Clarke KR and Warwick RM (1994) *Change in Marine Communities: an Approach to Statistical Analysis and Interpretation*. Plymouth: Plymouth Marine Laboratory.

Holme NA and McIntyre AD (eds) (1984) *Methods for the Study of Marine Benthos*, 2nd edn. Oxford: Blackwell.

Magurran AE (1991) *Ecological Diversity and its Measurement*. London: Chapman and Hall.

Sokal RR and Rohlf FJ (1981) *Biometry*. San Francisco: Freeman.

Underwood AJ (1997) *Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance*. Cambridge: Cambridge University Press.

Warwick RM (1993) Environmental impact studies on marine communities: pragmatical considerations. *Australian Journal of Ecology* 18: 63–80.

Warwick RM and Clarke KR (2001) Practical measures of marine biodiversity based on relatedness of species. *Oceanographic Marine Biology Annual Review*.

POLLUTION CONTROL

J. S. Gray, University of Oslo, Oslo, Norway
J. M. Bewers, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada

doi:10.1006/rwos.2001.0044

Approaches applied to the control of pollution have altered substantially over the last four decades. Historically, emphasis was given to management initiatives to ensure that damage to the marine environment was avoided by limiting the introduction of substances to the sea. This was typified by the attention given to contaminants such as mercury and oil in early agreements for the prevention of marine pollution. Marine environmental protection was achieved through prior scientific evaluations of the transport and effects of substances proposed for disposal at sea and defining allowable amounts that were not thought to result in significant or unacceptable effects. This reflects largely a management and control philosophy. In the closing stages of the twentieth century, however, the philosophy underlying pollution control has undergone substantial revision. Recent policy initiatives rely less on scientific assessments and place greater emphasis on policy and regulatory controls to restrict human activities potentially affecting the marine environment. During this period of change, practical pollution control and avoidance procedures have been adapted to improve their alignment with these new policy perspectives. Simultaneously, it has been widely recognized that pollutants represent only part of the problem. Other human activities such as overexploitation of fisheries, coastal development, land clearance, and the physical destruction of marine habitat are equally important, and often more serious threats to the marine environment. In recent years, the concept of marine pollution has been broadened to consider the adverse effects on the marine environment of all human activities rather than merely those associated with the release of substances. This is a most positive development, partly influenced by improved scientific understanding that has led to an improved balance of attention among the sources of environmental damage and threats.

Background

In this article, the term 'pollution' implies adverse effects on the environment resulting from human activities. This is consistent with, but broader than, the definition of pollution formulated by the United Nations Joint Group of Experts on Marine Environmental Protection (GESAMP) in 1969 that is restricted to adverse effects associated with the introduction of substances to the marine environment from human activities. The term 'contamination' infers augmentation of natural levels of substances in the environment but without any presumption of associated adverse effects. Indeed early approaches to marine pollution prevention reflected the distinction between these terms, while more recent approaches are based on more or less identical interpretations of these expressions with both implying adverse effects.

Early Agreements on Marine Pollution Prevention

The earliest international marine pollution prevention agreements of the modern era were the Oslo and London Conventions of 1972. These conventions were developed at the same time as the heightened awareness of marine pollution issues led to the first major international conference on the topic, the United Nations Conference on the Human Environment, that took place in Stockholm in the same year. Both the original formulation of the two Conventions and the results of this Conference reflect a commitment to management actions towards the prevention of marine pollution caused primarily by the release of contaminants from human activities. The Oslo and London Conventions adopted 'black' and 'gray' lists of substances and a set of measures to prevent pollution resulting from the dumping of wastes and other matter into the sea. Black list substances are essentially prohibited substances that may not be dumped in the ocean except in trace amounts. Gray list substances are those requiring specific special care measures to be considered in judging their suitability for disposal at sea. In addition, these Conventions require that all candidate materials for dumping at sea undergo a prior assessment to ensure that they do not cause significant adverse effects on the marine environment or pose unacceptable risks to human health.

