad, was already teeming with life forms, and various processes of isolation initiated the development of endemism, so typical for this closed sea (GOREN, 1987). For example, in a number of pairs of species currently found on both sides of the Bab el Mandad straits (Table 1), the Red Sea species originally developed from the Indian Ocean stock.

TABLE 1 - Fixation of fluctuation species pairs on both sides of Bab-el-Mandab Straits.

Red Sea	W. Indian Ocean
Dascyllus marginatus	*Dascyllus reticulatus*
Abudefduf vaigensis	*Abudefduf bengalensis*
Plectoglyphidodon leucozona	*Plectoglyphidodon cingula*
Stagastes nigricans	*Stegastes lividus*
Amphiprion bicintus	*Amphiprion alardi*
Chromis pelloura	*Chromis axillaris*

TABLE 2 - Vicaric Fish Communities.

N. Red Sea	E. Mediterranean Sea
Anthias squamipinnis	*Anthias anthias*
Chromis dimidiatus	*Chromis chromis*
Apogon cyanosoma	*Apogon imberbis*
Thalassoma klunzingeri	*Thalassoma pavo*
Adioryx diadema	*Adioryx ruber*
Pempheris vanicolensis	*Pempheris vanicolensis*
Epinephelus fasciatus	*Epinephelus aeneus*

TABLE 3 - Red Sea fish immigrants of commercial value in the Eastern Mediterranean.

Indian mackerel - *Rastrelliger kanagurta* (Cuv., 1817)
Pike conger - *Muraenesox cinereus* (Forsskäl, 1775)
Shrimpscad - *Alepes djedaba* (Forsskäl, 1775)
Goat fish - *Upeneus moluccensis* (Blecker, 1855)
Grunt - *Pomadasys stridens* (Forsskäl, 1775)

With the opening of the Suez Canal about 180 years ago, the Red Sea was again no longer isolated, and there began the process of cross-canal migration termed: “Lessepsian” by POR (1978), in honor of the Canal’s engineer. Most migrants were

Red Sea biota with only few species, such as the gobies *Gobius paganellus* and *G. cobitis* and the serranid *Serranus cabrilla*, leaving in the opposite direction (GOREN, 1989). Borne by the permanent along-shore west-east current, the majority of these migrants spread along the Israeli coast and later along the eastern Mediterranean littoral. Thus, "Red-Med" communities of species became established along the Israeli Mediterranean, with some species being remnants of the Thetys and with mixed assemblages of fish and invertebrates from both seas (Plates I and II). Two vicaric communities of fish dwelling within rocky outcrops, for example, can be found at depths of 6-12 m in both the Red Sea and the Mediterranean (Table 2). This immigration greatly enriched the East Mediterranean, which had been left with a very impoverished fauna in the wake of its past desiccation. An increasing number of species still continue to successfully establish themselves in the East Mediterranean. Some of these fish have become economically important for local populations (Table 3). Approximately 400 species of Red Sea origin can to be found along the Israeli littoral, including such economically important species as the shrimps *Penaeus sulcatus* and *P. japonicus*, and the fishes, *Saurida undosquamis*, *Siganus rivulatus* and *S. luridus*. In fact, the two latter species are the only herbivores able to control the algal lawns in this region.

Among the fish-species inhabiting the sandy bottom, 50 are of Red Sea origin (GOLANI, 1993). The importance of migratory fish for Israeli fishery was demonstrated by BEN-TUVIA (1985). According to SPANIER *et al*. (1989), 40.6% of fish biomass fished in the Mediterranean was comprised of total Red Sea species which were only 11.6% of species.

