Concluding Remarks

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THE EXTENT OF CONTAMINATION

The new millennium started with a legacy of unprecedented contamination of the world ecosystems left in the wake of the various activities of humankind. Chemical pollutants have become so diverse (see Chapter 1) and widespread that there is hardly any region of the world that is not currently affected by their impacts. With the exception, perhaps, of the desert wilderness areas (for which information on pollution is still lacking), every other ecosystem on earth, from the polar regions to the tropics, whether on land or in the oceans, has been shown to contain residues or traces of organic and inorganic pollutants of anthropogenic origin.

Even if most of the contaminants originate in industrial, developed countries located mainly in temperate regions, it has become obvious that natural transport processes have carried many pollutants far from their sources to places like mountain tops, polar caps and remote islands in the oceans. Those transport routes have been thoroughly examined in Chapter 2, which shows the enormous progress achieved to date in this field of environmental research. As a consequence, current models on fate and transport of contaminants are becoming more accurate, and no doubt will minimise in future the expensive analytical monitoring that was once required to understand the movement and accumulation of chemical pollutants in ecosystems. However, monitoring will still remain necessary to determine whether the remedial actions taken as a result of risk assessments and regulation are effective. This is particularly true of recent contaminant classes (e.g., fluorinated surfactants, pharmaceuticals) as little is known about these in terms of potential ecosystem level effects (see Chapter 7). Therefore, the use and development of monitoring devices such as passive samplers will be crucial in future.

As our knowledge of pollution increases, so also do the efforts to eliminate the most toxic pollutants. Encouraging examples of bioremediation by aquatic plants and micro-organisms are already available for some pesticides and metallic pollutants, as explained in Chapter 11. The natural capacity of aquatic ecosystems to eliminate most kinds of chemical pollutants is already being fostered by natural selection, because of the increasing pressure that such ecosystems experience in our heavily contaminated world. Indeed, nature always moves towards a point of equilibrium, thereby mitigating the impacts caused by pollution. Phytoremediation systems harness the adaptivity of natural systems and are already being used to sequester metal contaminants in many places, and in future could become essential management tools to eliminate pesticide residues in agricultural regions once long-term maintenance issues are resolved adequately. However, before they become widely accepted we need first to investigate the microbe-plant interactions in order to enhance the capabilities of the system, and also to explore the possibility of phytoremediation of 'emerging' organic contaminants such as new pesticides and even persistent organic compounds like dioxins, perfluorinated compounds, *etc.* The recalcitrant nature of the latter chemicals is certainly a problem that may require the combined action of both natural bioremediating systems and artificial remediation initiatives (e.g. incineration at high temperatures).

Impacts on Terrestrial Ecosystems

Throughout human history, metals and metalloids have accumulated within soils and surface waters of the earth, sometimes as a consequence of extraction from otherwise stable ore-bodies, redistribution of materials rich in metals (e.g., guano) or through combustion of fossil fuels. Our understanding of the ecological risks associated with increased environmental deposition of metals has improved as a consequence of the study of heavily polluted environments, where various elements such as Cd, Cu, Zn, Se, As and Hg have been deposited in high concentrations with severe and obvious detrimental effects on flora and fauna. However, we are only now beginning to appreciate the subtle and slow shifts in ecosystem function and dynamics that may occur through the movement of some elements through the food chains. Those flora and fauna that have been detrimentally affected through the bioaccumulation and biomagnification

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of elements such as Cd or MeHg, can only be detected by careful examination of their trophic movement through ecosystems, and by experimental manipulations. While the evidence to date has been summarised in Chapter 3, it is clear that more carefully planned studies in a wider selection of taxa (e.g., pelagic and coastal fish and invertebrates, insectivorous and predatory birds, and marine and terrestrial reptiles) are needed if we want to predict the overall consequences of increasing pollution by metallic and metalloid elements in ecosystems.

Among the most common organic pollutants are pesticides, which are routinely applied to the majority of the vast agricultural landscapes of the world as well as to many forested areas. Within the immense literature available on the subject, only effects at the community and ecosystem levels have been considered in this book. The known ecosystem impacts of pesticides have been studied mostly within the agricultural fields and pastureland with livestock, a summary of which is presented in Chapter 4. Our knowledge of pesticide impacts outside of those fields where pesticides are applied (the so-called off-crop areas) is scarce and in some cases anecdotal, which explains why the assessment of other terrestrial ecosystems surrounding the agricultural land, such as scrub or shrub landscapes and deserts, could not be considered in this book. This is precisely one of the areas where future studies on this topic should focus: the comparative assessment of impacts either of individual pesticides or their mixtures between the crop areas and the surrounding ecosystems (e.g., wetlands, scrubland, adjacent forests, etc). To a certain extent this has already been accomplished for bird communities in England and the USA, but much more work needs to be done in other countries (e.g., tropical ecosystems) to obtain a full picture of the effects at ecosystem level.

In parallel to scenarios in the agricultural field, Chapter 5 examines in detail four case studies of pesticides currently in use for forest management - two insecticides and two herbicides. Based on that evidence we are beginning to understand now the complex issues involved in these practices, but we are still unable to identify critical thresholds at which the system becomes unsustainable. Obviously, the damage that one single pest can cause in a monospecific boreal or temperate forest should not be measured only in economic terms, as it really affects entire animal and plant communities that depend on that forest. Here is where a balance must be struck between the need to control such pest, thus protecting those communities, and the ecological side-effects derived from the application of chemicals for controlling the pest. Thus, the need for identifying mitigative strategies under an adaptive management regime and their comparison with the 'do-nothing' approach. Since most of our knowledge on forest impacts comes from studies carried out in North America and Europe, it would be desirable to compare such impacts with those in other parts of the world, e.g., the more diverse forests of Japan, India or Australia.