In light of the rate of introduction of new chemicals into the market economy, flexibility is required in the assignment of substances to black and gray lists. Thus there is need for an international mechanism for reviewing and updating the list of substances based on an evaluation of their properties. GESAMP provides such a service for the assessment of hazards posed by chemicals transported by ships. There are no similar mechanisms for either substances dumped at sea or entering the marine environment from land-based activities. Meanwhile, each year some 1000 new chemicals are being produced in volume. Their level of toxicity to a sufficiently wide spectrum of marine species cannot be ensured before use and thus there are constant surprises about the effects of chemicals that were originally thought to entail low risk. The black and gray list approach is too simplistic and does not have the necessary supporting mechanisms to make it reasonably effective. The ocean has the ability to assimilate some finite amount of most substances without adverse effect, consistent with the concept of contamination as distinct from pollution. Thus, while not representing a wholly scientific approach, the adoption of these Conventions was a major step forward in the introduction of management measures to minimize the risks of marine pollution. However, as will be demonstrated, more recently perceived deficiencies in the provisions of these agreements resulted in their later revision.

Early Approaches to Marine Environmental Protection

The oldest strategy for protecting the marine environment from the adverse effects of the disposal of waste in the sea is that based on the application of water quality standards. This concept was borrowed from practices in freshwater environments, such as rivers, to which it had been applied successfully. The use of water quality standards is based on an assumption that the levels at which contaminants become damaging are well established. Even for chemicals having known effects, for which the severity of effect is proportional to exposure with an assumed threshold for the induction of adverse effects, this assumption has been shown repeatedly to be erroneous as more is learnt about their properties and interactions (see later discussion of the effects of tributyltin). For some contaminants, no 'safe' level can be established from entirely scientific considerations because they are postulated to pose risks of adverse effect at any concentration. Such substances have what are termed stochastic effects, where the probability of adverse effect is a function of exposure without any assumption of threshold. The regulation and management of radionuclides and the effects of nuclear practices is based on a postulation of stochastic effects at low doses. A further problem is that the concentrations of contaminants in the marine environment are frequently lower than in freshwater, making measurement more difficult. In coastal areas, the concentrations of heavy metals, for example, are low and thus are difficult to monitor. Chemical contaminants of most concern are generally particle-reactive with a strong tendency to attach to particles that end up in sediments, especially in depositional areas. Accordingly, marine sediments are usually a more appropriate focus for assessing the quality of the environment and for monitoring than seawater. However, sediments accumulate relatively slowly and, even where deposition rates are high, biological activity tends to mix sediment layers in the vertical, thus smearing out the record of particle accumulation and of the contaminants co-deposited with particles.

Scientific Perspectives

There has long been recognition by scientists that protection of the marine environment *per se* is inappropriate (see GESAMP 1991, for example). The overall approach to environmental protection should be holistic and take account of all human activities and their effects on all compartments of the environment – land, sea, and air. It has similarly been noted that contemporary government and intergovernmental arrangements and structures are inappropriately designed for such a task because they are segregated by development sector and, often, approaches to environmental protection are considered compartment by compartment rather than comprehensively. The development of protection measures for specific environmental compartments is entirely appropriate but it should follow, rather than precede, the formulation of a holistic framework for environmental management and protection.

One of the longest standing management systems is the Radiological Protection System largely developed by the International Commission on Radiological Protection (ICRP), primarily for the protection of human health from the effects of ionizing radiation. This is a scientifically based system that has pioneered concepts such as justification and optimization that require demonstration of the net benefits to society of new practices and minimization of the additional exposures to radiation resulting from all practices. Yet, this same system is predicated, no weakly supported arguments, that if human health is adequately protected, protection of the environment is ensured. While this assumption has been shown to be invalid in some rather special instances, only recently has there been significant professional scientific pressure to extend the protective focus of the system of radiological protection specifically to the environment.

Recent Changes in Policy Perspectives

There have also been some significant shifts in policy and management perspectives regarding marine pollution during the last three decades. In the 1960s and 1970s, primary concerns about marine pollution were expressed as concerns about chemical substances disseminated by human activities. With growing evidence of the physical effects of human activities on the land environment and increased public desires to protect the environment – especially areas of natural beauty and wildlife abundance – policy perspectives regarding the range of human activities that could cause adverse effects on the marine environment broadened considerably. Indeed, the term 'marine pollution' became perceived as a much broader topic than that defined by GESAMP in 1969. This led to greater consideration of the physical effects on the marine environment of coastal development and watershed activities and resource exploitation, for example. However, this broadening in perspective came about relatively slowly and preoccupation with chemical contaminants was, and remains, evident in international agreements of recent years such as the Global Programme of Action on the Protection of the Marine Environment from Land-Based Activities concluded in 1995. Indeed, the process leading up to this agreement resulted in the adoption of the term 'Activities' as the final word as a replacement for 'Sources' at a relatively late stage. Nevertheless, increasingly concerns became extended towards manifestations of human activities on the marine environment other than those solely associated with chemical contaminants.