It would appear, therefore, that in this instance a man-made artifact, the Suez Canal - has a very positive effect, enriching the East Mediterranean fauna and contributing economically important assets. However, some negative aspects of this immigration include, *e. g*., the transport by fish of fish-parasites, or the rhizocephalan, *Heterosaccus dolfusi*, parasite on the crab *Charybdis longicollis*: in the Red Sea this parasite is very rare on this crab, whereas it is found on 40-45% of the immigrant population of the same species (FISHELSON, pers. observ.). The fish *Siganus rivulatus* and *S. luridus* have also transported into the Mediterranean endo-and ectoparasites not known from this sea. Rocky piers along the shores, another man-made construction, have also became focal points for migrant fish-assemblages, in particular the crevice dwelling *Pempheris vanicolensis* and the holocentrid *Holocentrus ruber* (GOLANI & DIAMANT, 1991) (Plate II).

The shallow-water benthic species' assemblages present a unique mix of polychaets (FISHELSON & RULLIER, 1969; AMOROUX *et al*., 1978), molluscs (BARASH & DANIN, 1992) and other organisms. The Red Sea sea cucumber *Synaptula reciprocans* become the dominant echinoderm on numerous sites along the Israeli shores (Plate I). This enrichment of the Mediterranean Sea by Red Sea taxa is demonstrated in Table 4.

Plate I:
Older Indo-Pacific species in the Mediterranean:
A - *Sargocentrum rubrum*; B - *Aphanias dispar*; C - *Dasychone lucullana*; D - *Hermodice carunculata*; E - *Atergatis roseus* (a relative newcomer).

