Chapter 5

Protection of the Environment from the Effects of Radiation

5.1. Introduction

There is a growing awareness that radiation risk management needs to address the question of effects on the environment. Radiological protection has traditionally been based on the protection of man. This is because the international advisory body on such matters, the International Commission on Radiological Protection (ICRP), has maintained a strong bias toward human health. The ICRP has stated that: *'The Commission therefore believes that if man is adequately protected then other living things are also likely to be sufficiently protected'* (ICRP, 1977). More recently, a caveat has been added (ICRP, 1991) stating that *'individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species'*.

The inadequacies of applying this approach to environmental protection are increasingly recognized, from both scientific and ethical perspectives (Strand, 2002; Strand *et al.*, 2000). One problem is that no evidence is given to support the ICRP statements, with the result that regulatory bodies in many countries are not in a position to demonstrate explicitly that the environment is being protected for a given situation. Laboratory studies and accidents have shown that radiation can have a number of detrimental effects on biota, including mortality, and reproductive and genetic damage. Nevertheless, current knowledge about the effects of radiation on wild plants and animals is limited and subject to large uncertainties, and there is little consensus on the relevance and acceptability of these effects within the context of risk management. The ICRP statements are potentially invalid in certain situations, for example when pathways to man do not exist or are long and tenuous, or when accidents contaminate sparsely populated areas. Hence, there are likely to be situations where the resident biota are exposed to harmful doses but doses to man are maintained at levels well below the recommended dose limits (Pentreath, 1998). It could be anticipated that the Arctic, where human population densities are very low and exposure pathways to humans can be relatively long, is a prime example.

For these reasons, there has been increasing pressure to explicitly demonstrate environmental protection from radiation and to incorporate environmental considerations into the system of radiological protection. AMAP activities, focusing on radioactivity and other hazardous substances, have played an important role in driving the debate, particularly by highlighting inconsistencies between the approaches taken for radioactivity and other environmental pollutants (Strand *et al.*, 2002). Widespread international consensus has been reached over the last couple of years on the need to develop a rationale for the protection of the environment from ionizing radiation and to demonstrate explicitly that the ecosystem and its components are not being harmed by exposure to radionuclides (Strand and Oughton, 2002).

The subject is specifically addressed within some agreements, for example the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Furthermore, the second principle of the International Atomic Energy Agency (IAEA) Safety Fundamentals for the Management of Radioactive Waste states that: *'Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.'* In addition, several relevant agreements were made at the 1992 UNCED Earth Summit in which a number of general principles for environmental protection were laid down. An example is 'The Rio Declaration' (UNCED, 1992) which emphasizes the issue of sustainable development in Principle 4, by stating that *'Environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.'*

5.2. Frameworks for environmental protection

Developing and defending a practical and coherent system of protection for flora and fauna raises a number of dilemmas and conflicts, including those relating to scientific, ethical, and legal issues. A better understanding of ecological effects and their uncertainties primarily requires a framework for risk and impact assessment that can incorporate the sensitivities of various species and ecosystems. Factors influencing sensitivity include exposure pathways, uptake to biota, and dose-effect relationships. These can be ecosystem-dependent (for example, nutrient status or biological activity) and species-dependent (such as high bioaccumulation of ^{99}Tc by lobster or the radiosensitivity of pine compared to other tree species). Acute lethal doses can vary by several orders of magnitude among and within species. Moreover, reproductive and population health effects may occur at much lower doses than would kill an organism and there is little information about the effects of low chronic exposure.

Ethical issues include whether animals have moral status and why, the definition of harm in relation to the exposed population or individuals, the balance between the interests of humans and non-human species, and the fundamental issue of why the environment should be protected anyway. In common with many risk management policies, the answers will need to reflect both scientific knowledge and ethical values. Interestingly, many of the groups concerned with the protection of the environment from radiation, including the IAEA and ICRP, have identified a need to address the ethical and philosophical questions. AMAP has collaborated on work with the International Union of Radioecologists (IUR), which was one of the first international organizations to actively promote the need to focus on non-human biota and to propose a system for impact assessment.

