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Behavioural Responses of Marine Poikilotherms to Pollutants [and Discussion]

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Behavioural responses of marine poikilotherms to pollutants

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Selected behavioural responses of marine fishes and invertebrates which are reportedly capable of disruption or impairment by petroleum, heavy metals, pesticides and other pollutants are listed. The usefulness of these and other performance functions to regulatory agencies charged with formulation of saline water quality criteria appears somewhat limited. At present, however, motor functions such as swimming performance, locomotion, and equilibrium, as well as physiological responses, especially respiratory patterns, may have some potential for biomonitoring of wastes discharged into coastal environments.

Introduction

Behaviour as a diagnostic character in marine pollutant assessment studies has become the focus of a growing technical literature. Most of this effort has been restricted to research on effects of toxic substances, heated effluents and other anthropogenic wastes upon various performance functions of estuarine teleosts and macroinvertebrates under laboratory conditions. Paradoxically, toxicological assessment studies of marine pollutants rarely include behavioural parameters, and instead emphasize collection of data on survival, growth, reproduction and toxicant residues. Furthermore, there is no national or international regulatory agency which currently espouses the view that behavioural responses are necessary adjuncts in formulation of marine water quality criteria. An attempt to reconcile these conflicting approaches is the subject of this account. Specifically, it lists selected performance functions of individuals (e.g. sensory capacity, motor activity, motivation and learning, rhythmic activity, physiological responses) and of groups (e.g. social motivation, intraspecific visual attraction, aggregation and schooling, aggression, predation vulnerability) that are reportedly disrupted or impaired by pollutants entering marine environments. In addition, it considers the practicality of various behavioural responses as criteria for marine water quality, and as biomonitors of industrial effluents and surface water quality.

Background

Quantitative studies on biological aspects of pollutants to marine biota are of recent origin. As a consequence, numerous and disparate research approaches exist today among investigators in choice of methodologies, indicator organisms, and response parameters (Eisler 1972; National Academy of Sciences 1973; La Roche *et al.* 1973; U.S. Environmental Protection Agency 1976; Eisler 1977, 1979). As recently as 15 years ago, most of the effort in toxic substance evaluation was restricted to static bioassays with the use of death or immobilization of fish and non-sessile macroinvertebrates as end points. At that time, marine water quality criteria for individual toxicants were usually selected on the basis of the l.c.$_{50}$ (96 h) value, i.e. the concentration producing 50 % mortality in 96 h, and an application factor which when multiplied by the l.c.$_{50}$ (96 h) value would produce a 'safe' level. The application factor usually selected was 0.1, but ranged in what was apparently an arbitrary selection process between 0.4 and 0.001.

In the absence of additional data, many of these application factors remain unchallenged. About 10 years ago, long-term testing of toxicants was established on a systematic basis with primary emphasis on growth, survival, and reproduction; however, almost all of this effort was confined to freshwater teleosts (McKim 1977). More recently, a major effort in both salt and freshwater habitats has been directed to analytical determinations of toxicant residues in various organs and tissues of a wide range of indicator organism assemblages. From the viewpoint of regulatory agencies, toxicant residue concentration, regardless of transport mechanisms in organism, medium or sediment, is probably the single most effective datum in successful enforcement actions. Most recently, research effort has attempted to correlate toxicant concentrations in economically important species with biochemical, physiological, histological, and behavioural indices of stress. As one example, a recent analysis of response parameters used by various investigators during the 3 year period 1974–6 to measure effects of heavy metals and toxic cations on marine biota under laboratory conditions (Eisler 1979) produced the following distribution: 49 % of the total research effort was devoted to uptake, retention, and translocation studies; 17 % to survival studies; 14 % to growth and development; 7 % to reproduction; 6 % to biochemical and physiological parameters; and 4 % to histological investigations. Behavioural parameters accounted for only 3 % of the total effort and included inhibition by chromium of tube building in annelids (Oshida & Reish 1975); sluggishness, uncoordinated swimming movements, negative phototaxy, delayed migration, and inhibition of feeding response in teleosts by salts of mercury (Klaunig *et al.* 1975), zinc (Negilski 1976), chromium (Sherwood 1975) and copper (Lorz & McPherson 1976); and, in bivalve molluscs, interference with burrowing ability by copper (Stephenson & Taylor 1975), aberrant respiratory rates and valve movements by silver (Thurberg *et al.* 1975), and reduction in feeding rate by mercury (Dorn 1976). The significance of these parameters will be argued later.

