ATTI

DELLA

SOCIETÀ TOSCANA

DI

SCIENZE NATURALI

RESIDENTE IN PISA

MEMORIE - SERIE B

SUPPLEMENTO VOL. LXXXVI - ANNO 1979

ATTI XI CONGRESSO
DELLA SOCIETA' ITALIANA DI BIOLOGIA MARINA

ORBETELLO 23 - 26 MAGGIO 1979

ARTI GRAFICHE PACINI MARIOTTI - PISA - 1980

La Biologia Marina
e la gestione della Fascia Costiera

INDICE

Gestione delle risorse di pesca nella fascia costiera

Acque salmastre: biologia e acquacoltura

Inquinamento costiero: fonti, natura ed effetti

Conoscenza e promozione dell'ambiente costiero

Insediamenti su substrati duri artificiali

Attività subacquee e loro ruolo nella ricerca biologica in mare

Varia

CONOSCENZA E PROMOZIONE DELL'AMBIENTE COSTIERO

XI Congr. Soc. Ital. Biol. Mar., Orbetello 1979.
Atti Soc. Tosc. Sci. Nat., Mem., ser. B, **86**, suppl. (1979).

R.B. Clark

MONITORING CHANGE IN THE MARINE ENVIRONMENT

Abstract — Effluents discharged into the sea become pollutants when they create a threat to human health or cause undersirable environmental change. Research strategy in response to the former is reasonably clear, but monitoring environmental change induced by pollutants presents great difficulty. Except for gross pollution, such changes are often insignificant beside wide, natural ecosystem fluctuations, the causes of which are imperfectly understood. The very long-term and detailed studies of ecosystem response to disturbance and stress that are needed have not kept pace with experimental studies, but because of the genetic variability of marine organisms, among other reasons, the results of the latter cannot be applied to real-life situations and may be totally misleading.

Riassunto — *Adeguamento dei sistemi di rilevamento nell'ambiente marino.* Gli effluenti scaricati in mare sono considerati inquinanti quando divengono una minaccia per la salute dell'uomo o provocano alterazioni ambientali. Mentre la strategia di ricerca per quanto riguarda la salute umana appare abbastanza chiara, il rilevamento dei cambiamenti ambientali provocati dagli inquinamenti presenta grandi difficoltà. Tali cambiamenti, con l'eccezione di quelli determinati dagli inquinamenti più gravi, sono spesso insignificanti rispetto alle ampie variazioni naturali dell'ecosistema, le cui cause sono imperfettamente noti. Gli studi riguardanti la risposta dell'ecosistema a disturbi e alterazioni, che devono essere necessariamente a lungo termine e dettagliati, non hanno tenuto il passo con gli studi sperimentali. Fra le altre ragioni, a causa della va riabilità genetica degli organismi marini, i risultati degli studi sperimentali non solo non possono essere applicati alle reali situazioni di vita ma possono essere anche totalmente ingannevoli.

Key words — Pollution, marine environment.

Introduction

In many localized areas and sometimes over much wider areas of restricted water exchange, pollution of coastal waters and estuaries is so gross that major environmental deterioration is inevitable and very obvious when it occurs. While the precise links in the chain of events leading to this impoverishment of the environment may not be known in detail, the principal causes of the decline are usually self-evident. A relatively short and comparatively crude investigation is often adequate in these circumstances to prescribe an effective remedy. What is required is not more science but the political and economic will to apply those remedies.

Most pollution research is not concerned with the study of specta-

Department of Zoology and Dove Marine Laboratory, the University of Newcastle upon Tyne, England.

cular pollution at particular hotspots, but with the more subtle environmental change that may result from low-level but pervasive additions to the sea. Much of this effort is directed towards measuring the concentration of these contaminants in the water column, sediments and marine organisms, studying the behaviour, degradation or modification of these contaminants once they reach the sea, attempting to understand their transmission through food webs, and measuring their effects through toxicity tests of various degrees of refinement and sophistication, and by studying the physiological, developmental and behavioural responses of organisms exposed to them. No-one would deny the importance of knowing the quantity and source of inputs to the marine environment and their behaviour once they get there. But the fact remains that much of the enormous volume of quantitative data that is being accumulated cannot be applied to any real-life situation. Because of this, although much of the information is of great interest in its own right, it makes little effective contribution to pollution research.

I shall argue that much of this effort has no sharp focus on the objectives of pollution research and for this reason an imbalance has developed between the types of research that are undertaken. The main effort at present is directed towards relatively easy, if often sophisticated laboratory-based studies, but far too little effort is directed towards the far more difficult and frustrating task of studying the response of ecosystems to additions of various kinds. Until the balance is redressed, we shall be able to make little use of the flood of data emanating from distinguished laboratories around the world.

Objectives of environmental monitoring

Environmental monitoring may be undertaken for several different reasons. The most direct are when an addition to coastal waters poses a direct threat to human health. Additions of this kind include pathogenic bacteria and viruses in domestic sewage, mercury and cadmium, and radioactive wastes. The control of the exposure of local human populations to these threats is a public health measure. It is necessary to monitor the concentration and distribution of these pathogens and toxic substances, most particularly in sea food for human consumption because this is the usual vehicle by which humans are exposed to these dangers. The objectives and research strategy are clear and, for this reason, are in most cases being pursued vigorously and effectively. Where they are not it is not due to scientific ignorance but to inadequacies in the public health service.

Most monitoring, however, is concerned with vaguer threats. There is a concern that low level pollution may have a long-term, cumulative impact and change coastal ecosystems at a rate which is not obvious now, but which might cross some kind of threshold and suddenly escalate and become serious or, in the minds of some pessimists, catastrophic. By keeping a finger on the pulse of the marine environment to measure its state of health it is hoped to get warning of undesirable consequences of effluent discharges to the sea at an early enough stage that measures can be taken to prevent that threshold being crossed.