Any framework for the protection of the environment from radiation should be compatible with protection systems for other environmental stressors. However, it is important to be aware that this area of law is under continuing development. There is general worldwide consensus on the issue of human rights (although not total agreement on how those principles might be applied in practice), which simplifies the management of human radiation exposure in some respects. Nothing like the same level of agreement has been reached on environmental principles however, although progress is being made and is pertinent to the present assessment. There are three major points to bear in mind when addressing the development of frameworks for protection of the environment from radiation. First, legislation for environmental protection is relatively new and still undergoing development. Second, the issue is global, is deemed important by governments and the public alike, and has stimulated action on an international scale. Third, practical solutions are not without conflict and controversy. Not withstanding these difficulties, examples of environmental law can be found in the national laws of every country. Although their scope and detail vary considerably, progress during the last 30 years has led to a certain amount of agreement on what is meant by the 'environment' and its 'protection' and which principles should guide that protection (see Box 5·1).

5.2.1. General legal and ethical principles

A two-stage approach is useful when assessing the legal and ethical basis for the development of a framework for environmental protection, namely: to consider some general and/or common legal and ethical principles used in environmental protection; and then to derive some policy or management principles on the basis of these being specifically relevant and pertinent to protection from radiation.

The following principles are drawn from international and national environmental policy (i.e., the Rio Declaration; and policy arising from the European Union, the U.S. Environmental Protection Agency, and the U.K. Environment Agency) or from environmental ethics. The list is not exclusive and reflects the broad issues and spirit of international and national law.

1. It is the responsibility of all humankind, where possible, to prevent detriment to the environment and to preserve and protect the health and integrity of the Earth's ecosystem. (*Principle of responsibility*).

2. The use and exploitation of natural resources must be sustainable and should equitably meet the developmental and environmental needs of present and future generations. (*Principle of sustainable development*).

3. Society must recognize the serious impact of humans in causing extinction and a loss in species and actively promote conservation measures to preserve the Earth's biodiversity. (*Conservation/biodiversity principle*).

4. Humans should avoid causing suffering to other living organisms. (*Welfare principle*).

5. Humans should respect the inherent and intrinsic worth of nature, recognizing that the environment has a value beyond its direct impact on human interest. (*Principle of respect*).

6. Environmental management needs to be combined with concerns for economic and social justice (particularly in developing countries) and with the informed participation of affected citizens. (*Principle of environmental justice*).

7. Decisions on environmental issues should reflect scientific understanding, acknowledge uncertainties, and recognize the identity, role, culture, and specific knowledge of indigenous peoples, traditional practices, and local communities. (*Transparency and participation principle*).

8. In order to protect the environment, a precautionary approach should be encouraged. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation. (*Precautionary principle*).

9. Authorities should promote the internalization of environmental costs taking into account that the polluter should bear the costs of pollution, including those connected to liability and compensation. (*Polluter pays principle*).

10. The need to prevent environmental damage at source requires that environmental impact assessments should be carried out for all new developments, proposals, and technologies. (*Environmental impact; justification principle*).

Box 5·1. *Definitions*

The term *environment* has been defined in a number of national and international laws. Common to most definitions is the notion that the environment consists of man, biota (e.g., microorganisms, plants, and animals), abiota (e.g., soil, water, and air), physical surroundings (e.g., climate, and light), and their interactions. Some definitions extend to both natural and man-made features of the environment (i.e., cultural heritage, and buildings); some limit the definition to those external factors having a direct effect on living organisms.

Protection of the environment is predominantly perceived as the prevention of detriment to the environment and its living components. But the term can also encompass restoration, enhancement, and maintenance of environmental quality. While recognizing natural environmental stressors, most legislation and international conventions deal specifically with anthropogenic effects.