However, when toxicants other than metals were investigated, it was found that in many cases it was not possible to detect measurable residues of pollutants in test species. These include heated effluents from power plants, brines from desalination plants, chemical toxicants such as chlorine which kill without bioaccumulating, and most important, complex mixed wastes typical of most municipal and industrial outfalls. It is well known that deleterious effects and biomagnification potential of complex wastes are not necessarily predictable on the basis of individual components; some may act synergistically, others antagonistically. It is in this large general area that sublethal responses may have the greatest value for application in water quality criteria.

Of these sublethal effects, behavioural changes are probably among the least studied. Behaviour is difficult to assess quantitatively owing to variability over time and subject, and to difficulties in the acquisition of reliable data. Nevertheless, behaviour, whether genetically or environmentally controlled, is a highly complex adaptive response to environmental modifications. Consequently, toxicological modification of a specific behavioural pattern, while it may not be evident in an easily recognizable major behavioural change, may be associated with subtle effects of an organism's ability to deal with environmental changes. Fundamentally, the success of the behavioural approach depends on the ability to define quantitatively normal patterns of behaviour. It is also generally agreed that data on pollutant-induced alterations in behavioural patterns can be collected only through the development and use of sensitive bioassays that closely parallel conditions present in the field (Atema *et al.* 1973). To be of maximum use in the design of behavioural bioassays, field studies should be conducted to establish the prime characteristics of the test species including spatial distribution, spontaneous activities, and sexual, social, defensive, feeding and other activities (Olla *et al.* 1974). In the laboratory bioassay system, physical and chemical régimes of light, temperature, pH, salinity, dissolved oxygen, water circulation, and other parameters should approximate those normally encountered by the test organisms. Appropriate organisms must be selected for study. These should be representative of the ecosystem that is affected, and should incorporate certain social and ecological criteria including economic importance, trophic level representation, importance in habitat and community structure, differential sensitivity of various life stages, suitable behavioural traits capable of quantification, and adaptability to laboratory conditions (Olla *et al.* 1974). The behavioural response parameter selected for study should meet several minimal criteria, namely: it must be important for species survival; certain components of the behaviour sequence must be stable, reproducible, and with a well defined and quantifiable endpoint; and the stimulus (pollutant) must be capable of initiating, or inhibiting, the behavioural sequence either on an 'all or none' or on a graded basis.

Behavioural responses

Many behavioural responses of marine poikilotherms have been used as indicators of pollutant-induced stress under controlled conditions. These, together with their accompanying pollutant stressors, are shown in table 1. It is emphasized that the information in table 1 is limited in several respects. First, owing to a paucity of research in this subject area until recently, data from only a few of the more recent and representative papers are listed. Secondly, many of the responses listed were *reflexive* in nature, rather than *perceptive*. That is, they were external manifestations of physiological or biochemical effects, rather than integration into higher brain centres for recognition of the inimical nature of the contaminant, i.e. learning-conditioned paradigms. Finally, several papers mention behavioural stress only incidentally, and fail to supply documentation of effects. For example, loss of equilibrium may be functionally equivalent to death in many cases; however, it is more probable that other effects were evident well before equilibrium loss.

Within these constraints, it appears from table 1 that most of the total effort (85 %) was devoted to individual performance functions, and only 15 % to group performance functions. For all studies, teleosts were used most frequently (45 %), followed by crustaceans (33 %), molluscs (16 %) and others (6 %). For individual performance functions, most studies were on motor activities (43 %) and physiological responses (24 %) followed by sensory capacities (18 %), motivation and learning (12 %), and others (3 %). Incidentally, almost half of the motor activities studies were restricted to aberrations in swimming performance and spontaneous locomotor activity effects. Similarly, disruptions in respiratory rates constituted about half the physiological response effort. The significance of these findings will be discussed later.