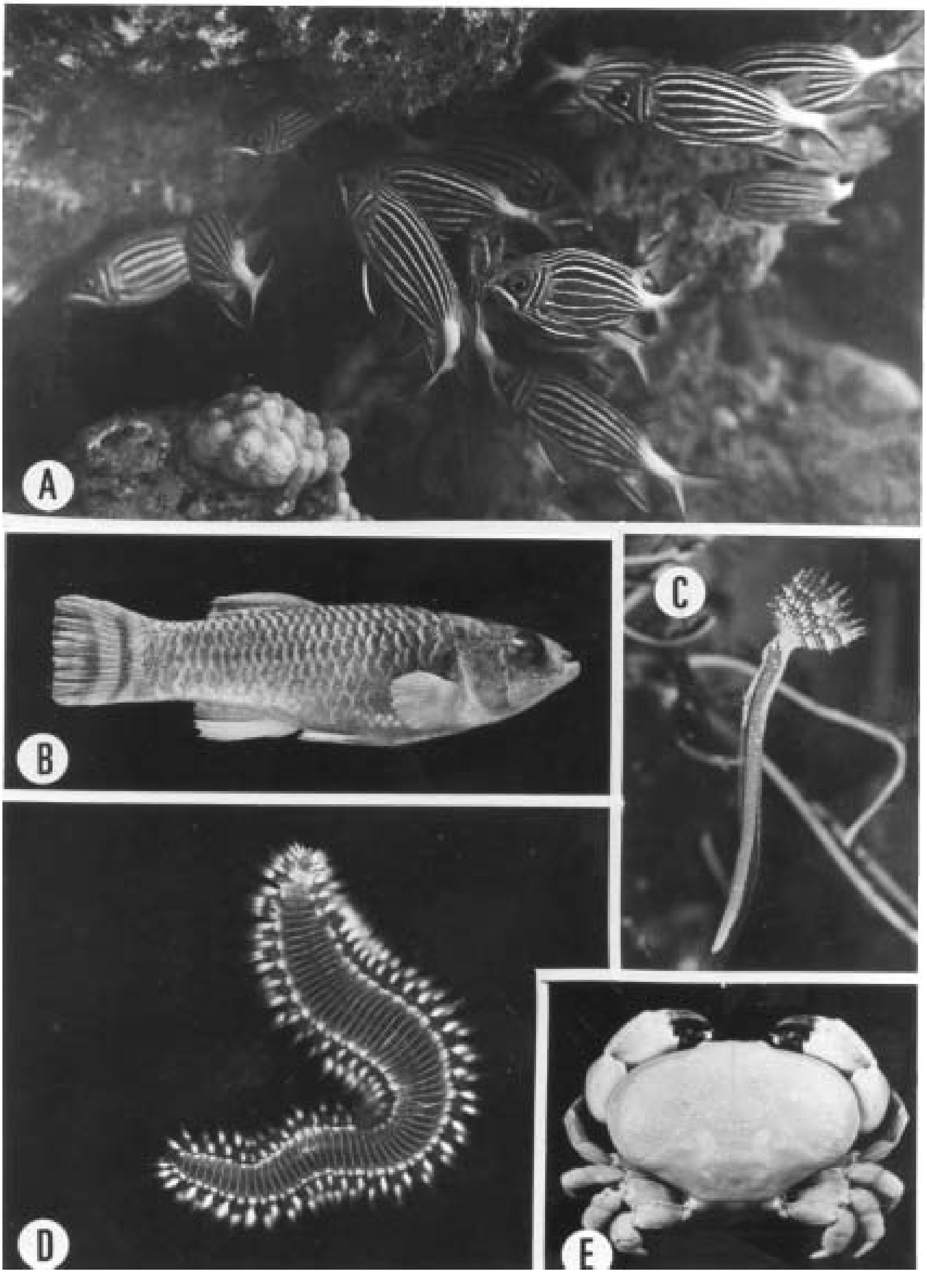
A
B
C
D
E

Plate II:
Latest Red Sea immigrants along the Israeli littoral:
A - *Pempheris vanicolensis*; B - *Pterois mollis*; C - *Cellana rotha*; D - *Cassiopea andromeda*; E - *Synaptula reciprocans*; F - *Cerithium scabridum*.

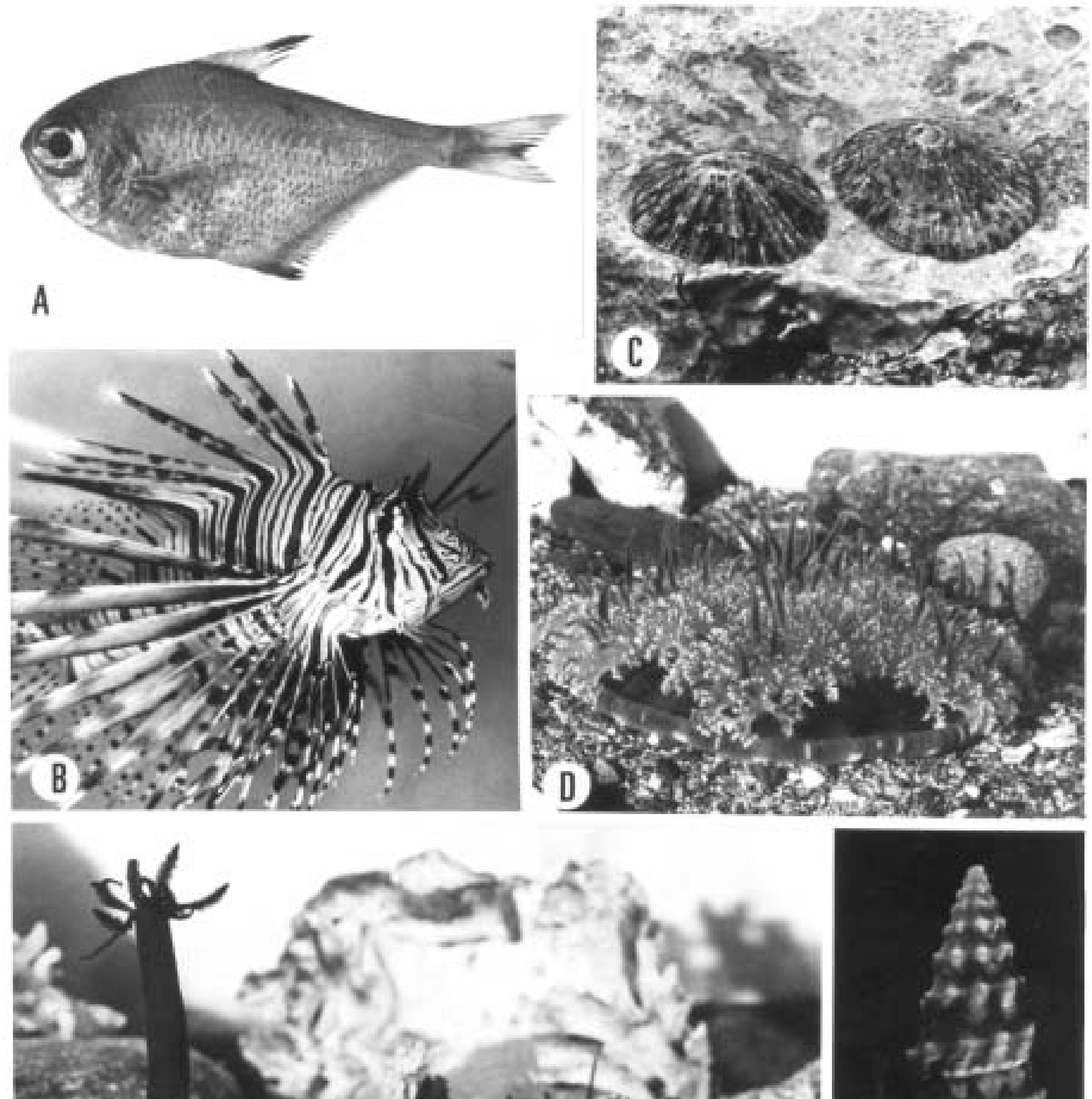
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TABLE 4 - Invertebrates of Red Sea origin dominant along the Israeli Mediterranean shore.