A second reason for monitoring the response of marine ecosystems to pollutants relates, paradoxically, to the need which I suggest we now have, to maximize effluent discharges to the sea. This may sound alarming in areas where pollution is already so great that it is patently having undesirable effects in human health, commercial fisheries, or more generally. But it is naive to suppose that all discharges to the sea constitute pollution in any real sense because this is to ignore the considerable physico-chemical and biological homeostatic mechanisms in marine ecosystems. Public opinion in many countries, alarmed by reports of damage resulting from spectacular pollution accidents, applies pressure to reduce, control or treat at source almost any effluent discharged into the sea or which by some circuitous route might end up there. It must be said that they are supported in this view by many scientists. This is a laudible sentiment, but it can be satisfied only at some cost: cost of land for treatment plants, but more importantly, cost in energy. Energy costs (in the broadest sense) depend on the stringency of effluent standards that are set, and if the standards are high the costs escalate very rapidly. The prospect of a very substantial increase in energy prices, to say nothing of the possibility of an energy shortage, means that the cost of effluent treatment to a high standard will become very high indeed. And this will be at the expense of other desirable activities.

Under these circumstances, it is not difficult to forsee a strong temptation to discharge all wastes into the sea. This could only lead to the damaging consequences that have already been observed in a number of areas that have been overloaded with effluents. It will be necessary to walk a narrow tightrope to avoid the wastefulness of treating, expensively, more effluent on land that we need, and the wastefulness of discharging too much untreated effluent to the sea with serious consequences for living marine resources. We need to know how much can ' safely ' be discharged, and this leads to the question which marine biologists can scarecely begin to answer and which most pollution research is not designed to answer: how much perturbation to a marine ecosystem is caused by the presence of a particular level of additive to the sea? Until some approach can be made to answering this, it will be impossible to assess the cost-benefit of treating wastes on land or discharging them to the sea, and much pollution research will have no clearly defined objective.

MORTALITY AND MORBIDITY

A considerable volume of pollution research is concerned with measuring toxic concentrations and the sublethal effects of pollutants and the behavioural responses of animals to them. Yet many of these substances can evidently be added to the sea in considerable quantities without perceptible effect on marine ecosystems. Even the heavy mortality of an animal need not necessarily have much impact. During treatment of floating 'Torrey Canyon' oil by very toxic dispersants, there was observed 90% kill of pilchard (*Sardina pilchardus*) eggs in the area of spraying and a 50% kill over a very much wider area (SMITH, 1968). Cornish pilchard are considered to be a small isolated population and it was expected that the stocks would be seriously affected by this mortality. In fact, there was no shortfall of this year's class when it entered the commercial fishery 2-3 years later. Lobster (*Homarus vulgaris*) larvae were also in the surface plankton at this time and are likely to have been killed in large numbers, yet these, too, showed no shortfall in the commercial fishery 8-9 years later. Evidently it is possible for a fecund species to absorb very heavy additional mortality at early stages in its life history without influencing the size of the adult population.

Other species may not have the capacity to withstand heavy juvenile mortality. This is particularly true of species with a boreal reproductive pattern which is characterized by erratic breeding, low fecundity, slow growth and maturation, but long adult life. In temperate waters, this is best exemplified by auks such as guillemots (*Uria aalge*) which do not breed every year and lay only one egg when they do so. It is estimated that loss of eggs and chicks from predation and falling off the breeding ledges is so great that only 20% of the young reach the sea (SOUTHERN *et al.*, 1965). The life expectancy of those that survive this hazardous birth and infancy is very good, however, and the birds may live for 20 years or more. With this breeding pattern, numbers lost through pollution cannot rapidly be made good and LESLIE (1966) calculated that it would take 53 years for a colony of guillemots to double in size. These birds are particularly subject to mortality through oil pollution and this is reflected in the decline of a number of colonies in south-west England and Brittany (CLARK, 1969).

Observed mortality, even if on a massive scale, has little significance unless it has some durable impact on the adult population of the species. Whether this is so or not depends on the fecundity, reproductive biology and population dynamics of the species involved. This is rarely considered. As, for example, in the observation that experimental ingestion of crude oil by young herring gulls (*Larus argentatus*) leads to damage in the intestine and liver, and impairs nasal gland function (MILLER *et al.*, 1978), it is claimed that these sub-lethal effects must reduce the viability of gulls exposed to oil pollution and result in a hidden additional mortality. Yet these gulls on European Atlantic coasts, which have been exposed to as much oil pollution over the last 50 years as those in any part of the world, far from declining in numbers, have shown a dramatic increase and are now subject to not very successful control measures in several places in the interest of public health and nature conservation. Unfortunately, this example is not isolated and most studies of sub-lethal pathological conditions or behavioural changes in animals exposed to toxic substances in the laboratory cannot be interpreted because we do not know whether heavy mortality, let alone morbidity, matters in the species concerned.

KEY SPECIES IN ECOSYSTEMS

The loss or decline of a particular species in polluted areas may be of concern to particular interests, but is much less critical than if ecological change follows its loss. The reduction in the number of breeding auks in southwest England appears to have had no wider ecological impact and even if the 1967 year class of Cornish pilchards had been catastrophically reduced by 'Torrey Canyon' oil dispersants, although the local commercial fishery would have suffered, there is no reason to suppose there would have been more widespread ecological repercussions. The loss of limpets (*Patella* spp.) on the other hand, led to major ecological change. These herbivores have a dominating influence on beaches where they occur and at a number of sites where they were killed by over-enthusiastic use of toxic dispersants, the rocks were rapidly colonized by diatoms and algae, leading to the establishment of a dense

Fucus community (SMITH, 1968; NELSON-SMITH, 1968). Eventually, *Patella* became re-established, grazed down the *Fucus* and, to a considerable extent, these affected beaches have now returned to their former condition, although the proces has taken a decade (SOUTHWARD and SOUTHWARD, 1978). A similar phenomenon, probably with a similar recovery period, was observed in a small bay on the Pacific coast of Baja California following the wreck of the 'Tampico Maru' (NORTH *et al.*, 1965). Here the pollutant was diesel fuel, the herbivores that were eliminated were *Haliotis* and the echinoid *Strongylocentrotus*, and the alga which then became dominant was *Macrocystis pyrifera*. Apart from the fact that these events tooks place subtidally rather than on the shore, they were essentially the same as in the Cornish experience.