On the basis of the information in table 1 it was difficult to generalize about species responses to various pollutants. Thus, some pollutants were associated with increasing respiration rates and swimming activities while others produced the opposite effect. Shrimp exposed to organophosphorus insecticides were more susceptible to predation by fish; but the reverse was observed with organochlorine insecticides. The issue is further complicated by the fact that closely related species, teleosts as one example, with similar sensitivities to chemical pollutants, may exhibit markedly different behavioural patterns, many of which appear to be dependent on the trophic level occupied.

Table 1. Behavioural responses of marine biota used as sublethal indicators of environmental stress (modified from Olla *et al.* 1974)

individual responses

	stressor	authority
(i) sensory capacity		
(*a*) phototaxis		
Crustacea		
Cancer irroratus larvae	oil	Bigford (1977)
Copepod spp.	xanthine dyes	Bjonberg & Wilbur (1968)
Uca pugilator larvae	mercury	Vernberg *et al.* (1973)
fishes		
Fundulus heteroclitus	mercury	Klaunig *et al.* (1975)
(*b*) geotaxis		
Crustacea		
Cancer irroratus larvae	oil	Bigford (1977)
(*c*) chemotaxis		
Mollusca		
Nassarius obsoletus	kerosene fraction	Jacobson & Boylan (1973); Blumer *et al.* (1973)
(*d*) chemoreception		
Crustacea		
Balanus amphitrite	DDT	Meith-Avcin (1974)
Homarus americanus	crude oil, fuel oil, kerosene	Blumer *et al.* (1973); Atema & Stein (1974); Atema (1979)
Pachygrapsus crassipes	crude oil fractions	Takahashi & Kittredge (1973)
fishes		
Fundulus heteroclitus, *Menidia menidia*	copper	Gardner & La Roche (1973)
Mollusca		
Nassarius obsoletus	fuel oil	Atema (1979)
(*e*) temperature preference		
fishes		
Salmo salar	DDT	Ogilvie & Anderson (1965)
(*f*) tactile inhibition		
Coelenterata		
Pocillopora damicornis	crude oil	Reimer (1975)
Crustacea		
Balanus amphitrite	DDT	Meith-Avcin (1974)
fishes		
Fundulus heteroclitus, *Menidia menidia*	copper	Gardner & La Roche (1973)
Mollusca		
Mercenaria mercenaria	pesticides	Eisler (1970)
(*g*) lateral line sensitivity		
fishes		
Fundulus heteroclitus, *Menidia menidia*	Cu, Hg, Ag, Cd, Zn, methoxychlor, crude oil, pulp mill effluents	Gardner (1975); Gardner & La Roche (1973)
(ii) rhythmic activities		
(*a*) reproductive cycle		
Crustacea		
Gammarus sp.	thermal shock	Ginn *et al.* (1976)
fishes		
Clupea harengus	benzene	Struhsaker (1977)

TABLE 1 (*cont.*)