ECHINODERMATA	*Synaptula reciprocans*
	Ophiactis parva
CRUSTACEA	*Peneus semisculatus*
	Alpheus rapacida
	A. innopinatus
	Charybdis helleri
	C. longicollis
	Portunus pelagicus
	Atergatis roseus
MOLLUSCA	*Pinctada radiata*
	Cerithium kochi
	C. scabridum
	Strombus decorus
	Brachidontes pharaonis
POLYCHAETA	*Eurythoe complanata*
	Hermodice carunculata
	Dasychone lucullana
MEDUSA	*Rhopiloma nomadica*

In some instances, immigrants overcompete with the autochtone species: *e. g.*, the intertidal mussel *Brachidontes variabilis* has displaced the local *B. minimus*, and the fish *Saurida undosquamis* has displaced the local *Saurida*. Certain questions have remained unsolved in this and similar cases of faunal mixtures: How profound are the developing cytological-biochemical differences between the root-populations and those of established immigrants and how deep is the genetic asymmetry between the two parts of one taxon?

Anthropogenic stress

The increase in human population, concomitant with the increased use of resources and production of goods to fulfill the needs of this population, has, during the last few decades, greatly increased the anthropogenic stress on natural ecosystems, particularly the aquatic one. Stress may generally be defined as a set of environmental factors that adversely affect the organism. These may range from sublethal to lethal, negatively influencing the physiology and defense mechanisms at the subcellular level or reducing reproductive success, such as, for example, by inducing sex-change (MANELIS *et al*., 1993), or imposex phenomena. Additional stress is imposed by the huge tourism and associated industries that bring scores of bathers, divers and spear-fishers to the various, even most remote, littoral regions, directly and negatively influencing the natural ecosystems. The delicately balanced coral reef habitats in the tropical and sub-tropical seas are especially vulnerable. Data on reef-destruction from all over are rapidly accumulating from all over the world, including information on species' disappearance. For example, the northern, Israeli part of the Gulf of Aqaba, has seen the disappearance of the Harlequin shrimp, *Hymenocera picta*, possibly because its major prey, the sand dwelling sea-stars, have become extremely rare. The cone, *Conus textilis*, has also disappeared because its main source of nourishment, the tube gastropod, *Dendropoma maxima*, has been depleted by pollution (FISHELSON, 1995). Censuses taken above the coral reef tables in the protected part of the Red Sea Israeli shore show an immense decline in numbers of the small, surface dwelling fish there: *e. g*., in 1985, in a count taken along 10 transects of 10 m each, 85 (±6) gobies, blennies and clinid fishes were counted per transect. A repeated census at the same site in 1994 showed only 24 (±4) individuals/transect. In the past, the lagoon of this site harbored over 120 colonies of the damselfish, *Dascyllus aruanus*, within the coral bushes of *Stylophora piscillata* (SHPIGEL & FISHELSON, 1986). Today almost all of them have disappeared.