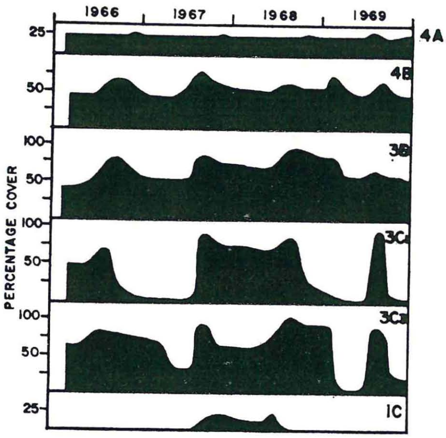
A potentially far more serious ecological change following the severe reduction in numbers of a key species has been recorded on the coast of Nova Scotia, Canada (BREEN and MANN, 1976, MANN, 1977). Here there was a stable kelp bed ecosystem with *Laminaria* spp. as the main producer. Most algal production was exported as detritus but these areas supported a population of herbivores, mainly *Strongylocentrotus droebachiensis*, which were preyed upon and controlled chiefly by lobsters, *Homarus americanus*. The lobster population has declined greatly since 1968 due, it is thought, to overfishing, not pollution, and with the reduction in predation *Strongylocentrotus* has increased greatly in numbers and considerable areas of *Laminaria* forest destroyed. Continued settlement of *Strongylocentrotus* prevents the re-establishment of algae and MANN (1977) claims that this urchin-dominated, barren ground is a new, stable configuration of the ecosystem. The loss of primary and secondary productivity of the coastal waters of considerable parts of Nova Scotia coast that follows is potentially serious and likely to be long-term.

The existence of key species which determine, by their abundance or absence, the character of an entire ecosystem should simplify the enormous task of monitoring environmental change. If more attention were paid to the biology of these species and to their susceptibility to pollution damage, as LEWIS (1976, 1978) has advocated, environmental monitoring would have a sharper focus and the capability of predicting change would be much improved. With this predictive ability, it would be possible to decide whether or not the likely environmental change resulting from a discharge was acceptable or not. The substantial loss of production on considerable stretches of the Nova Scotia coast, which is likely to persist, would almost certainly be judged disadvantageous. Whether or not the replacement (even if temporary) of relatively barren barnacle-covered rocks by a fucoid cover with its rich associated fauna on some Cornish beaches, was the ecological disaster it was widely claimed to be, is largely a matter of taste. The marine biologist might find the latter of greater interest, though the tourist probably would not. But the decision of the acceptability or otherwise of a predicted environmental change is a political one which must take into account the conflicting interests of industry, fisheries, tourism, conservation, and so on; it is not a scientific problem and different decisions would obviously be taken, and rightly so, in different places.

Natural population fluctuations

In studying the impact on an ecosystem of an effluent load, it is common to use a neighbouring area supporting a similar ecosystem, but not exposed to the effluent, as a ' control ' or reference site. It is now becoming clear that there are very wide population fluctuations in marine ecosystems from purely natural causes, although the latter are rarely understood in detail. Not only is it extremely difficult to distinguish pollution-induced change againt this fluctuating background, but sometimes the natural fluctuations are of such a nature that they produce major ecological change comparable to that resulting from what would be regarded as a catastrophic pollution incident. The same problems are encountered in ' baseline ' studies, may of which are conducted for too short a period to reveal the full range of fluctuations in the ecosystem and therefore have little value.

The extent of this problem was dramatically shown by Lewis (1972) following several years' continuous study of a rocky coastal area in north-east England (fig. 1). The winter of 1965-66 was cold and stopped the growth of the 1965 class of the carnivorous gastropod *Thais lamellosa* which was then eaten in large numbers by a shorebird, the purple sandpiper *Calidrys maritima.* The following winter was milder and the 1966 class of *Thais* fed and grew continously becoming too large to be eaten by *Calidrys.* The large surviving population of *Thais* fed on *Mytilus* and seriously reduced its numbers, so making space available for colonization by *Balanus.* However, in 1967 there was an exceptionally heavy settlement of *Mytilus* which destroyed all other species on the rocks. Their large numbers led to competition for space and resulted in an insecure, hummocky growth of the mussels. In March 1969, severe storms swept many of the *Mytilus* away, so leaving space once more for *Balanus* settle-



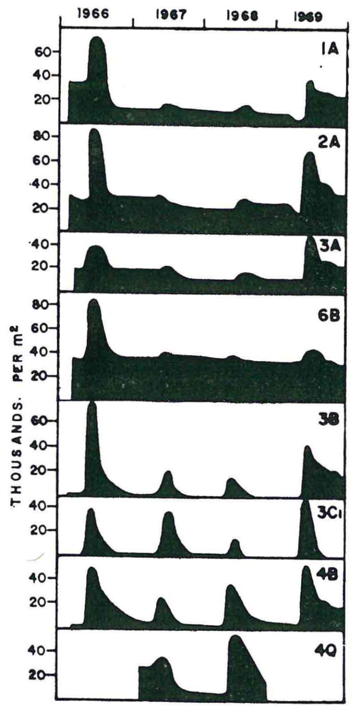


Figure 1 - Fluctuations in (left) the percentage cover of *Mytilus* at five sites, and (right) the numbers of *Balanus* at eight sites, during 1966-1969. (From LEWIS, 1972).

ment in June. But because the dense growth of *Mytilus* had excluded the limpet *Patella* and the mussels were not destroyed until after the settlement of young *Patella,* diatoms and ephemeral algae developed quickly and abundantly, and prevented the settlement of *Balanus.* The rocks then became dominated by algae.