(*b*) daily activity cycle		
Mollusca		
Monodonta articulata	mercuric sulphate	Saliba & Vella (1977)
Crustacea		
Uca pugilator	mercuric chloride	Vernberg *et al.* (1974)
(iii) motor activity		
(*a*) avoidance		
Crustacea		
Palaemonetes pugio	pesticides	Hansen *et al.* (1973)
Uca pugnax	fuel oil, insecticides	Krebs & Burns (1977); Ward & Busch (1976); Krebs *et al.* (1974)
fishes		
Clupea harengus	pulp mill effluents	Wildish *et al.* (1977)
Cyprinodon variegatus	pesticides	Hansen (1969)
Fundulus grandis	pulp mill effluents	Lewis & Livingston (1977)
Lagodon rhomboides	pulp mill wastes	Lewis & Livingston (1977)
Salmo salar	copper, zinc	Saunders & Sprague (1967)
Mollusca		
Monodonta articulata	mercury	Saliba & Vella (1977)
Mytilus edulis	copper	Davenport (1977)
(*b*) attraction		
Crustacea		
Homarus americanus	kerosene fraction	Atema *et al.* (1973)
(*c*) shelter seeking, including substrate attachment and burrowing activity		
annelids		
Nereis arenaceodentata	chromium	Oshida & Reish (1975)
Coelenterata		
Halitholus cirratus	crude oil	Percy & Mullin (1977)
Crustacea		
Balanus amphitrite	DDT	Meith-Avcin (1974)
Onismus affinis	crude oil	Percy & Mullin (1977)
Pagurus spp.	DDT	Grant (1972)
Uca pugnax	fuel oil	Krebs & Burns (1977)
fishes		
Tautoga onitis	thermal	Olla & Studholme (1975); Olla *et al.* (1978)
Mollusca		
Mytilus spp.	crude oil, dispersants	Swedmark *et al.* (1973) Eisler (1975)
Tellina tenuis	copper, phenol	Stirling (1975)
Venerupis decussata	copper	Stephenson & Taylor (1975)
(*d*) equilibrium		
Crustacea		
Uca pugnax	fuel oil, DDT	Krebs & Burns (1977); Odum *et al.* (1969)
fishes		
Cyprinodon variegatus	Kepone	Hansen *et al.* (1977)
Fundulus heteroclitus	mercury	Klaunig *et al.* (1975)
Fundulus majalis	aziridines	Eisler (1966)
Fundulus similis	napthalenes	Dixit & Anderson (1977)
Oncorhynchus gorbuscha	hydrocarbons	Rice *et al.* (1977)
Mollusca		
Nassarius obsoletus	metals	MacInnes & Thurberg (1973)

TABLE 1 (*cont.*)

(*e*) swimming performance or spontaneous locomotor activity		
Coelenterata		
Heteroxenia fuscescens	petroleum	Cohen *et al.* (1977)
Crustacea		
Balanus amphitrite	DDT	Meith-Avcin (1974)
Balanus spp.	copper	Lang *et al.* (in press)
Cancer irroratus larvae	oil	Bigford (1977)
Eupagurus bernhardus	crude oil, dispersants	Swedmark *et al.* (1973)
Homarus americanus	fenitrothion	McLeese (1974)
Hyas araneus, *Leander adspersus*	crude oil, dispersants	Swedmark *et al.* (1973)
Palaemonetes pugio	cadmium, dissolved oxygen	as quoted in Olla *et al.* (1974)
Rhithropanopeus harrisi	detergents	Czyzewska (1976)
Uca pugilator	mercury	Vernberg *et al.* (1974); DeCoursey & Vernberg (1972)
Uca pugnax	DDT	Odum *et al.* (1969)
fishes		
Aldrichetta forsteri	zinc	Negilski (1976)
Clupea harengus	benzene	Struhsaker (1977)
Clupea spp.	crude oil, chemical oil dispersants	Linden (1975)
Fundulus heteroclitus	mercury	Klaunig *et al.* (1975)
Fundulus similis	napthalenes	Dixit & Anderson (1977)
Gadus morhua	crude oil, dispersants, ethanol	Swedmark *et al.* (1973); Lindahl *et al.* (1977)
Pomatomus saltatrix	thermal	Olla & Studholme (1971, 1975); Olla *et al.* (1975)
Scomber scombrus	thermal	Olla & Studholme (1975); Olla *et al.* (1975)
Sphaeroides maculatus	methyl parathion	Eisler (1967)
Mollusca		
Littorina littorea	fuel oil, chemical oil dispersants	Hargrave & Newcombe (1973)
(iv) motivation and learning phenomena		
(*a*) feeding		
Crustacea		
Homarus americanus	crude oil, various petroleum fractions	Atema & Stein (1974); Blumer *et al.* (1973)
Palaemonetes vulgaris	aziridines	Eisler (1966)
Uca sp.	mercury	as quoted in Olla *et al.* (1974)
fishes		
Citharichthys stigmaeus	chromium	Sherwood (1975)
Cyprinodon variegatus	Kepone	Hansen *et al.* (1977)
Fundulus majalis	aziridines	Eisler (1966)
Pomatomus saltatrix	temperature	Olla & Studholme (1971)
Sphaeroides maculatus	organophosphorus insecticide	Eisler (1967)
Tautoga onitis	thermal	Olla *et al.* (1978)
Mollusca		
Mytilus edulis	methyl mercury	Dorn (1976)
Nassarius obsoletus	pesticides	Eisler (1970)
(*b*) conditioned avoidance response		
Crustacea		
Palaemonetes pugio	mercury	Barthalmus (1977)