Despite the foregoing, there has been little policy change regarding the adoption of holistic environmental management. Indeed, most of the international and national instruments for the protection of the marine environment are just that – they do not specifically consider the effects of human activities on other environments. It is this fact that creates the impression that the marine environment is being accorded preferential protection, at least in the context of international agreements. This may well be due to the largely international nature of ocean space, whereas other environments – particularly land and freshwater – lie within national jurisdiction, making governments less inclined to reaching international agreements potentially infringing on their sovereignty. Nevertheless, the fact that the marine environment has been the prime subject for the initial advancement and adoption of new policy initiatives, especially the precautionary approach, supports the impression that the sea is being accorded a greater degree of protection than other compartments of the environment.

There was also a growing perception among the public, which soon became part of the policy perspective, that in some way previous regulatory approaches to environmental protection had been a failure. Whether this was associated with some disillusionment about the benefits and efficacy of science is a matter of conjecture, but it was abundantly clear that scientists working on behalf of governments or industrial proponents were regarded with scepticism if not outright suspicion when giving professional judgements on environmental matters. The growth in membership and advocacy of the various green lobbies throughout the world is a reflection of this distrust. This, in turn, led to demands for more stringent measures, including extreme policy decisions, to reduce the effects of anthropogenic activities on the environment. More recently advocated approaches to the control of marine pollution reflect these altered perspectives.

Recent Approaches to Marine Environmental Protection

A more recent approach to pollution prevention was the so-called 'best available technology' strategy that requires that the best technology be applied in human practices to minimize associated effects on the environment. At first sight, this approach appears to be logical and appropriate, but it is fundamentally flawed. It provides neither a guarantee of environmental protection nor of effective use of resources. This approach may result in ineffective environmental protection, because the substances being regulated in this way still have adverse effects on the environment even at the lower release rates achieved. This results in a waste or misdirection of resources. On the other hand, the approach may result in far greater expenditure of effort than that required to prevent environmental damage thereby also being wasteful of resources that could be used to better purpose. The point is that, in itself, such an approach achieves little without the knowledge base that allows the tailoring of technology to the needs of society while providing appropriate protection of the environment. A good example is insisting on nitrogen removal for all sewage discharged into coastal areas of Europe. Primary treatment and phosphorus removal is relatively cheap. Nitrogen treatment is expensive and the amounts of nitrogen discharged in human sewage are small compared with the huge amounts in agricultural wastes that are washed down rivers. In areas with poor water exchange that suffer from eutrophication (enhanced biological production associated with adverse effects such as increased light attenuation, toxic effects on organisms, and increased oxygen demand, such as the inner Oslofjord), there is no doubt that nitrogen treatment of sewage is warranted. However, it is a waste of money to apply the best available sewage technology in other areas where there is no significant risk of eutrophication because there exists sufficient dispersion to ensure that the nutrients are assimilated with little change in the rates and distribution of primary production. There may not be appropriate technology to solve some waste problems so that even the best contemporarily available technology remains wholly inadequate. For example, some organic chemicals are known to result in widespread effects even at very low concentrations so that contemporary technology, no matter how effective and expensive, is unable to prevent these effects. Various attempts have been made to improve the best technology approach by referring to terms such as 'best practical technology', but all these derivatives suffer from similar difficulties in achieving environmental protection at optimal cost.

One of the more recent approaches to pollution prevention that has been widely advocated and adopted in agreements during the last decade is the so-called 'precautionary approach'. Initially, it had been promoted in the form of 'the Precautionary Principle'. This appears to have been an outgrowth of a policy development in Germany called the '*Vorsorgeprinzip*' (or literally the 'principle of foresight'). In its original form, the explanation adopted by the German Ministry of the Environment (FRG, 1986) avoided many of the pitfalls that later became intrinsic components of its application in other arenas. The German version, for example, states that not all effects should be treated as representing significant damage and that all risks cannot be avoided. It also placed considerable emphasis on science as a basis for defining risks whose acceptability could be judged in management and policy contexts.