In the broadest sense *protection of the environment from ionizing radiation* might include all biotic and abiotic components of the Earth's biosphere. In a more practical sense, the abiotic component of the biosphere is known to be unaffected directly by the effects of radiation under all but the most extreme of conditions. In some instances, an interpretation of 'damage' might reflect that an environment is contaminated *per se*, particularly for ecosystems perceived as 'pristine' such as the Arctic. However, in most cases, efforts to quantify systematically the consequences of radiation exposure and to develop a system for protection might be more constructively focused on the most sensitive components of the biosphere, i.e., living organisms, but not totally excluding the abiotic environment.

At present, the only part of the environment explicitly considered for protection from ionizing radiation is man.

Depending on the context, some principles may be deemed more relevant than others and some more fundamental than others. In practice, the principles may even conflict (e.g., 5 and 6). Principles 1 to 5 concern the question of *why* it is necessary to protect the environment, and 6 to 10 *how* to achieve this protection in practice.

The IAEA recently concluded that despite the apparent diversity of values in the different ethical outlooks, consensus on principles of environmental protection was sufficient to identify five common principles, namely: conservation of habitat and species; maintenance of biodiversity; sustainability; environmental justice; and human dignity (IAEA, 2002). Clear support for these five principles was obtained at the IUR consensus conference in 2001, which was attended by participants representing a wide range of disciplines connected to radiation protection and environmental protection. Participants identified a need for 'development of policy in an open, transparent, and participatory manner', considered that 'the best available technology, including consideration of economic costs and environmental benefits, should be applied to control any release of radionuclides into the environment', and supported a precautionary approach to risk management (Strand and Oughton, 2002).

5.2.2. Management of environmental risk

In general, programs addressing the management of environmental risk can be grouped (although somewhat arbitrarily) into three categories:

- management through pathway-based analysis of exposure, often involving environmental standards (e.g., radiation dose to certain organisms or concentrations of radionuclides in environmental media);
- management through process standards relevant to specific source(s) based on *best available technology* (BAT) and similar criteria of technical status and performance; and
- pure management standards, which may include certification schemes or schemes that ensure that positive action is taken to protect the environment and where continuous performance improvement is sought. An example is the EC Eco-Management and Audit Scheme (EMAS).

Pathway-based schemes are generally considered most relevant to the development of assessment frameworks for the environment, but aspects of other schemes may be incorporated when appropriate.

5.2.3. System for environmental impact assessment

A coherent and logical environmental impact assessment methodology for ionizing radiation is essential (Pentreath, 1999). Components that could form the basis for such a system include:

- a set of reference organisms – not all organisms can be studied, necessitating a selection procedure;
- a set of quantities and units to express doses to biota. Currently, doses are expressed in Grays per unit time, which does not reflect the variable biological effects arising from equal absorbed doses of differing radiation types;
- a defined set of dose models for a number of reference flora and fauna. Methodologies exist which allow the calculation of doses to organisms with varying geometries (e.g., consensus is required in adapting these algorithms for use within a protection framework); and
- a set of dose–effect relationships for reference organisms that could include data from low-exposure (e.g., cytogenetic effects) to high-exposure (e.g., lethal effects) situations.

Discussion within the scientific community has led to the adoption of these points into a proposed strategy comprising three key components (IUR, 2000), namely: exposure pathways and retention of radionuclides by biota; dose calculations; and dose-effect relationships.

5.2.3.1. Exposure pathways and retention of radionuclides by biota

The outcome of the work on exposure pathways will be based on the acquisition and synthesis of information concerning ecological characteristics and radionuclide uptake within selected ecosystems. Simple reference models could be developed for the simulation of radionuclide migration and uptake to the whole organism (and organs if applicable) for those reference species living in representative terrestrial and aquatic ecosystems.