TABLE 1 (*cont.*)

(v) physiological responses		
(*a*) respiration		
Crustacea		
Acartia clausi	thermal	Gaudy (1977)
Uca pugilator	mercury	Vernberg & Vernberg (1972)
fishes		
Fundulus heteroclitus	mercury	Klaunig *et al.* (1975)
Fundulus majalis	aziridines	Eisler (1966)
Oncorhynchus spp. fry	petroleum	Thomas & Rice (1975); Rice *et al.* (1977)
Pseudopleuronectes americanus	mercury, cadmium	Calabrese *et al.* (1975)
Tautogolabrus adspersus	silver	Thurberg & Collier (1977)
Mollusca		
Littorina littorea	fuel oil, chemical oil dispersant	Hargrave & Newcombe (1973)
Monodonta articulata	mercuric sulphate	Saliba & Vella (1977)
Mya arenaria	chromium, silver	Capuzzo & Sasner (1977); Thurberg *et al.* (1974)
Mytilus edulis	chromium, copper, silver	Capuzzo & Sasner (1977); Brown & Newell (1972); Scott & Major (1972); Thurberg *et al.* (1974)
Nassarius obsoletus	arsenic, cadmium, copper, silver, zinc	MacInnes & Thurberg (1973)
Spisula solidissima	silver	Thurberg *et al.* (1975)
(*b*) Filtration rate		
Mollusca		
Mya arenaria	chromium	Capuzzo & Sasner (1977)
Mytilus edulis	chromium, fuel oil	Capuzzo & Sasner (1977); Gonzalez *et al.* (1979)
(*c*) pigmentation pattern		
Coelenterata		
Montiporra verrucosa, Porites lobata, Pocillopora meandrina	thermal shock	Jokiel & Coles (1974)
Pocillopora meandrina	crude oil	Reimer (1975)
Crustacea		
Homarus americanus larvae	crude oil	Forns (1977)
fishes		
Cyprinodon variegatus	Kepone	Hansen *et al.* (1977)
Gadus morhua	crude oil extracts	Kuhnhold (1974)
(*d*) heart beat rate		
fishes		
Cyprinodon sp., *Fundulus* sp.	petroleum extracts	Anderson *et al.* (1977)
Tautoga onitis	cadmium, zinc	Mallet (1972)
(*e*) morphological changes		
fishes		
Cyprinodon variegatus	Kepone	Hansen *et al.* (1977); Couch *et al.* (1977)
(*f*) autotomy		
Crustacea		
Chionoecetes bairdi	crude oil	Karinen & Rice (1974)

Table 1 (*cont.*)

inter-individual responses		
(vi) migration		
fishes		
Oncorhynchus kisutch	copper	Lorz & McPherson (1976)
Salmo salar	copper–zinc mining wastes	Saunders & Sprague (1967)
(vii) intraspecific visual attraction		
fishes		
Tautoga onitis	thermal	Olla *et al.* (1978)
(viii) aggregation and schooling		
fishes		
Kuhlia sanvicensis	insecticides	Hiatt *et al.* (1953)
Menidia menidia	carbaryl insecticide	Weis & Weis (1974)
Pomatomus saltatrix	thermal	Olla & Studholme (1971)
(ix) aggression		
Crustacea		
Palaemonetes vulgaris	aziridines	Eisler (1966)
Homarus americanus	kerosene	Blumer *et al.* (1973)
fishes		
Tautoga onitis	thermal	Olla & Studholme (1975); Olla *et al.* (1978)
(x) predation vulnerability		
mollusc on mollusc		
Drupa granulata on *Mytilus variabilis*	crude oils	Eisler (1975)
fish on shrimp		
Fundulus grandis on *Palemonetes pugio*	organophosphorus pesticides	Farr (1977)
Lagodon rhomboides on *Palaemonetes vulgaris*	organochlorine pesticides	Tagatz (1976)
fish on fish		
Fundulus majalis on larval *Paralichthys dentatus* or larval *Menidia menidia*	acute thermal shock	Deacutis (1979)
birds on Crustacea		
Rallus longirostris, *Catoptrophorus semipalmatus*, *Limnodromus* sp; all on *Uca pugnax*	Temefos insecticide	Ward *et al.* (1976)