Erratic, but major faunistic changes caused by climatic changes or biological interactions of this kind have been observed in a number of situations where sufficiently detailed and prolonged studies have been made (SOUTHWARD, 1967; SOUTHWARD and CRISP, 1954, 1956; WILSON, 1971; CRISP, 1958, 1964; CONNELL, 1970; PAINE, 1974). On temperate, rocky intertidal shores subject to moderate wave exposure, the habitat is equally suitable for *Mytilus, Patella* and *Balanus,* or *Fucus,* each with a characteristic associated fauna. Which faunistic and floristic assemblage dominates depends on historical climatic and biological events. *Patella,* as the principal herbivore of rocky shores, plays a particularly important role. BOWMAN and LEWIS (1977) have shown that the success of its recruitment in any year is little influenced by gamete production but is strongly affected by the occurrence of frosts, to which the young are susceptible, during the first few weeks after settlement (fig. 2). They are also susceptible to desiccation and these two factors appear to determine the northern and southern geographical limits of *Patella vulgata,* and also account for erratic changes in the algal cover of rocky beaches.

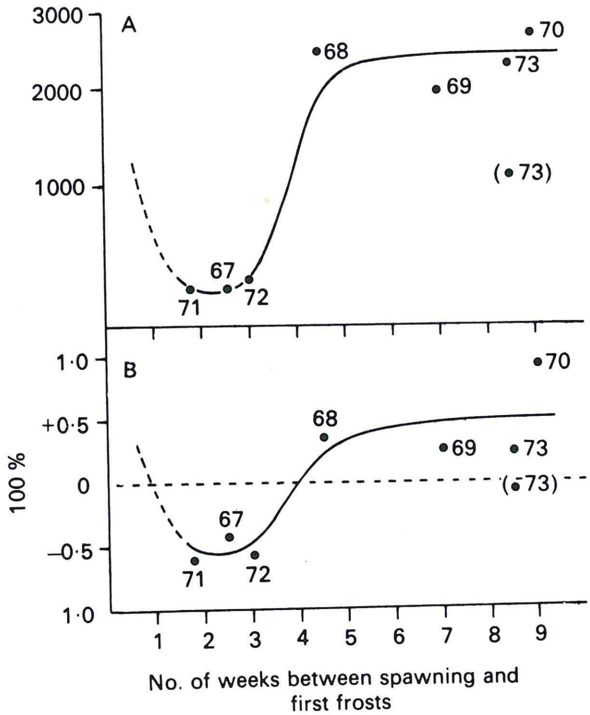
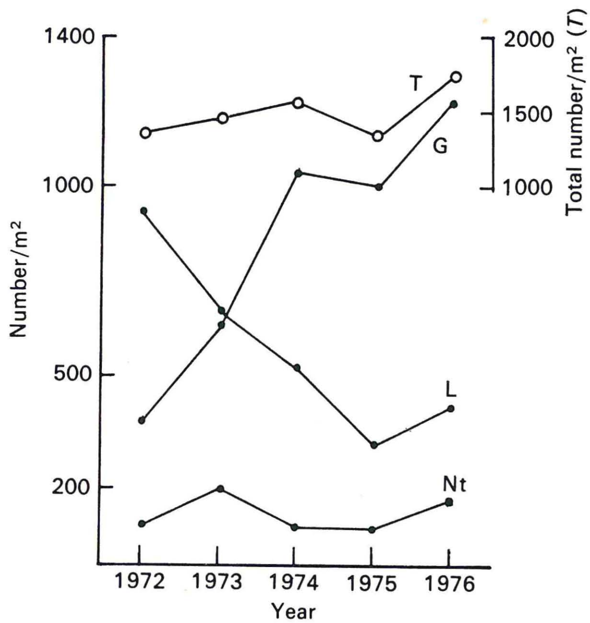


Figure 2 - The relationship between annual recruitment of *Patella vulgata* and the duration of frost-free time after spawning. (A) annual total of juvenile maxima on all sites, (B) summation of individual site variation astride their means in % units of the mean. Data for 1967 based on 3 sites, 1968 on 4 sites, others on 5 sites in north east England. Bracketed 1973 data are uncorrected. (From BOWMAN and LEWIS, 1977).

This knowledge enabled BOWMAN (1978) to illustrate the pitfalls of instant assessment of pollution damage. A spillage of fuel oil from a storage tank at Dounreay on the north coast of Scotland in February 1977, contaminated a flat rocky beach which was cleaned by dispersants. Subsequent examination of the beach revealed deaths of *Balanus, Patella* and other intertidal organisms and a dense growth of diatoms, *Enteromorpha* and *Porphyra.* This is typical of the damage reported after clean-up of oil by dispersants in many pollution incidents. In fact, the Dounreay beaches had been regularly monitored by BOWMAN since 1971. An exceptionally hot summer in 1976 was responsible for the death of many intertidal organisms, including, by September, a considerable proportion of the limpets. This reduction in the limpet population made the development of a dense algal cover inevitable. The oil spill and use of dispersants were almost entirely irrelevant and had minimal effects.

One of the few other long time-series of observations is of benthic soft-bottom fauna off the north-east coast of England by Buchanan and his collaborators. The faunistic assemblage is a balanced one but has shown changes in the pattern of relative species abundance in response to a slight increase in average winter sea temperature from 6.25°C in the period 1965-70 to 6.75°C in 1971-76. There is some evidence that by the end of that period the bottom community was adjusting to a stable ' warm water state ' (fig. 3), but no species had been eliminated and in a fluctua-



Gaining species 1972–76 (G) Species	Gain/m²	Losing species 1972–76 (L) Species	Loss/m²	Neutral species 1972–76 (Nt) Species
Paraonis gracilis	238	*Spiophanes bombyx*	219	*Ampharete finmarchica*
Prionospio malmgreni	144	*Chaetozone setosa*	129	*Glycera rouxi*
Myriochele oculata	129	*Ampelisca tenuicornis*	112	
Thyasira flexuosa	115	*Amphiura filiformis*	50	*Goniada maculata*
Owenia fusiformis	104	*Nephtys hombergi*	31	
Magelona minuta	100	*Scoloplos armiger*	26	
Tharyx multibranchiis	27	*Rhodine gracilior*	24	
		Ammotrypane aulogaster	17	

Figure 3 - Contribution of the top 17 ranked species to the total number of individuals present at one sub-tidal station off the north-east English coast. Divided into gaining (G), losing (L) and neutral (Nt) species listed below. Total number of individuals (T). (From BUCHANAN *et al.*, 1978).

ting environment these changes could be reversed (BUCHANAN *et al.*, 1978). It should be noticed that changes in temperature have had little effect on community production; the available energy is progressively transferred from one suite of species to another which thrives better, in response to the environmental change (BUCHANAN *et al.*, 1974).