5.2.3.2. Dose calculations

Radiation dosimetry models will be developed for the reference organisms. These will be designed to estimate the actual or potential absorbed dose rates to the organisms from internal and external sources of α-, β-, and γ-radiation. The final output will be a tabulation of absorbed dose rate coefficients (Gy/hr per unit radionuclide activity concentration in the relevant environmental compartment) for each reference organism for the radionuclides of concern. It is likely that the reproductive organs will be important targets for inclusion in the dosimetry models.

5.2.3.3. Dose–effect relationships

Endpoints of concern in individual generic organisms could be defined and dose rate/response relationships for the chosen endpoints tabulated. This would involve the integration of data from earlier reviews, and assessments of the potential impacts of radiation in the environment, assessments of the wider radiobiological literature, and assessments of newly available information from the Kyshtym (see Section 7.5.1) and Chernobyl accidents. Relevant effects of radiation will probably include, but not necessarily be limited to, changes in morbidity, mortality, fertility, fecundity, and mutation rate. Information will be organized so as to indicate the approximate dose rate/response relationships. An attempt should be made to quantify the intrinsic uncertainty in these threshold dose rates (e.g., through the extrapolation of laboratory data to natural conditions) and to indicate possible modifying influences (e.g., the influence of other environmental variables).

5.2.4. Target level of biological hierarchy

It is generally recognized that protective action should be taken in such a way as to ensure that populations of organisms receive an adequate level of protection (IAEA, 1992, 2000) and that the functioning of their associated ecosystems is unaffected by the presence of a contaminant. A practical approach to ensure that unacceptable effects on populations are avoided is to target protective action at the organizational level below populations, i.e., individuals. This is justified on the basis of a number of precepts, including:

- population effects are unlikely to be manifested if individuals are unaffected;
- population effects are more complex to assess than effects on individuals and more likely to be masked by the normal range of spatial and temporal ecosystem variability;
- scientific information on population effects is comparatively scarce; and
- in protecting threatened or endangered species, consideration of individuals is necessary.

However, the reasoning is not straightforward in all cases, bearing in mind that:

- for a variety of species (e.g., with asexual or vegetative propagation), individuals and populations in the conventional sense may be difficult to differentiate;
- there are cases where individuals may be affected (e.g., in the case of endocrine disrupters) while populations remain unaffected; and
- in the case of stochastic effects, effects may be observed in individuals while not affecting the viability of the population.

5.2.5. Dose or dose rate as an indicator of actual or potential impact

One approach to environmental assessment involves the calculation of the dose or dose rate to reference organisms. The rationale being that biological effects of radiation are mediated through the absorbed dose and much information is available linking the severity of effects to the dose or dose rate.

Alternatively, assessments could be based on radionuclide activity concentrations. However, the dose is further modified by the type of radionuclide and external and internal geometry, as well as other factors such as lifespan and size. Activity concentrations could be of relevance in compliance discussions, e.g., by comparing expected/observed concentration data with data from dose standards (e.g., U.S. DOE, 2002). However, for assessing effects, including the radiation dose or dose rate adds transparency.

Several dosimetry models are available for aquatic and terrestrial environments, although these are not necessarily sufficiently comprehensive for developing a framework for environmental protection. For the aquatic environment, the generic models relate to: small and large phytoplankton; pelagic and benthic crustaceans; benthic molluscs; and pelagic and benthic fish. These have been developed to the point at which dose rate factors have been tabulated for a range of radionuclides in environmental media (Amiro, 1997; Pentreath and Woodhead, 1988). It is envisaged that future work will focus on the development of the dosimetry models, and the associated dose conversion factors that relate directly to the reference organisms (and their local environment).

5.2.6. Practical and ethical advantages of the framework

A number of practical and ethically-relevant advantages of this framework can be highlighted; the framework is site- and case-specific, transparent, involves stakeholder participation, enables comparison with other environmental contaminants, is 'bottom-up'; is applicable to individuals and populations; and is compatible with anthropocentric and ecocentric environmental philosophies.