There have been many subsequent definitions of the precautionary approach. Such revised versions were later adopted as legal instruments in the North Sea Declaration of 1987; the Declaration adopted at the Rio Conference on the Environment and Development (UNCED) in 1992; and several other international agreements, most notably the UN Law of the Sea Convention and the Global Plan of Action for the Prevention of Marine Pollution from Land-Based Activities in 1995. The general form of these new formulations has been given as:

> When an activity raises threats of serious or irreversible harm to human health or the environment, precautionary measures that prevention the possibility of harm shall be taken even if the causal link between the activity and the possible harm has not been proven or the causal link is weak and the harm is unlikely to occur. (Holm and Harris 1999)

Essentially, as later developed from its German origins, the precautionary approach implies that any lack of knowledge about the environmental hazards associated with a practice justify the adoption of special precautionary measures. Subsequently, such precaution has been deemed to warrant the adoption of extreme preventive measures including the banning of certain practices or chemicals. Several of the agreements that have adopted the precautionary approach emphasize its application to contaminants that are described as 'persistent, toxic and liable to bioaccumulate'. However, threshold values for these three properties at which greater precaution is warranted are not specified, either individually or in combination. This is a fundamental flaw in the application of precaution expressed in this way, as all substances have the properties of persistence, toxicity, and liability to bioaccumulate to some degree. Clearly more precision is needed if the precautionary approach is to be of any practical value.

The precautionary approach has been debated and criticized from both practical and philosophical perspectives and is not the panacea for the prevention of environmental problems that its exponents claim it to be. Its biggest danger is that it makes science essentially redundant; mere suspicion of an effect or lack of complete scientific knowledge is a good enough argument to initiate bans on the use and dissemination of a substance. It has resulted in the replacement of the black and gray list approaches with so-called 'reverse lists' of materials that can be considered for dumping at sea under the Oslo and London Conventions. These severely curtail management flexibility in the options available to management with little probability of increased environmental protection as a whole. Following pressure from 'green' lobbies, for example, the Swedish Government is considering banning the discharge of chemicals unless they are proven to be safe. At the 1966 Esbjerg Ministerial Conference on the North Sea the participants went one step further, requiring that chemicals be proven not to cause effects before they are allowed to be discharged to the sea. The problem here is that safety is the opposite of risk and nothing is devoid of risk. Accordingly, complete safety can neither be proven nor guaranteed no matter how good the associated science. Are we to stop all human activities because of the inherent risk (lack of absolute safety) they entail? Surely not.

Another element of recent approaches to pollution prevention generally is environmental impact assessment (EIA). It is a procedure for prior evaluation of the environmental consequences of some proposed human activity such as the construction and operation of a new industrial facility. It is a requirement of organizations of all kinds under European and most national legislation where impacts on the environment may occur. As such, EIA is a useful component of the arsenal of environmental protection measures. Yet, far too frequently, EIAs are simply paper exercises incorporating inadequate accountability if their predictions are wrong and the environment is destroyed. This is deplorable and yet need not be the rule.

This concept can be applied fairly widely, not only to specific industrial installations, but also to potential investments in entire new industries and other human activities – such as coastal development and tourism, for example. In this sense, it is somewhat analogous to the justification of practices in radiological protection. New ideas regarding EIAs provide environmental authorities with improved means of assessing and controlling potentially damaging activities. The process needs detailed and careful science to:

- make quantitative and realistic predictions of effects;
- suggest criteria for testing such predictions; and
- design proper and effective monitoring programmes with regulatory feedback.

In this context, it should be noted that the process of preparing EIAs needs to involve all parties, including the green movement. It should not be solely the prerogative of the company concerned and its experts. It must also act as a basis for designing scientifically based assessment and monitoring programmes.

Predicting the Effects of Chemicals on the Marine Environment

The classical way of predicting effects of chemicals on the marine environment is by first conducting toxicity tests. These usually involve testing a variety of organisms from bacteria through algae to small animals and then fish. Likely effects are predicted on the basis of assuming by extension from freshwater models that a concentration of 10% or 1% of the LC_{50} (50% lethality concentration) is safe. This does not always work, as can be demonstrated by data pertaining to the effects of tributyltin (TBT) used as an antifoulant for vessel hulls and marine structures.