A similar decline has been observed in the shallow-water schools of *Paranthias squamipinnis* and the crevice dwelling *Pempheris vanicolensis* (*oulaensis*) (FISHELSON *et al*., 1974). Various anthropogenic stresses in the seas have also caused a decline in commercial fish fecundity, and fisheries are collapsing in various regions of the world, such as the North Sea and the Baltic. This is the consequence of land generated effluents bearing large amounts of fertilizers which produce eutrophication; as well as synthetic antibiotics, steroid-mimicking chemicals and various heavy metals. All these alien substances accumulating in the natural habitats, generate specific and non-specific changes, whose long-term outcome is unpredictable. We are, in fact, facing a potential, massive taxa extinction, similar to events of some 65 million years ago, which resulted in the catastrophic destruction of the dinosaurs and other taxa. Today the change in these communities - from stable to unstable, once regulated by biological phenomena, is now being regulated by unpredictable stresses and xenobiotics (FISHELSON, 1977, 1995). The more sensitive organisms are being eliminated and replaced by opportunistic ones, able to withstand such instability. The disastrous anthropogenic impact is being felt by the various marine ecosystems.

The role of ecology

Ecology is the discipline best equipped with the necessary theories, practice and methodological tools to expose stress-induced phenomena in biological communities; to provide reasonable argumentation for protection; and, consequently, to help preserve the natural resources. Most ecologists who also study the xenobiotic-rich habitats, however, continue to use quantitative methods and models developed for ecosystems regulated by stable, biological and physical phenomena. For example, multivariate, deterministic models are used to monitor changes observed in various ecosystems, as if the regulating environmental factors observed in the past are inherent in the ecosystem and will continue to dominate them in the future too (LEWINS & LEWONTINE, 1980). The basis for such thinking began with the simplest population index of Verhulst. Various equations, such as Sorenson's similarity index, Shannon's diversity index, Pielou's evenness index and Simpson's dominance index, which currently form the bases of ecological theory, were formulated in the first half of the century. All of these statistical equations are based on long-term species or individual/per species counts, within quadrants or along transects, to reveal the population densities in the biota, as the basis for population analyses and community studies. In essence, they effectively count those organisms that have perished during past events and these that have survived, using what can be termed a "post-mortem" technique. As BRADBURY *et al*. (1986) stated, by focusing on quantitative data, ecologists lose vital biological information, sometimes critical to the future of the ecosystem.

Today, evidence is accumulating that this long-term species-count approach is merely revealing results of phenomena that acted in the past, and as such is inadequate to assess current community health and potential fate. The collected data reflect past realities and are devoid of predictive value. The changes occurring in ecosystems, primarily of an anthropogenic nature, are inherently unpredictable as to their effect (FISHELSON, 1995). Interacting with biological taxa, these stressors can affect the genotypic, and ultimately the phenotypic attributes of local populations. Biological taxa, experience changes on two time scales: (1) a long-term evolutionary scale that is modulated by the genotype and becomes evident in speciation; and (2) a short-term, small-scale phenotypic change induced by local adverse stress. In a stabilized environment the outcome can be predicted; mutation is minimal, thus population uniformity is preserved. This outcome is based on the existence of a stable genome and a set of physiological defense mechanisms. In contrast, in strees situations, with increasing quantities of biologically active substances (*e. g*., heavy metals and organic substances) being released into the natural environment, the ability of biological defense systems to shield the genotype is decreasing, and an increase in mutation rates can be observed. This, in turn, results in higher variability and fractionization of phenotypes. The outcome could lead to a type of punctuated evolution and consequently unpredictable biological succession, which will undoubtedly ultimately be manifested in the biology and physiology of organisms. Our ability to expose these subtle and cryptic changes before the complete and partial extinction of taxa, is a function of analytical scaling and methodology.