5.2.6.1. Site- and case-specific

That the framework is site- and case-specific promotes the notion that there may be a number of different reasons for protecting the environment. For example, the case may depend on available alternatives, the ecosystem itself (e.g., a protected habitat or common resource), and/or the organisms it contains (e.g., endangered species). There is also uncertainty in going from a measurement of concentrations in abiotic compartments (e.g., soil, water), to calculations of accumulation and doses in organisms, and to estimates of cellular up to ecosystem effects. Source-specific, site-specific, species-specific, and individual-specific variability all contribute to such uncertainty. This complexity has the disadvantage of introducing difficulties and there may be cases where a simple approach is sufficient. Until better scientific evidence is available to support such judgments, oversimplification should be avoided.

5.2.6.2. Transparency

The framework is transparent in that it indicates the potential consequences of actions and how these were derived. It also provides information relevant to the issue of 'risk', for example, uncertainties as to outcome, probabilities of harmful effect, errors in dose-risk calculations, and model sensitivity. Honesty about the level of scientific knowledge (meaning some distinction between what is widely acknowledged as fact, generally accepted, disputed, difficult to predict, unknown, etc.) is fundamental to building public trust; short-sightedness or dishonesty is one of the fastest ways to lose this trust.

5.2.6.3. Stakeholder participation

The framework promotes a more open debate on the acceptability of the consequences of radiation exposure to biota, and encourages public and stakeholder participation in such debates. A simple statement that 'releases are below dose limits' tends to beg the question as to where the limits came from and whether they are appropriate. It is also questionable whether the public is sufficiently competent to participate in such debates, and whether the perceptions influencing attitudes to their *own* risk – for example, whether voluntary or imposed – are equally relevant to the question of what is acceptable to animals and *other* living organisms. The public is not always 'rational' and consistent in the way it values animals (dogs and pandas being more important than mosquitoes and worms). Who decides which factors are relevant?

5.2.6.4. Comparison with other environmental contaminants

Because the framework provides information on effects and uncertainties for a range of endpoints, it should be possible to use that information to compare the environmental effects of other practices or alternative actions. Effects from radiation exposure may be compared directly with effects of other environmental stressors, many of which result in the same biological endpoints. This is an important step towards 'holistic' environmental management, and promotes coherence with other methods.

5.2.6.5. Bottom-up

In ecotoxicology, there is often talk of a distinction between 'bottom-up' and 'top-down' systems. This paradigm has attracted increasing attention, largely owing to scientific developments in the analytical techniques used to study the mechanisms and processes of environmental effect (e.g., molecular biology, population studies, and vulnerable species). A 'bottom-up' system means that the framework first acknowledges that actions can have a variety of effects on the environment (from DNA to ecosystems), and considers a range of biological endpoints, changes, and causes. From a risk management point of view, the question is: What might we do and how can we avoid doing it? A 'top-down' system focuses on constraints, standards, and compliance, usually derived from 'no observed effect level' or 'critical load' criteria. In this case, the question is: How much can we do?

5.2.6.6. Applicable to individuals and populations

The main area of focus for the framework is individual organisms. This is sometimes necessary from the point of protection, as in the case of protected species. But evaluation of possible population effects can also be derived from individual effects. Also, the individual is often the highest level at which scientific experiment and hypothesis testing can be directed. Observed biological or physiological effects on an individual organism (or its cells, DNA, etc.) may be reduced causally to the radiation exposure; subsequent effects at a population or ecosystem level require more complicated ecological modelling.

5.2.6.7. Compatible with anthropocentric and ecocentric environmental philosophies

Lastly, the framework is compatible with anthropocentric and non-anthropocentric (i.e., ecocentric) environmental philosophies and can be incorporated into national environmental legislation.