Long-term trends in the abundance of various species of north Atlantic zooplankton were detected in a 22 year Continuous Plankton Recorder survey from 1948 to 1969 (GLOVER *et al.*, 1972). Some species such as *Pleuromamma borealis* and *Euchaeta norvegica* show an upward trend, *Spiratella retroversa* and two calanoids show a significant downward trend, but no trend was detectable in *Temora longicornis* or *Clione limacina* (fig. 4). All these species are subject to erratic and sometimes very large fluctuations in abundance, some fluctuations extending over several years, and the long-term trends would not have been detected without this very long time-series of observations. Unlike previous examples, it has not been possible to relate these long fluctuations and trends to any known climatic or human factors.

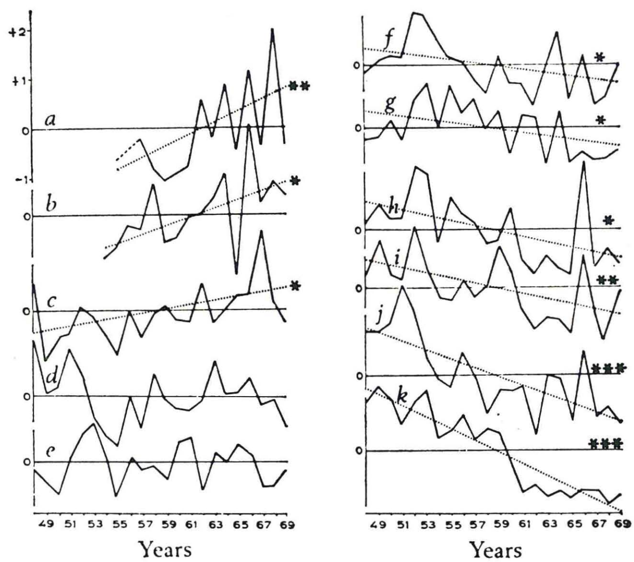


Figure 4 - Fluctuation is numbers of zooplankton species in the North east Atlantic. a) *Pleuromamma borealis,* b) *Euchaeta norvegica,* c) *Acartia clausi,* d) *Temora longicornis,* e) *Clione limacina,* f) *Calanus helgolandicus* and *C. finmarchicus,* stages V and VI, g) *Metridia lucens,* h) *Candacia armata,* i) *Centropages typicus,* j) *Spiratella retroverson,* k) *Pseudocalanus* and *Paracalanus,* *** $P < 0.1\%$, ** $P < 1.0\%$, * $P < 5.0\%$. (From GLOVER *et al.*, 1972).

In addition to the difficulties these natural fluctuations in marine ecosystems pose for baseline studies and reference sites in pollution studies, they make it very difficult to state, except within very broad limits. what is the normal faunistic and floristic configuration at a particular site. As a result, it is difficult to identify with any confidence small pollution-induced changes without very detailed and prolonged investigations and an unwelcome vagueness is introduced into studies of the recovery of ecosystems after polluting sources have been removed.

Genetic variability

Marine invertebrates, in general, show a high degree of genetic variability and fish are genetically the most varied of all vertebrates. Views of the adaptive significance of this condition (reviewed by Grassle and Grassle, 1978) are still largely speculative, but there is some evidence that this, rather than physiological or behavioural regulatory ability of individuals, is commonly an adaptation to unpredictably variable environments. Genetic variability is, if anything, even more pronounced in some species from uniform environments (e.g. deep-sea benthos) where, presumably, other selective factors are responsible for this condition (Valentine, 1976; Valentine and Ayala, 1978).

In environments such as estuaries which have regular, predictable short-term fluctuations, organisms living there are able to evolve physiological tolerence or regulatory ability. This is not possible if the fluctuations are unpredictable or occur at intervals comparable to the life-span of the individual; short-term selection is then an important component of adaptation. This accounts for opportunistic species which show rapid population changes and are able to respond to environmental disturbances. One of the group of sibling species formerly known as *Capitella capitata* is genetically variable and showed a dramatic increase in numbers after an oil spill (Grassle and Grassle, 1974), and Gray (1979) described a similar response of *Capitella* to other forms of pollution.

In habitats which are spatially rather than temporally varied, there may be selection of larvae after settlement in each microhabitat and the survivors be adapted to a somewhat different set of local conditions at each site. There is great variation in the size and structure of the stype of *Laminaria* and while to some extent this is the result of a phenotypic response to water movements, there is also strong genetic selection for different kinds of plants at different sites which may be very close together (Chapman, 1974). Doyle (1974, 1975) found important genetic differences between *Spirorbis borealis* in open coast and sheltered rock pools only a few hundred metres apart. *Littorina* populations show genetic differences with respect to shell shape to withstand wave action and desiccation (Newkirk and Doyle, 1975), and *Crassostrea virginica* from different sites have genetic differences in growth rates and salinity tolerance (Newkirk *et al.*, 1977).

The strategy for survival in the marine environment thus appears often to be, not an efficient machinery for individual regulation or tolerance, but genetic flexibility. The discovery that a number of species are, in fact, groups of sibling species (e.g. *Capitella capitata* (Grassle and Grassle, 1974), *Ophryotrocha labronica* (Akesson, 1972, 1977) and no doubt many more yet to be uncovered) reveals an extension of the same phenomenon. This may underlie the surprising apparent robustness of many marine ecosystems to substantial levels of anthropogenic additions. There may well be subtle changes but they are beyond the limit of resolution of ecologists, since they involve the replacement of one genotype or sibling species, which cannot be readily distinguished, by others. But this genetic flexibility poses practical problems for environmental monitoring and even greater problems for laboratory studies of pollution effects.

The selection of genotypes that will thrive in local conditions which vary within the space of a few metres or even on opposite sides of the same boulder results in a mosaic. Mann (1972) measured the growth rates of the algae *Laminaria* and *Agarum* on the Nova Scotia coast, but despite measuring hundreds of individual plants, still found standard deviations up to ± 100% of the mean values (fig. 5). To get useful results in these circumstances involves a large amount of time-consuming and expensive replication of measurements.