Typical toxicity data show that concentrations of TBT of the order of $1\,\mu g\,l^{-1}$ induce toxic effects. A level of 1/100th of this value should not lead to negative effects. However, misshapen oysters, round as golf balls, were found in the Blackwater River estuary in the UK and elsewhere. Through excellent detective work it was later shown that TBT was responsible for such effects even at concentrations below $2\,ng\,l^{-1}$. These effects had not been predicted because toxicity tests are generally short-term, lasting at best for 48 h. Growth effects occur over much longer periods of time. Other scientists discovered that TBT caused the female gastropod snail *Nucella lapillus* to develop a penis. The most extreme effect was the appearance of a penis having the same size as the male, a condition known as imposex, with the affected females being infertile. Imposex in the field has since been used as an excellent marker for long-term exposures to TBT resulting from the use of antifouling paints containing TBT. France was the first country to introduce a ban on the use of such paints on vessels <25 m in length because of the value of its shellfish industry. Many other countries subsequently followed suit.

These lessons teach that laboratory toxicity tests are unable to predict the long-term effects of some chemicals. TBT, with its effects on reproductive organs, now falls into a general category known collectively as hormone disrupting chemicals. There exists a large range of chemicals having little commonality in chemical structure, other than that they are all organic, that produce similar effects. Organic chemicals are now justifiably the clear focus of toxicity research rather than the 'heavy metals' that were regarded as the key contaminants in the 1970s and 1980s.

Recently, a range of new techniques for assessing effects on individuals has been produced. They are referred to as biomarkers that reflect stress in marine organisms. One example of such techniques involves the measurement of an enzyme (EROD) in flatfish that is induced by exposures to polycyclic aromatic hydrocarbons (PAH). Another is the measurement of acetylcholinesterase production that is inhibited by chemical stressors, primarily organophosphates in fertilizers used in agriculture. The successful development of biomarker techniques suggests that strategies for monitoring the condition of the marine environment should emphasize the application of biological rather than chemical measurements. A suite of biomarkers covering the range of responses from genetic to whole organism, combined with the use of multivariate statistical techniques now in widespread use for the analysis of marine community data, now offer both the sensitivity and efficiency required for impact detection in the environment. These can be followed up by chemical measurements when indicative biological response signals are detected. In this way science is providing methods needed for an effective environmental management and protection framework.

Uncertainty, Risk Assessment and Power Analyses

Generalized frameworks for the management of activities potentially affecting the marine environment have been devised (e.g., GESAMP, 1991; USEPA, 1992). These involve initial desk studies of the sources and amounts of chemicals released and physical disturbance planned. These can then be combined with specifications of the physical and chemical properties of substances (i.e., hazards, including the properties of toxicity, persistence, and liability to bioaccumulate) and biological effects information. Such information can then be considered in the context of understanding of the physical, chemical, and biological characteristics of the potentially affected area to yield potential changes in these conditions caused by the human activity proposed including the exposures of marine organisms and humans to chemicals. This will provide a basis for assessing the consequences of the proposed activity including the risks to human health, the effects on marine organisms posed by chemical exposures, and any effects on other marine resources and amenities caused by changed sedimentation rates, altered physical dynamics, etc. This constitutes a risk assessment process.

The risk assessment will indicate what effects are likely and the uncertainties that require to be considered in judging the associated risk to the marine environment, its resources and amenities, and to human health. The risk assessment should incorporate appropriate degrees of pessimism that are the equivalent of conservatism to allow for uncertainties in scientific terms and should correspond to precaution in policy terms. Ultimately, the acceptability of effects and risks is not a scientific matter, it lies within the policy and a management spheres, although scientists may be consulted. If certain risks are deemed unacceptable, the regulatory authority will legitimately require additional mitigation measures and the risk assessment incorporating the new measures iterated. If this reveals no significant problem from management and protection perspectives, the conditions and predictions should be used as a basis for compliance and effects monitoring of the activity. In this context, the purpose of environmental monitoring is to ensure that the predicted changes are within expectations and not exceeded. If they are, feedback from monitoring to management should ensure that regulatory constraints are revised to reduce the impact further. Equally important is the fact that the results of monitoring can be used to reveal deficiencies or invalid assumptions in previous risk assessments, thereby offering the benefits of future improvements in predictive ability.