Impacts on Aquatic Ecosystems

Pesticides impacts on freshwater communities are quite well understood and have been studied more widely than in any other ecosystem (see Chapter 6). Under normal circumstances, most pesticide residues in soil move eventually into water bodies found in the landscape. However, studies on this topic are biased towards fish and macro-invertebrates, whereas field studies about the effects of pesticides on macrophytes and microorganisms are scarce. Moreover, fungicides have received very little study [1], even though they are routinely applied to agricultural systems [2]. Of course, the effects of mixtures and multiple stressors in aquatic systems are still an important topic of research which has not been developed sufficiently. One area that requires more attention in future investigations is the effect of pesticides on ecosystem function as well as the services provided by the aquatic systems, whose potential losses have not been quantified yet. In connection with this objective, studies on ecosystem-based traits have already been proposed [3]. Another area that deserves more attention is recovery from pesticide exposure. It is not known which processes weigh more in the recovery of communities in freshwaters (recolonisation, compensatory effects of nutrients, higher temperatures?), and how widespread is the occurrence of long-term effects in the field.

A common problem encountered when evaluating the impacts of toxic pollutants in ecological risk assessments, whether they are pesticides, pharmaceuticals or any other chemical, is that predictions are based on rough extrapolations from effects at low levels of organization (e.g., individual or population effects measured by EC50s or NOECs). At the same time, measurements such as NOEC are unreliable and should be replaced by more accurate alternatives such as the no-effect concentration (NEC) [4,5]. Direct testing of individual chemicals or mixtures of chemicals using micro- and mesocoms is one effective way to overcome our current deficient approaches, and thus reduce our dependence on extrapolating results from lower levels of biological organization for both risk assessment and regulation. This is particularly relevant in the case of the emergent pollutants of concern (see Chapter 7), for which very few ecotoxicological data are available in the first place. It follows from this that we need to develop improved empirical and experimental methodologies for evaluating field-based observations (and mesocosms) of anthropogenic stressors at higher levels of biological organization in both terrestrial and aquatic systems. Only then we will be able to determine the real impacts at community and ecosystem levels without flawed extrapolations [6], and improve our risk assessment modelling [7].

If freshwater ecosystems are the recipient of the first load of residues emanating from industrial processes, urban wastes or agricultural practices, eventually all pollutants enter the oceans. Those which are persistent or bioaccumulate in organisms will almost inevitably end up at the top of the marine food chain, and therefore will impact our fisheries. From the start, coastal ecosystems receive the bulk of the pollution *via* the discharges of rivers into estuaries and adjacent coasts. Marine currents spread these contaminants not only between the pelagic and benthic communities but also up and down the coastline, reaching coral reefs and finally the open ocean, where pelagic ecosystems represent the ultimate frontier. The complexity of these interactions in regard to chemical pollution is well described in Chapter 8, where the effects of ecotoxicants are analysed from the cellular and tissue level to the community level in progressive steps, culminating in the integrative assessment of overall impacts using various methods. The lack of information on how individual responses are transferred to ecosystem level is the major hurdle in the latter assessments: although bioassays have improved our understanding of the effects of pollutants, it is difficult to extrapolate their results to the ecosystem, as they lack ecological ‘realism’ [8]. As indicated above, this calls for new approaches to evaluate the effects at the highest level of organization, as well as for agreed methods for integrative assessment.

A similar approach was followed in Chapter 9 to describe the effects of a wide range of pollutants in coral reefs, an ecosystem often described as the ‘rainforest of the oceans’ due to its high biodiversity. Here, more than in any other ecosystem, is where our ecotoxicological knowledge is still lacking considerably. Since reefs are often exposed to multiple stressors simultaneously and for prolonged periods there is a need for information on the effects of chronic exposure to pollutants and stressor interactions (e.g., climate change factors) on a broad range of species and life history stages. In particular, there is concern that prolonged exposure to herbicide mixtures may trigger a cascade of unknown effects in the delicate and complex food web associated with the corals [9]. At the same time, more effort needs to be directed towards characterisation of the reef system’s potential to recover from and adapt to ever increasing anthropogenic contaminants in a globally changing environment.

Finally, because pelagic processes (see Chapter 10) are important to both the surface layer (plankton) and benthic communities, further research in the ecotoxicology of these ecosystems should be directed towards integrating, not dividing, our understanding of the effects of pollutants in the different environmental compartments. There is a need for more research on how contaminants affect both primary producers and microbial loop components. Current knowledge is limited to effects on single algal species, and there is virtually no knowledge of impacts in more complex systems that include bacteria and protists. Although there is a better understanding of how contaminants affect some zooplankton species (e.g., calanoid copepods), there is an urgent need for more research on mesozooplankton species, including metamorphosing stages of numerous invertebrate taxa.

The chapters in this book provide a comprehensive review of the known ecological impacts of a wide variety of pollutants in all major ecosystems of the planet at the present time. Ignorance about the world is indeed the greatest enemy of humankind, so by bringing these facts to the public we hope will encourage the new generations to take more care in managing our activities. Only by knowing where we stand can we start thinking about solutions to minimise the release of contaminants and device capable remediation systems that may reduce or eliminate completely the major chemical threats to the environment. It is from this perspective that this book was conceived in the first place.

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