5.2.7. Conclusions

A system for assessing the consequence of radiation exposure on Arctic flora and fauna should have high priority. This requires collaboration at the international level and, with this in mind, joint activities are planned between AMAP and IUR. The European Commission has also initiated further scientific developments through the research projects FASSET (Framework for Assessment of Environmental Impact) and EPIC (Environmental Protection from Ionising Contaminants in the Arctic).

There is a need for the development of a framework for the protection of the environment from ionizing radiation. This is also required to structure the information derived from earlier studies in order to direct future scientific research. Such a system will include environmental transfer models, environmental dosimetry models, and tabulated dose-effect relationships. The system will also require 'reference organisms' (i.e., a group of organisms that are selected from a number of criteria such as radiosensitivity, accumulation potential, ubiquity, and importance to ecosystem functioning) and the derivation of relevant quantities and units. The final system should allow regulators to explicitly and transparently demonstrate a commitment to environmental protection and should provide a basis for developing standards against which to test for compliance of current and future practices.

5.3. Arctic-specific issues

The Arctic requires special attention in the selection of reference organisms owing to its greater vulnerability and lesser abundance of species. The project EPIC – an EC Inco-Copernicus funded research project coordinated by the Norwegian Radiation Protection Authority – aims to develop a methodology for the protection of natural populations of organisms in Arctic ecosystems from radiation. One component has been the development of a list of Arctic-specific reference organisms (Beresford *et al.*, 2001). These were proposed on the basis of their ecological niche, radiosensitivity, likely internal and/or external exposure to radionuclides, and their suitability for monitoring and/or future research.

5.3.1. Identification of reference organisms

5.3.1.1. Biological endpoints

The four 'umbrella' types of biological effect are morbidity (the general well-being of the organism), mortality, reproductive success, and cytogenetic effects.

The choice of endpoints will be facilitated by the development of a database for biological effects on a number of groups of terrestrial and aquatic fauna and flora. The effects of radiation on plants and animals have been reviewed many times from the perspective of assessing the potential impacts of radioactive waste disposal (IAEA, 1976, 1988, 1992; NCRP, 1991; UNSCEAR, 1996). The present need is to structure this information so as to identify the levels of dose rate at which different degrees of damage might be produced in the endpoints of interest. This will also identify gaps in scientific knowledge that could lead to further research to improve the level of understanding of these topics.

5.3.1.2. Identification based on exposure

For a suite of radionuclides, expert judgment and transfer models can be applied in order to identify which organisms assimilate and retain radionuclides to a high degree and which organisms occupy habitats that are likely to concentrate enhanced levels of radioactivity.

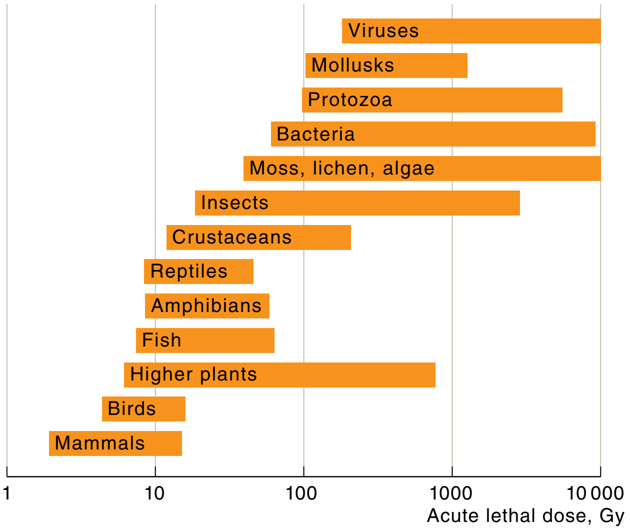

Figure 5·1. Comparative radiosensitivity of different organisms represented by the acute lethal dose ranges (UNSCEAR, 1996).