Previous environmental monitoring activities have been widely criticized as being ill-conceived, ill-conducted, and the results inadequately evaluated. In too few cases have monitoring programs been designed around testable hypotheses that allow rigorous scientific evaluation. Furthermore, there has been an unwillingness to evaluate results periodically to ensure that a program is meeting its objectives and yielding useful information. Far too often, the results of monitoring are archived without benefit of human analysis, thereby constituting a waste of resources. These tend to be more general criticisms, but there are also improvements that could be made at a more detailed level. Power analysis to determine the ability of a measurement sequence to detect a change of a given amount is not used sufficiently and greater attention to type II, rather than type I, statistical errors is warranted. A type I error occurs when it is accepted that a harmful effect occurs when it does not. We guard against making this error by accepting at least 95% probability ($P < 0.05$) and thereby allowing a 5% error due to pure chance. A type II error, on the other hand, is where it is accepted that a harmful effect has not occurred when in fact it has. Several scientists have argued that this is a far more serious error in the context of marine environmental protection than a type I error and yet is rarely considered. Commonly, the criterion adopted for the probability of type II errors is not 95% but 80%.

Improving Marine Environmental Protection

Some of the improvements needed in scientific endeavours supporting marine environmental protection have been outlined. Use of pessimistic approaches to take account of uncertainties, improvements in the design and objectives of monitoring programs and greater consideration of type II statistical errors are among the more important of these. Scientists have been poor at explaining the benefits and limitations of science, not only to environmental managers, but more crucially to the public. Indeed, previous failures of environmental protection have often been attributed to scientific deficiencies rather than to those of management faced with compromises between political pressures and environmental protection. This is somewhat analogous to similar conflicts and failures in fisheries management. The green movement has been far better at getting its message across not only to managers and legislators, but more importantly to the general public. Unfortunately, this has led to perception being used as a measure of the severity of environmental damage or threat and to the adoption of unwarranted and extreme policy measures for the resolution of perceived problems. The public, and ultimately governmental, reaction to the proposal to dispose of the used field storage tank, *Brent Spar*, was out of all proportion to the scale of possible damage to the marine environment. Some 2 years have passed and a further $30 million have been spent but the platform still lies in a Norwegian fiord demanding surveillance. Herein lies the danger; that extreme measures may not solve existing problems or prevent future problems, while placing unnecessarily severe constraints or disincentives on economic and technological development. Attention is being diverted from the adoption of rational, considered, and scientifically based approaches to the protection of the environment that will permit the greatest opportunity for social and economic development.

Society should be demanding the increased use of prior environmental impact assessments to provide quantitative predictions of what effects are to be expected and of their spatial distribution. These should be backed up by properly designed monitoring programs that have adequate power to detect the changes expected and provide routine feedback to regulatory controls. The necessary science already exists – what is needed is the will to apply it effectively to ensure that the best possible environmental protection is achieved in the face of the demands for human development.

See also

Anti-fouling Materials. Anthropogenic Trace Elements in the Ocean. Law of the Sea.

Further Reading

Bewers JM (1995) The declining influence of science on marine environmental policy. *Chemistry and Ecology* 10: 9–23.

Freestone D and Hay E (1996) *The precautionary principle and International Law: The challenge of implementation*. The Hague: Kluwer Law International.

FRG (1986) *Umweltpolitik: Guidelines on Anticipatory Environmental Protection*. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

GESAMP (1991) *Scientific Strategies for Marine Environmental Protection*. GESAMP Reports and Studies No. 45. London: International Maritime Organization.

Gray JS (1998) Risk assessment and management in the exploitation of the sea. In: Calow P (ed.) *Handbook of Environmental Risk Assessment and Management*, pp. 452–473. Oxford: Blackwell Science.

Holm S and Harris J (1999) Precautionary principle stifles discovery. *Nature* 400: 398.

Milne A (1993) The perils of green pessimism. *New Scientist* 1877: 34–37.

NRC (1990) *Managing Troubled Waters: The Role of Environmental Monitoring*. Washington, DC: United States National Research Council, National Academy Press.

USEPA (1992) *Framework for Ecological Risk Assessment*. Washington, DC: Office of Research and Development, US Environmental Protection Agency.

Wynne BG and Mayer S (1993) Science and the environment. *New Scientist* 1876: 33–35.