APPLICATIONS

From the information in table 1 it was not unexpected that current biomonitoring approaches, at least those used to assess the quality of freshwaters, relied heavily on teleost motor responses (Besch *et al.* 1977; Kleerekoper 1977; Poels 1977) and respiratory functions (Westlake & van der Schalie 1977; Morgan 1977*a*, *b*).

Morgan (1977*a*, *b*), for example, devised an automonitoring system based on the evidence of others that opercular rhythms of freshwater fishes were disrupted by various organic and inorganic pollutants including copper, cadmium, mercury, lead, phenols, cyanides, and organochlorine and organophosphorus insecticides. Morgan's system, intended to complement physical and chemical monitoring techniques, was based on the hypothesis that fish opercular rhythms increased under toxic conditions, i.e. 0.05–0.10 times the $\mathrm{l.c.}_{50}$ (48 h) concentration; continuous electronic monitoring recorded any increases in opercular rates above that expected under normal conditions. Features of this design included a visual alarm system to warn of the development of a critical toxic condition, and this was tied to electronic circuits to control rate of toxic industrial discharges. Morgan concluded that future development of biological automonitoring systems, based upon a variety of fish physiological and behavioural responses to pollutants, may provide the answer to the problem of continuously and automatically monitoring surface waters. Morgan's system appears sufficiently flexible at this time for measurement of other fish response parameters such as oxygen consumption, cough reflex, movement patterns, avoidance, and rheotaxis, either singly or in combination. In another example, the automatic monitoring and alarm system of Besch *et al.* (1977) is adaptable to continuous flow as well as static tests. That system used swimming performance, equilibrium, and schooling behaviour of freshwater teleosts after initial studies demonstrated that all of these parameters were disruptable by DDT, mercury, petrol and phenol. With some modification this system could be used to assess quantitatively pollutant-induced locomotor disorientation in marine invertebrates, especially decapod crustaceans.

The picture is quite different in saline environments. There, no biomonitoring studies have been conducted with complex wastes using whole organism behavioural patterns. The reasons for this are unclear, but may be attributable partly to a lag in development and construction of reliable marine biomonitoring facilities, partly to a general lack of agreement on choice of appropriate indicator species, and partly to contention in selection of meaningful behavioural responses for the wastes under investigation. In addition, there is a shortage of personnel with training and experience in marine behavioural toxicology. However, in regard to the coastal zone, it *is* clear that increasing numbers of steam electric stations, electroplating plants, petroleum refineries, paper mills, sewage treatment plants, and others of similar nature are either under construction or planned. Accordingly, initiation of a marine biomonitoring programme with the use of sublethal behavioural responses as indices of water quality is strongly recommended.

At present, behavioural criteria appear to be of limited worth in formulation of uniform marine water quality standards. Despite an abundance of data collected under controlled laboratory conditions on behavioural responses of single species to individual pollutants, field verification data are notably absent. To receive serious consideration in the standards setting process, behavioural responses selected in laboratory studies should correlate significantly with observed changes in mixed populations of affected ecosystems and, specifically with changes in survival, wellbeing, toxicant residues where applicable, species diversity, and community structure. This has not yet been reported. It is clear that collection of the desired supporting field data will require a multidisciplinary group with expertise that includes behavioural toxicology, analytical chemistry, quantitative biology, hydraulics, and physiological ecology. Formation of one or more of these research groups appears warranted; once formed, provisions for long-term funding are essential. With proper staffing and financing it is likely that these multidisciplinary groups will achieve two goals: the production of reliable predictive models, with emphasis on behavioural parameters, of potential damage effects from marine pollutants; and a material contribution to the amelioration of pollutant-induced changes now encountered and documented in heavily populated coastal areas.