The habits and habitat of different life stages of some organisms may vary considerably (e.g., bird and egg, larval and adult insects) and this may lead to different exposure pathways. This should be considered when selecting reference organisms. A selection of candidate reference organisms for European ecosystems based purely on radioecological criteria were drawn up by Strand *et al.* (2001).

5.3.1.3. **Identification based on ecological relevance**

Ecological sensitivity is defined in terms of the role of the organism in the ecosystem concerned. A number of factors are relevant, e.g., population size; trophic level; reproductive strategy, including generation time; size; habitat; seasonal variations; physiological features; and biological complexity.

The *simple* approach, as used in EPIC, is to assess the requirements for representation of each trophic level. Dominant organisms at each trophic level are responsible for the major energy and nutrient flows in the ecosystems; therefore, it could be argued that protection of these organisms (by their selection as reference organisms) will ensure the protection of the ecosystem as a whole.

5.3.1.4. **Identification based on radiosensitivity**

The effects of ionizing radiation on living organisms have been reviewed extensively (Rose, 1992; UNSCEAR, 1996). The comparative sensitivity of different organisms to radiation in terms of acute lethal dose is shown in Figure 5·1. Although other radiation-induced effects (e.g., morbidity, fertility, and fecundity) may also be important; as a thorough review of these 'other' factors has not yet been conducted the comparative lethal dose (mortality) was used to aid the selection of reference organisms.

Available data on acute lethal dose exposures indicate that mammals and birds are the most radiosensitive groups, although the radiosensitivity ranges are large and sensitivities for different groups overlap considerably. These criteria indicate that mammals and birds should be included in any suite of reference organisms.

5.3.1.5. **Distribution and practicality for research and monitoring**

There is little point selecting reference organisms that are not widely distributed through at least one of the three Arctic zones (High-, Low-, and subarctic). Species known to occur in these zones, for those groups for which there is sufficient information, are listed in the EPIC report (Beresford *et al.*, 2001). The practicality of collecting the organisms for monitoring purposes (to determine the radionuclide content or to assess effects due to exposure) or to enable further radiosensitivity and radioecological studies is a further consideration. For some groups, this would be difficult owing to their protected status (e.g., raptors, marine mammals) or their perceived public sentiment (e.g., marine mammals, large terrestrial carnivores). Also, some potential reference organisms are of commercial importance, for example, macroalgae (in the Norwegian, Barents, and White Seas), benthic fish (haddock, Greenland halibut, European plaice) and pelagic carnivorous fish (Atlantic cod). Taking these factors into account, a selection of appropriate organism groups are listed in Table 5·1.

5.3.1.6. **Examples of reference organisms**

A search for candidate reference organisms occurred during the EPIC project. In this respect, it must be emphasized that the term 'reference organism' does not imply *a* particular species, but serves as a surrogate. Thus, in principle, it should be possible to identify specific plants and animals that are listed under the heading 'reference organism' (Table 5.1). In the practical application of the system, 'secondary reference organisms' may need to be defined at the species level. For example, in the case of a carnivorous terrestrial mammal, the Arctic fox (*Alopex lagopus*) might be selected and in the case of a marine benthos-eating bird, the common eider (*Somateria mollissima*). The selection process is driven by factors such as ubiquity and practicability for monitoring.

Table 5·1. Groups from which aquatic and terrestrial reference organisms should be selected (Beresford *et al.*, 2001).

Aquatic reference organisms	Terrestrial reference organisms
Benthic bacteria	Lichens and bryophytes
Macroalgae (marine)	Gymnosperms
Aquatic plants (freshwater)	Monocotyledons
Phytoplankton	Dicotyledons
Zooplankton	Soil microorganisms
Molluscs	Soil invertebrates
Polychaetes (marine)	Herbivorous mammals
Insect larvae (freshwater – benthos)	Carnivorous mammals
Pelagic fish (planktotrophic)	Bird eggs
Pelagic fish (carnivorous)	
Benthic fish	
Carnivorous mammals	
Benthos-eating birds	
Fish eggs	