The incorporation of such cryptic changes in the biological world often induces pathological changes (MANELIS *et al.*, 1993), such as genotoxicity marked by micronucleation and chromosomal damage; or, as recently documented, a decrease in sperm production and infertility. Some of the polluting substances interfere with oxidation, desulfurisation, sulfoxidation and methylation; and if not subjected to detoxification, additional malfunctions occur.

The established numerical ecology does not recognize these crucial factors and BRADBURY *et al.* (1986) have already noted the need for a technique to enable the collection of qualitative data for systematic analyses of the ecosystems. The monitoring of biochemical and physiological deviations from the normal, or what MAYR (1982) calls "soft data", may provide an immediate means for evaluating community health and identifying the possible nature of the stressors long before the disappearance of sensitive taxa. The various methods of chemical ecology that can be employed include techniques that enable us to determine impact areas and specificity of stressors. For example, along the shore of Haifa Bay, at a chemical factory site, levels of mercury found in sand-dwelling mussels, *Donax trunculus*, were 25 times higher than in conspecifics from clean sites, and their cytological and physiological attributes differed from those in the control area (Table 5). It is reasonable to assume that if such a situation persists, as well as killing a part of the population, an alternative phenotype will develop from the surviving one, differing from that of non-affected populations.

TABLE 5 - Permeability of epithelia of *Donax trunculus* to acid fluorescein (as a percentage to a clean site).

	SITE		
	Clean	Organic Pollution	Chemical Pollution
Mantle	100	170.3 (±55)	2159.5 (±417)
Hepato-Pancreas	100	320 (±132)	462 (±150)
Gills	100	133 (±23)	198 (±67)
Lysosomal activity	100	68 (±12)	53 (±15)
Micronucleation	100	211 (±8.6)	268 (±8.5)

By analyzing such deviations from the norm, we can begin to describe quantitatively and in biological terms the responses to human disturbance, which, in turn, could be used to define an ecologically meaningful concept of sustainable development. This is particularly important in the tropics and the subtropics, where high temperatures and intensive solar input, acting synergistically, induce an immense turnover of metabolites. In such situations, various alien xenobiotics are quickly incorporated into the metabolic cycles of the organisms, inactivating their defense systems, disrupting their endocrinic activities or destroying their progeny. The more we know of these "biological information transfer" processes (RYAN, 1980), the more we will be able to judge the health of the organisms under study (FISHELSON *et al*., 1994).

At present, in order to determine health parameters, we can use stress-protein levels, enzyme activities, membrane transport systems of organic anions (SATOA) and cations, especially the state of the multixenobiotic resistanse-mediating transporter (MXRt). By using specific flourescent markers we can determine the state of nucleic acids, micronucleation, state of mitochondria, permeability of membranes, and levels of heavy metals and organochlorides (Table 6). The monitoring of these parameters also involves antibodies and fluorescent microscopy. The method developed by BRESLER & FISHELSON (1994) and BRESLER & YANKO (1995), implements *in vivo* contact and epimicroscopy, and specific fluorescent anionic and cationic markers, and has proven to be equally valuable for unicellular organisms and mammals.

TABLE 6 - Parameters of animal health that reflect stress that can be studied for comparison in different taxa of the same habitat.

A.	Stress - Protein levels
B.	Enzyme activity, especially: MFO, Acetylcholesterase, Peroxidases
C.	Membrane transport systems of organic anions (SATOA) and organic cations
D.	MXT's - Multixenobiotic transport systems
E.	State of DNA, RNA, Micronucleation
F.	State of mitochondria
G.	Permeability of membranes

These *in vivo* techniques examine not only what occurred in the past, but also what is actually happening now in the ecosystem, providing instant tools and guidelines for possible management and protection. By implementing the newest, prophylactic methodologies of health investigation in the ecosystems, we will be able to contribute to sustainable development and the preservation of biodiversity, and limit the destructive, anthropogenic impact on marine and terrestrial ecosystems.

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