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Discussion

G. C. Carney (*Science Department, Bristol Polytechnic, Bristol, U.K.*). I believe that a great deal of work has been done on learning behaviour and pattern recognition in the octopus. Has anyone made use of this knowledge in looking for effects on the behaviour of this organism of the various pollutants that Dr Eisler has mentioned?

R. Eisler. Various aspects of cephalopod behaviour are the subject of chapters in two recent books: Wells, M. J. 1978 *Octopus. Physiology and behaviour of an advanced invertebrate*. London: Chapman & Hall; and Nixon, M. & Messenger, J. B. (eds) 1977 *The biology of cephalopods*.

London: Academic Press. However, I am not aware of any controlled behavioural studies with anthropogenic pollutants on octopods or decapods.

A. P. M. Lockwood (*Department of Oceanography*, *University of Southampton*, *Southampton SO*9 5*NH*, *U.K.*). Would Dr Eisler care to comment on the concentration levels of pollutant which cause behavioural changes in relation to recognized application factors for the same materials? What evidence is there that pollution effects on larval behaviour could affect the distribution of adult populations of benthic organisms in estuaries?

R. Eisler. Current biomonitoring techniques can accurately measure toxicant-induced behavioural changes in aquatic biota at concentrations between 5 and 10 % of the l.c.$_{50}$ (48 h) value. For those toxicants which have application factors of 1–10 % of the l.c.$_{50}$ (96 h) value, biomonitoring has no apparent advantage. However, the application factor concept is not trustworthy in my opinion if the waste stream contains, as it usually does, fluctuating concentrations of several potentially hazardous and interacting materials. Under these conditions the organism will become the sole arbiter of its environment as reflected by disrupted behavioural patterns and other manifestations of generalized stress. Afterwards it will become necessary to isolate the causative agent or agents. For these reasons, laboratory research must continue with single toxicant effects, and with greater emphasis on effects of complex wastes at field level concentrations and ratios of individual components.

As for the second question, there is little evidence to demonstrate conclusively that pollutant-induced changes in larval behaviour will be reflected by adult communities. The low rate of survival to adulthood normally encountered among unstressed populations of most marine larvae, including the benthos, is probably a prime confounder at this time. Among the benthos, it would appear that preservation of the reproductive integrity of the parent stock is more important in terms of enforceable water quality legislation than acceptance of the premises linking changes in larval behaviour to adult population distributions.

E. J. Perkins (*Marine Laboratory*, *University of Strathclyde*, *Kilcreggan*, *Helensburgh G*84 0*JQ*, *U.K.*). Regarding the effect of pollutants upon the predator–prey relation E. Gribbon examined this in relation to oil emulsifiers, and found that the whelk (*Buccinum*) preferentially consumed the dog whelk (*Thais*) treated with these materials. However, when treated and untreated oysters (*Ostrea*) were offered to *Buccinum*, the hermit crab (*Eupagurus*) and the starfish (*Asterias*), only *Eupagurus* consumed the oysters and in so doing selected against the treated animals. This response may therefore be too ambiguous for practical use.

The need for avoidance tests which Dr Eisler so passionately advocated is recognized in this country. However, our estuaries can perhaps be considered under one of two alternatives, namely either so bad that the question does not arise, or waste disposals at levels below this are such that fish are often taken close to or in outfall water from chemical factories, pulp mills and power stations. On the open coast the latter alone pertains. It is therefore difficult in the present financial climate to justify the expenditure required in specialized equipment and the requisite skilled operators.

R. Eisler. The apparent willingness by Dr Perkins to dismiss badly polluted estuaries as irretrievably lost and to hope for the best among those not similarly afflicted is surprising. In the United States it is the mandated goal of water quality agencies to prevent further deterioration in desired usages of streams, rivers, estuaries and other bodies of waters, and to restore as much as possible the quality of badly polluted water bodies to the extent that fish, wildlife, recreation, aesthetics, and other amenities are preserved. I hope that similar goals exist for U.K. water agencies. Despite the money shortage, some funds should be diverted to behavioural responses, especially those involving locomotor abilities. These appear to be especially promising for measurement of generalized stress and stress reduction among affected waters.