A more critical consequence of this variation relates to laboratory studies. The whole philosophy of experimental biology is to achieve reproducible results under known, controlled conditions. Experimentalists expect to get low standard deviations and indeed, experimental results with a standard deviation of ± 100% of the mean would be quite unacceptable. Genetic variability between the experimental organisms is to be avoided if at all possible, and the ultimate achievement to this end has been the development of the laboratory rat. In experimental pollution research, the equivalent has been the use of a small number of 'standard' animals, the use of laboratory cultures in preference to natural populations (Reish, 1973), the development of the pure genetical strains of the polychaete *Ophryotrocha* (Akesson, 1970, 1976) and, most strikingly,

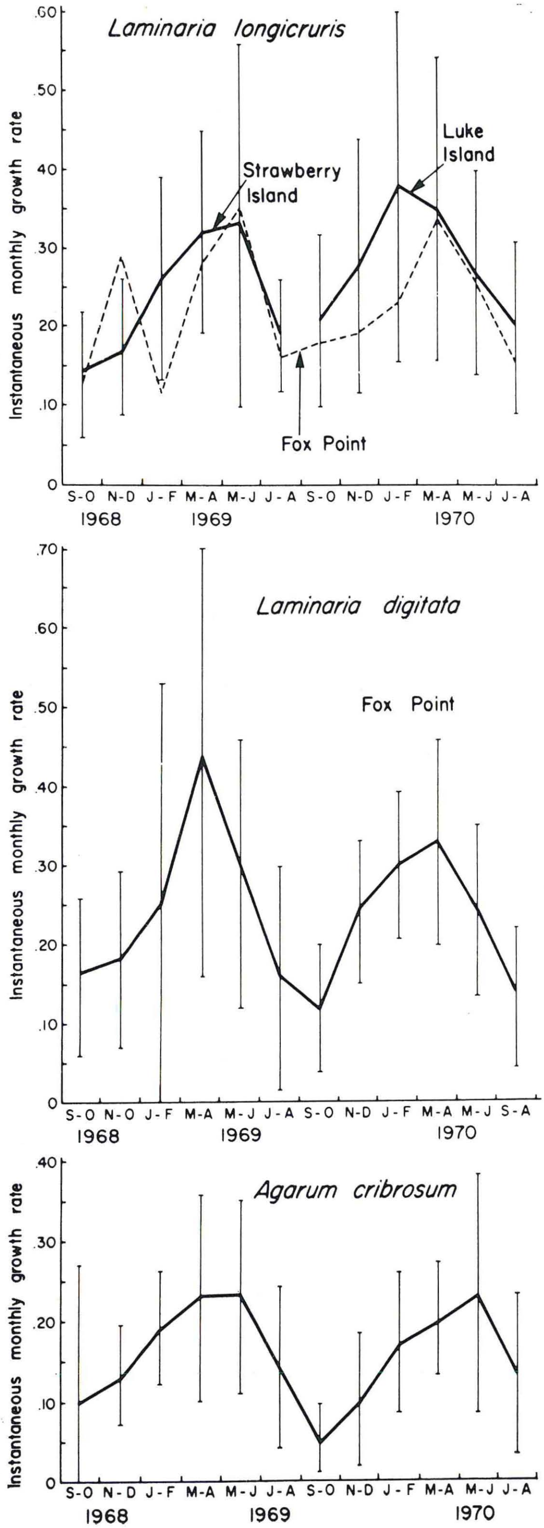


Figure 5 - Seasonal growth of seaweeds in eastern Canada. Standard deviations and means plotted. (From MANN, 1972).

of cloned hydroids for use in the bioassay of pollutants in low concentrations (STEBBING, 1976).

This approach is in the best traditions of experimental biology, but as it now appears, may completely falsify the situation that actually obtains in the sea and make it virtually impossible to translate the results of such laboratory experimental studies into real-life terms. It is quite possible that we are wasting a good deal of money, time and effort on conventional laboratory experimentation, to say nothing of routine toxicity testing on a small spectrum of ' standard ' marine organisms. Because of the inadequacy of our knowledge of the response of populations and communities of marine organisms to toxicants and other stresses in the natural environmental, the experimental results, at best, cannot be interpreted and, at worst, may be totally misleading.

CONCLUSIONS

In all science, the right answers emerge only if the right questions are asked, and the answer to one question should lead to further questions. Effluents discharged to the sea or reaching it by a circuitous route constitute pollution only when they have some undesirable effect, but this raises many questions about what is undesirable or acceptable, and to whom, and the answers to them are political, not scientific. The primary scientific questions relate to the environmental change. Before a sensible political decision can be taken, is is necessary to discover the nature, extent and duration of an environmental change and to identify the causative agents. Political decisions often have to be taken in advance of scientific investigations and even when the necessary information is available, there is no guarantee that a wise political decision will be taken, but if scientists cannot begin to provide it, the chances of adequate and economical remedial action being undertaken are remote indeed.

Because of the uncertainties of the situation, there is a temptation to play safe and in some countries, remedial action is instituted before it is known if an effluent is damaging in any material way. This is expensive and wasteful of resources and may soon prove to be a luxury we cannot afford. It is essential, therefore, that we get a much better knowledge than we have about the response of ecosystems to the addition to the sea of potentially harmful substances. This is not an easy task.

A number of marine ecosystems, certainly including those it is important to monitor, show wide erratic natural fluctuations caused by climatic or biological events which we are only just beginning to understand.

They can be on a scale comparable to the effects of the most severe pollution damage, sometimes, as in the case of the loss of the dominant herbivores, producing exactly the same kind of change or, as in the case of the exceptionally cold and prolonged winter of 1962-63 in Britain, causing even greater and more widespread change (CRISP, 1964). These are only the most conspicuous natural fluctuations and there are no doubt constant adjustments on a much smaller scale. Against such a background it is difficult to detect pollution-induced changes unless they are very large and obvious or are clearly related to a single point input. To get early warning of pollution damage, particularly from diffuse inputs, requires a much more detailed and prolonged knowledge of ecosystem structure and performance than we usually have. In addition to this need, it must be remembered that the collection of data is complication by the genetic variability which is now coming to light of organisms within small areas. To get reliable measurements for comparative purposes, it is necessary to replicate samples to an unusually large extent.

These difficulties create purely practical problems. It is difficult to gain financial support for long-term projects which may require at least ten years sustained effort without any guarantee that the commitment of large sums of money to it will yield commensurate results. And grant-awarding agencies, perhaps more familiar with experimental sciences, are not always sympathetic to the need for the very intensive and repetitive sampling, or for the manpower needed to analyse the samples that these investigations produce. It is also difficult to persuade scientists to undertake such programmes; scientific reputations are rarely enhanced by tedious research which is unlikely to yield results of any interest in less than ten years and may not do so even then.

It is not altogether surprising that both funding agencies and scientists should have turned their attention much more to short-term surveys, experimental studies, and chemical monitoring of the pathways, concentrations and fates of additions to the marine environment for which sensitive analytical equipment can be employed. Unfortunately, it has now become clear that the results of this very considerable volume of work do not provide an answer to the crucial question of the safe limit of effluent discharge to particular areas of sea. This situation is not likely to change until we achieve a better balance between ecological and experimental studies of the consequences of marine pollution. When we have a more secure knowledge of the response of ecosystems to stress, it will be possible to give focus to studies in the laboratory and allow that work to produce results that can be applied to real situations in the sea.

SUMMARY

Effluents discharged to the sea or reaching it indirectly cause pollution when they present a threat to human health or result in changes in ecosystems. The point at which such threats or changes become unacceptable is a political decision for which adequate scientific knowledge, among other things, is essential. Research strategy depends on the nature of the problem. Gross and obvious pollution generally requires a short and relatively crude investigation to identify causes and prescribe remedies. Health hazards are largely through contaminated sea-food and are primarily a public health problem: research strategy is nearly always clear and in most cases is vigorously pursued. The detection of more subtle changes in ecosystems is more difficult and has been neglected in comparison with other pollution studies. It is vital to understand and monitor these changes to provide a focus for other studies and to set realistic but safe limits for the discharge of wastes to the sea, which will become increasingly important in the future.

Whether or not heavy mortality of organisms influences the size of the population, depends on the population dynamics of the species in question. Very large (50-90%) mortality of eggs of an isolated population of *Sardina pilchardus* by toxic oil spill dispersants had no perceptible impact on the local fishery in subsequent years. Losses of some seabirds, on the other hand, have had a major impact on the size of some colonies. Laboratory tests of the toxicity of pollutants and of their sublethal effects have therefore little value at present because they cannot be interpreted in realistic terms. In cases were populations of a species are reduced, the ecological consequences are much greater if they occupy a key role in an ecosystem, (e.g. key predators, some herbivourous gastropods and echinoids). Their loss may result in major ecological change of long duration. A number of prolonged studies of marine ecosystems (intertidal, pelagic and benthic) have revealed ecological change from natural climatic or biological causes which are of a similar type and scale to those following major pollution. There are also less pronounced natural fluctuations, the causes of which are generally unknown.

It is extremely difficult to detect small, pollution-induced changes against this naturally fluctuating background without very detailed and long-term investigations. The problem is made worse because many marine organisms are genetically very variable and strategy for survival is short term selection rather than individual tolerance, physiological regulation or adaptation. Different genotypes may be selected over very short distances where physical or other factors are different and the extreme variability of natural populations demands much replication of sampling in ecological studies. In experimental studies, genetic variability of test organisms is avoided or reduced if possible, and has led to the use of genetically « pure » strains or clones for toxicity tests, etc. This appears to falsify the situation in marine ecosystems and the results of these experiments cannot be interpreted or may even be misleading. Because of the difficulties, monitoring the response of ecosystems to pollution or other stress has not been undertaken as vigorously as other types of pollution research, but it is important that this imbalance be corrected.

REFERENCES

AKESSON B. (1970) - *Ophryotrocha labronica* as test animal for the study of marine pollution. *Helgol. wiss. Meeresunters.*, **20**, 293-305.

AKESSON B. (1972) - Incipient reproductive isolation between geographical populations of *Ophryotrocha labronica* (Polychaeta, Dorvilleidae). *Zool. Scr.*, **1**, 207-210.

AKESSON B. (1976) - Bioassay studies with polychaetes of the genus *Ophryotrocha* as test animals. In J.H. Koeman & J.J.T.W.A. Strik eds. *Sublethal Effects of Toxic Chemicals on Aquatic Animals.* Elsevier, Oxford, pp. 121-135.

AKESSON B. (1977) - Crossbreeding and geographical races, experiments with the polychaete genus *Ophryotrocha. Mikrofauna Meeresboden*, **61**, 15-24.

Bowman R. S. (1978) - Dounreay oil spill: major implications of a minor incident. *Mar. Pollut. Bull.*, **9**, 269-273.

Bowman R. S., Lewis J. R. (1977) - Annual fluctuation in the recruitment of *Patella vulgata* L. *J. mar. biol. Ass. U.K.*, **57**, 793-815.

Breen P. A., Mann K. A. (1976) - Destructive grazing of kelp by sea urchins in eastern Canada. *J. Fish. Res. Bd Can.*, **33**, 1278-1283.

Buchanan J. B., Kingston P. F., Sheader M. (1974) - Long-term population trends in the benthic macrofauna in the offshore mud of the Northumberland coast. *J. mar. biol. Ass. U.K.*, **54**, 785-795.

Buchanan J. B., Sheader M., Kingston P. F. (1978) - Source of variability in the benthic macrofauna off the Northumberland coast, 1971-1976. *J. mar. biol. Ass. U.K*, **58**, 191-209.

Chapman A. R. O. (1974) - The genetic basis of morphological differentiation in some *Laminaria* populations. *Mar. Biol.*, **24**, 85-91.

Clark R. B. (1969) - Oil pollution and the conservation of seabirds. *Proc. intern. Conf. Oil Pollution of the Sea, Rome, 1968*, 76-112.

Connell J. H. (1970) - A predator-prey system in the marine intertidal region. I. *Balanus glandula* and several predatory species of *Thais*. *Ecol. Monogr.*, **40**, 49-78.

Crisp D. J. (1958) - The spread of *Elminius modestus* Darwin in north-west Europe. *J. mar. biol. Ass. U.K.*, **37**, 483-520.

Crisp D. J. (1964) - The effects of the severe winter of 1962-63 on marine life in Britain. *J. Anim. Ecol.*, **33**, 165-210.

Doyle R. W. (1974) - Choosing between darkness and light: the ecological genetics of photic behaviour in the planktonic larvae of *Spirorbis borealis*. *Mar. Biol.*, **25**, 311-317.

Doyle R. W. (1975) - Settlement of planktonic larvae: a theory of habitat selection in varying environments. *Am. Nat.*, **109**, 113-126.

Glover R. S., Robinson G. A., Colebrook J. M. (1972) - Plankton in the north Atlantic - an example of the problems of analysing variability in the environment. In M. Ruivo ed., *Marine Pollution and Sea Life*. Fishing News (Books) Ltd., London, pp. 439-445.

Grassle J. F., Grassle J. P. (1974) - Opportunistic life histories and genetic systems in marine benthic polychaetes. *J. Mar. Res.*, **32**, 253-284.

Grassle J. F., Grassle J. P. (1978) - Life histories and genetic variation in marine invertebrates. In B. Battaglia & J.A. Beardmore eds., *Marine Organisms, Genetics, Ecology and Evolution*. Plenum Press, New York, pp. 347-364.

Gray J.S. (1979) - Pollution - induced changes in populations. *Philos. Trans. R. Soc. Lond.*, **283**, 545-561.

Leslie F. H. (1966) - The intrinsic rate of increase and overlap of successive generations in a population of guillemots (*Uria aalge* Pont.). *J. Anim. Ecol.*, **35**, 291-301.

Lewis J. R. (1972) - Problems and approaches to baseline studies in coastal communities. In M. Ruivo ed., *Marine Pollution and Sea life*. Fishing News (Books) Ltd., London, pp. 401-404.

Lewis J. R. (1976) - Long-term ecological surveillance: practical realities in the rocky intertidal. *Oceanogr. Mar. Biol., Ann. Rev.*, **14**, 371-390.

Lewis J. R. (1978) - The implications of community structure for benthic monitoring studies. *Mar. Pollut. Bull.*, **9**, 64-67.

MANN K. H. (1972) - Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. II. Productivity of seaweeds. *Mar. Biol.,* **14**, 199-209.

MANN K. H. (1977) - Destruction of kepp-beds by sea-urchins: a cyclical phenomenon or irrevirsible degradation. *Helgol. wiss. Meeresunters.,* **30**, 445-467.

MILLER D. S., PEAKALL D. B., KINTER W. B. (1978) - Ingestion of crude oil: sublethal effects in herring gull chicks. *Science,* **199**, 315-317.

NELSON-SMITH A. (1968) - Effects of oil and emulsifiers on shores in south-west Britain. *Rep. Challenger Soc.,* **3** (20), 60.

NEWKIRK G. F., DOYLE R. W. (1975) - Genetic analysis of shell-shape variation in *Littorina saxatilis* on an environmental cline. *Mar. Biol.,* **30**, 227-237.

NEWKIRK G. F., HALEY L. E., WAUGH D. L., DOYLE R. W. (1977) - Genetics of larval and spat growth in the oyster *Crassostrea virginica. Mar. Biol.,* **41**, 49-52

NORTH W. J., NEUSHAL H., CLENDENNING K. A. (1965) - Successive biological changes observed in a marine cove exposed to a large spillage of mineral oil. *Symp. Comm. int. Explor. scient. Mer Mediterr., Monaco,* **1964**, 335-354.

PAINE R. J. (1974) - Intertidal community structure. Experimental studies on the relationship between a dominant competitor and its principal predator. *Oecologia,* **15**, 93-120.

REISH D. J. (1973) - Laboratory populations for long-term toxicity tests. *Mar. Pollut. Bull.,* **4**, 46-47.

SMITH J. E. (1968) - « *Torrey Canyon* », *Pollution and Marine Life.* University Press, Cambridge.

SOUTHERN H. N., CARRICK R., POTTER G. W. (1965) - The natural history of a population of guillemots (*Uria aalge* Pont.). *J. Anim. Ecol.,* **34**, 649-665.

SOUTHWARD A. J. (1967) - Recent changes in abundance of intertidal barnacles in south west England: a possible case of climatic deterioration. *J. mar. biol. Ass., U.K.,* **47**, 81-95.

SOUTHWARD A. J., CRISP D. J. (1954) - Recent changes in the distribution of the intertidal barnacles *Chthamalus stellatus* Poli and *Balanus balanoides* L. in the British Isles. *J. Anim. Ecol.,* **23**, 163-177.

SOUTHWARD A. J., CRISP D. J. (1956) - Fluctuations in the distribution and abundance of intertidal barnacles. *J. mar. biol. Ass. U.K.,* **35**, 211-229.

SOUTHWARD A. J., SOUTHWARD E. C. (1978) - Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. *J. Fish. Res. Bd Can.,* **35**, 682-706.

STEBBING A. R. D. (1976) - The effects of low metal levels on a clonal hydroid. *J. mar. biol. Ass. U.K.,* **56**, 977-994.

VALENTINE J. W. (1976) - Genetic strategies of adaptations. In F.J. Ayala ed., *Molecular Evolution.* Sinauer Associates Inc., Sunderland, Mass., pp. 78-94.

VALENTINE J.W., AYALA F. J. (1978) - Adaptive strategies in the sea. In B. Battaglia & J.A. Beardmore eds., *Marine Organisms, Genetics, Ecology and Evolution.* Plenum Press, New York, pp. 323-345.

WILSON D. P. (1971) - *Sabellaria* colonies at Duckpool, North Cornwall, 1961-1970. *J. mar. biol. Ass. U.K.,* **51**, 509-580.